REPUBLIC OF TURKEY
ACIBADEM MEHMET ALİ AYDINLAR
UNIVERSITY INSTITUTE OF NATURAL
AND APPLIED SCIENCES

LENS DESIGN AND FABRICATION METHOD FOR PORTABLE/HAND HELD SLIT LAMP BIOMICROSCOPE

METEHAN KÖKLÜ
Master Thesis

Graduate School of Natural and Applied Sciences-Biomedical Engineering MSc.

SUPERVISED
BY

Asst. Prof. Ceyhun Ekrem Kırımlı
Assoc. Prof. Yiğit Dağhan GÖKDEL

ACIBADEM UNIVERSITY

OCT 18TH, 2023

ACKNOWLEDGEMENTS

We would like to express our deep gratitude to Assoc. Prof. Dr. Yiğit Dağhan GÖKDEL for his valuable and constructive suggestions during the planning and development of this design project. His willingness to give his time so generously has been very much appreciated.

We would also like to thank appropriate staff and organizations in the Istanbul Bilgi University for enabling us through the facilities that they have and the financial support that we’ve received.

Finally, we wish to thank my dear uncle Mehmet KÖKLÜ for his support regarding the modeling and the fabrication of our flat lap machine.

ÖZET

"Portatif-Elle Tutulur Yarık Lamba Biyomikroskobu için Lens Tasarım ve Fabrikasyon Methodu" başlıklı tez projemizin amacı kompakt ve taşınabilir bir biyomikroskop için yeni bir lens üretim yöntemi geliştirmektir. Bu hedefe ulaşmak için yaklaşımımız cam üretiminde zımparalama ve cilalama tekniklerinin uygulanmasını içermektedir. Bu, geleneksel mercek üretim yöntemlerinin gerektirdiği süreyi azaltmayı ve cam merceklere bir alternatif sağlamayı amaçlamaktadır. Ayrıca, uluslararası alanda ilgi gören ve pazarda öne çıkan bir konum elde eden 3B Baskılı Lens teknolojisi alanına da başarıyla giriştik. Merceklerin işlenmesi, laboratuvar tesislerinde uygulanan ve endüstriyel sektör standartlarınave koşullarına uygun bir taşlama (lepleme) makinesinin kullanılmasıyla kolaylaştırılmaktadır.Lepleme makinesinin tahmini maksimum 2750 Rpm'de çalıştığı ve 15V güç kaynağından güç alan bir makinedir. Bizim uygulamamız ile yaklaşık 1350-1375 Rpm'de çalışıyor.

Projemizin temel amacı, makineyle üretilen lenslerin doğal yüzey kusurlarını azaltmaktır. Bu, merceklerin önceden belirlenen spesifikasyonlara göre hassas şeklinin kolaylaştırılmasıyla sağlandı. Çabalarımızın çok önemli bir yönü, lenslerin şeffaflığını arttırmaktı. Tasarım parametreleriyle, 3B yazıcıyla lenslerin üretilmesi sonucu elde edilen katman aralığı 0,01 mm ulaşan mercekler kalıp olarak kullanıldı, böylece basılı katmanlar arasındaki düşük katman boşlukları nedeniyle taşlama işlemi daha doğru sonuç gösterdi. Odak uzaklığı yaklaşık 5 cm olan, 20 diyoptri özelliğine sahip bir prototip lens üretildi. Bu lens daha sonra tasarlanmış, elde taşınır, taşınabilir bir biyomikroskopa yerleştirildi.Bu merceklerin yüzey analizleri topografik görüntüleri 10000µm altında çekilmiş olup yüzey pürüzleri minimum düzeye indirgenmeye çalışılmıştır.Bu çalışma sonucunda boyutları 1-1,5 inç arasında değişen bir çok lens kalıbı tasarlanmış ve oluşturulmuştur.

Anahtar Kelimeler; Portatif , Biyomikroskop , 3 Boyutlu Basım , Epoksi , Optik Lens

ABSTRACT

The aim of our thesis project titled "Lens Design and Fabrication Method for Portable-Handheld Slit Lamp Biomicroscope" is to develop a new lens production method for a compact and portable biomicroscope. To achieve this goal, our approach includes the application of sanding and polishing techniques in glass production. This aims to reduce the time required by traditional lens manufacturing methods and provide an alternative to glass lenses. We have also successfully ventured into the field of 3D Printed Lens technology, which has attracted international attention and achieved a prominent position in the market. Processing of lenses is facilitated by the use of a grinding (lapping) machine implemented in laboratory facilities and complying with industrial sector standards and conditions. The lapping machine operates at an estimated maximum speed of 2750 Rpm and is powered by a 15V power supply. With our application it runs at approximately 1350-1375 Rpm.

The main goal of our project is to reduce the natural surface defects of machine-produced lenses. This was achieved by facilitating the precise shaping of the lenses to predetermined specifications. A very important aspect of our efforts was to increase the transparency of the lenses. Lenses with a layer gap of 0.01 mm, obtained as a result of producing lenses with a 3D printer with design parameters, were used as molds, thus the grinding process showed more accurate results due to the low layer gaps between the printed layers. A prototype lens with a focal length of approximately 5 cm and 20 diopters was produced. This lens was then placed in a designed, handheld, portable biomicroscope. Surface analysis topographic images of these lenses were taken below 10000µm and surface roughness was tried to be minimized. As a result of this study, many lens molds ranging in size from 1-1.5 inches, each 5 gr were designed and created.

Keywords; Portable, Biomicroscope, 3D Printing, Epoxy, Optical Lens

DECLARATION

I have stated that this thesis is my own work, that I have not had any unethical behavior at all stages from the planning to the writing of the thesis, that I have obtained all the information in this thesis within academic and ethical rules, that I have cited all the information and comments that were not obtained through this thesis study, and that I have included these sources in the list of resources, I declare that I have not acted in violation of patents and copyrights during the study and writing of this thesis.

Date:18.10.2023

Metehan KÖKLÜ

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. BACKGROUND

Slit lamp biomicroscopy, also known as biomicroscopic examination or simply slit lamp examination, is a diagnostic technique used in ophthalmology to examine the anterior segment of the eye. It involves using a specialized instrument called a slit lamp biomicroscope, which combines a microscope with a high-intensity light source and a slit-shaped beam of light.

The invention of the slit lamp biomicroscope is credited to the German ophthalmologist, Alvar Gullstrand, who developed the instrument in the early 20th century. Here is a summary of the invention of the slit lamp biomicroscope:

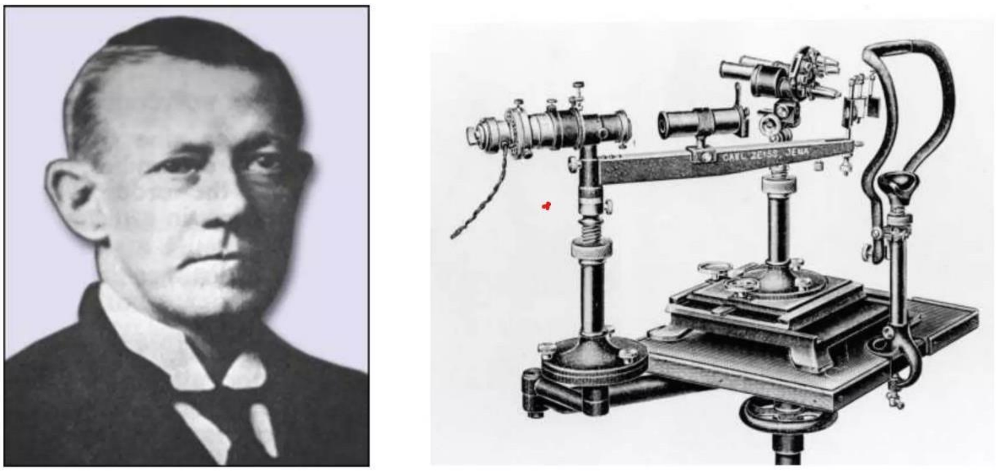


Fig. 1.1.1: Alvar Gullstrand and first slit diaphragm.

During the latter half of the 19th century, ophthalmologists predominantly utilized manual magnifying lenses as their primary tool for ocular examination. Although these lenses were shown to be beneficial, they exhibited several limitations in relation to their range of vision and depth perception. Alvar Gullstrand identified the necessity for a more advanced and accurate apparatus to investigate the anatomical components of the eye.[1]

Gullstrand introduced the first slit lamp biomicroscope in 1911. The equipment included a binocular microscope on a flexible arm and a mechanical slit and high-intensity light source. The aperture can be adjusted in width and height to precisely control the light beam to the eye.

The slit lamp biomicroscope revolutionized ophthalmology. The device showed ophthalmologists the cornea, iris, lens, and anterior chamber. Slit lamp lighting helped detect corneal abrasions, cataracts, and foreign objects.[2]

The slit lamp biomicroscope is essential in ophthalmology. It helps diagnose and treat conjunctivitis, uveitis, glaucoma, macular degeneration, and other ocular disorders. It is also used in regular ocular exams and pre-operative assessments like cataract surgery.

Alvar Gullstrand's invention of the slit lamp biomicroscope revolutionized ophthalmology by providing a powerful diagnostic tool for evaluating the anterior ocular structure. Progress in this field has led to its integration into modern eye care. This has made ocular structure assessment more thorough and accurate.

Portable slit lamp biomicroscope inventor Dr. Charles D. Kelman is well known. Dr. Kelman, a pioneering American ophthalmologist, advanced cataract surgery.

In the early 1960s, Dr. Kelman invented the first handheld and portable slit lamp biomicroscope, known as the "Kelman portable slit lamp." The invention made anterior eye evaluation easier and had a major impact on ophthalmology.

The Kelman portable slit light made cornea, iris, lens, and anterior chamber evaluations more efficient and versatile for ophthalmologists. Mobility made the device suitable for use in many clinical settings, allowing ophthalmologists to perform exams outside of the clinic.[3]

The portable slit lamp biomicroscope developed by Dr. Charles D. Kelman improved ocular diagnostics and surgical procedures, particularly cataract surgery. It is still used in ophthalmology to diagnose and treat many ocular disorders.

The operational mechanism of a portable slit lamp biomicroscope entails the utilization of a compact and handheld device designed for the purpose of examining the anterior segment of the eye. The aforementioned apparatus combines a luminous emitter, optical elements for magnification, and a beam of light in the form of a narrow opening. The patient's mentum is positioned on a support, while the handheld slit lamp is oriented towards the ocular region. The utilization of an adjustable slit beam facilitates meticulous examination of the cornea, iris, lens, and anterior chamber. Portable slit lamp biomicroscopes are highly advantageous in situations where on-site examinations, emergency settings, and areas with restricted space are encountered.[4]

Fig. 1.1.2: Modern portable slit lamp biomicroscope examples.

The slit lamp biomicroscope has evolved due to technological advances. Electric lighting sources like halogen and xenon lamps replaced incandescent ones. Newer sources were brighter and more efficient, enabling more precise tests. Binocular viewing systems, adjustable slit widths, and wavelength-specific filters greatly improved practitioners' vision and analysis.

Imaging and digital technology marked a major device advancement. High-resolution cameras and video recording have made documenting and analyzing ocular issues easier, improving patient treatment. Advanced imaging techniques like optical coherence tomography (OCT) have improved diagnosis by providing comprehensive retinal layer imagery and detecting small structural irregularities.[5]

When considering the future, the slit lamp biomicroscope has great potential. The instrument will change due to downsizing, optics, and digital technology. AI algorithms for automated analysis could revolutionize diagnosis and improve eye care through telemedicine.

In summary, the historical development of the slit lamp biomicroscope serves as a monument to the remarkable inventiveness and unwavering determination of mankind. This description provides an overview of the instrument's historical roots, significant improvements, and the profound revolutionary effects it has had on the field of ophthalmology. The distinctive tale of this instrument serves as a source of inspiration for subsequent generations, motivating them to persistently explore new frontiers and advancements in the field. This, in turn, facilitates the progress of eye care and enhances the accuracy of diagnostic procedures.

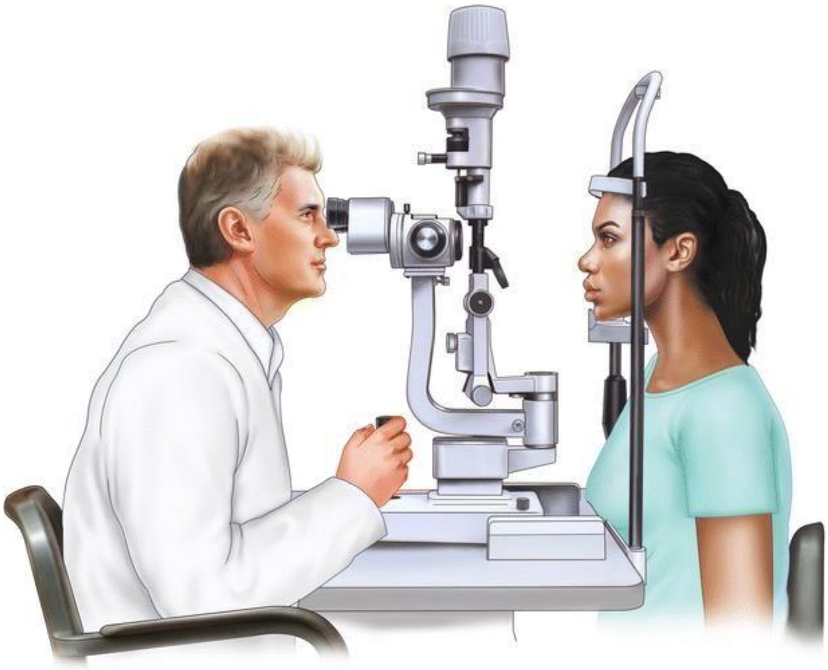


Fig. 1.1.3: Slit lamp examination.

Doctors use a slit lamp biomicroscope for several reasons, primarily for the detailed examination and evaluation of the anterior segment of the eye. Here's how doctors conduct an examination using a slit lamp biomicroscope:

The patient sits facing the slit lamp biomicroscope. Patients rest their chins on chin rests to stabilize their heads. The doctor adjusts the device's vertical and horizontal positioning for accurate alignment.

The physician activates the slit lamp biomicroscope's light source, emitting a bright beam. The apparatus' mirrors and lenses focus illumination on the patient's eyes.

The doctor adjusts the microscope's magnification to see ocular anatomy better. Depending on the area, magnification can be adjusted.

The doctor manipulates the slit beam to get the right width, height, and angle. The slit beam can be oriented horizontally, vertically, or obliquely to illuminate specific areas.

The doctor carefully examines the anterior eye segment with the slit lamp biomicroscope. This exam examines the cornea, iris, lens, and anterior chamber. A slit beam can assess structural integrity, visual clarity, and irregularities in these entities.

Medical professionals may use supplementary techniques to improve visualization and diagnosis. These may include using cobalt blue filters to detect corneal abrasions or fluorescein dye to detect corneal abnormalities.

Medical professionals may use the slit lamp biomicroscope to photograph or film eye structures for documentation and communication. These recordings are for future reference or consultation with other healthcare experts.

Medical professionals may explain findings and advise patients on ocular health during the exam. The healthcare professionals will discuss irregularities, treatment options, and patient concerns.

The slit lamp biomicroscope can detect conjunctivitis, corneal ulcers, cataracts, glaucoma, and other ocular disorders by examining the anterior region. Additionally, it aids therapy and post-operative care monitoring.

In general, the slit lamp biomicroscope is a highly important instrument that allows ophthalmologists to conduct comprehensive and exact evaluations of the eye, hence aiding precise diagnoses, efficient treatment strategies, and continuous monitoring of ocular ailments.[6]

1.2. OBJECTIVE, APPROACH AND METHODOLOGY

One of the tools that ophthalmologists use most to diagnose diseases is the biomicroscope. It is not possible to perform an eye examination without the use of a slit lamp. The reason for this is that it is not possible to examine the eye tissues with the human eye without magnification. Thanks to the biomicroscope, which is a special device used in this field; cornea, iris, lens and retina layers are examined in detail by the specialist physician.

Considering today's economic conditions, it is a very difficult situation to be taken outside of private examinations and hospitals in our country, since it is supplied from abroad and usually sold in dollars (average sales price; between $4000-1500). On the other hand, considering the other medical devices built on this type of optical lens, in order to make a domestic biomicroscope, we first need to be able to produce our own lens under the laboratory conditions we have. Apart from ASELSAN, which is one of the leading companies in our country and works in the field of military industry, there is no other company focused on lens production. As a matter of fact, apart from the lens production and the glass material generally used in production, which are among the most important plans of this project, the "3D Printed Lens", that is, lenses printed in special 3D printers, and the lens have taken their place in the market. Since it can be printed and processed more than once, it is not as hard as glass and its processing is not as difficult as glass, it provides many conveniences with this type of production.

There is Luxexcel, one of the largest companies and one of the first, that has taken its place in the market by using this new production technology.[7] Thanks to the special machines they use in production, Luxexcel enables them to perform "grindig" and "polishing" operations, respectively, immediately after printing their 3D-printed lenses in a mold. It is expected that the "3D Printed Lens" technology will be the leading production method of the future, with its easy processing and installation on the lens in its electronic circuits.[8] Considering these issues, the lenses we aim to produce in our project were planned to be made using the Phrozen Mini 8K printer, and the test results proved that it could be done.

Fig. 1.2.1: Luxexcel 3D printed lenses.

2. MATERIALS AND METHODS

Currently, there is a persistent drive in the field of optical lens manufacture to surpass existing limitations. This is achieved by continuous research and development efforts, which primarily concentrate on enhancing lens performance, minimizing dimensions and mass, and investigating novel materials and designs. The advancement of lens manufacturing has been crucial in influencing our comprehension of the natural world and has facilitated a wide range of scientific, industrial, and practical uses.

Optical lenses assume a pivotal position within the medical domain, facilitating healthcare practitioners in the diagnosis, treatment, and enhancement of patients' visual capabilities. Optical lenses hold significant importance within the medical domain due to many primary factors.

The correction of visual impairments is a prominent use of optical lenses within the field of medicine. Various visual conditions, including myopia (nearsightedness), hyperopia (farsightedness), astigmatism, and presbyopia, can be efficiently managed by the utilization of eyeglasses or contact lenses that are tailored to specific lens prescriptions. These optical lenses assist individuals in attaining enhanced visual acuity, resulting in a heightened standard of living.

Optical lenses play a crucial role within the disciplines of ophthalmology and optometry. Lenses are employed by ophthalmologists to facilitate meticulous inspection and accurate diagnosis of ocular diseases. Specialized lenses are also employed in surgical operations, including cataract surgery and refractive treatments like as LASIK. In contrast, optometrists utilize lenses as a primary tool for doing thorough examinations of the eyes, prescribing corrective lenses, and overseeing the treatment of diverse ocular conditions.

The utilization of optical lenses is widespread in medical equipment for the purpose of magnifying and seeing small-scale features during exams and treatments. In the context of microscopy, lenses are utilized to enhance the magnification of tissue samples, hence facilitating the process of disease diagnosis. Lenses inside endoscopes play a crucial role in aiding the vision of interior organs and tissues, hence enabling the performance of minimally invasive operations.

Lenses play a vital role in several medical imaging modalities, including cameras, ultrasound systems, and optical coherence tomography (OCT). The lenses in question possess the ability to collect and concentrate light, hence facilitating the production of intricate visual representations of anatomical structures. This capability is beneficial in the identification and assessment of various medical problems, as well as in the ongoing monitoring of the advancement of diseases.

Optical lenses play a crucial role in surgical and interventional treatments across several medical disciplines. In several disciplines such as ophthalmology, neurology, and microsurgery, surgical microscopes employ lenses of superior quality to facilitate improved visualization and precision during complex operations. Lenses are employed in lasers and other light-based therapeutic applications to administer precise treatments, hence reducing potential harm to adjacent tissues.

These technologies provide precise diagnosis, efficient treatment, and enhanced visual acuity for patients, eventually leading to improved patient outcomes and overall healthcare quality. The ongoing progress in lens technology and production processes serves to augment the capabilities and expand the range of uses of optical lenses within the medical domain.

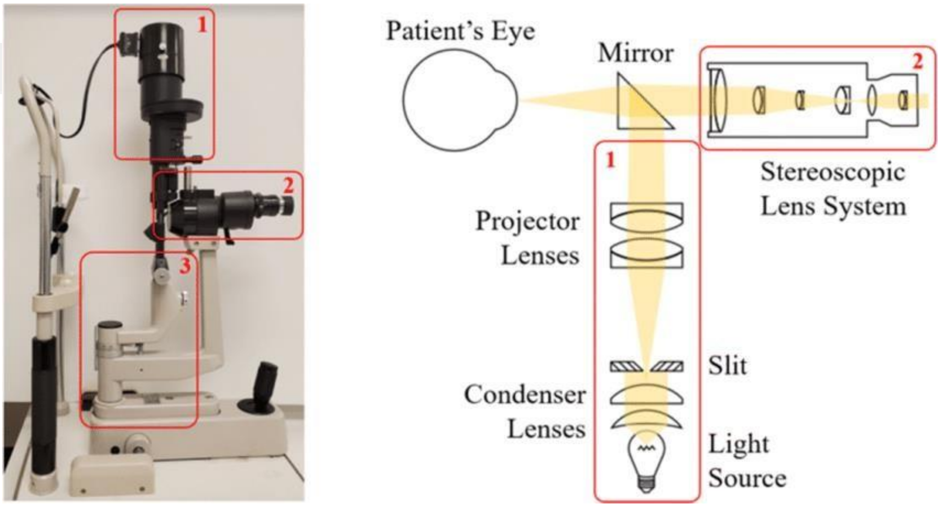


Fig. 2.1.: Basic working schematic for slit lamp biomicroscope.[9]

Slit lamp biomicroscopy is a diagnostic technique used in ophthalmology to examine the anterior segment of the eye. The working principle involves using a specialized instrument known as a slit lamp biomicroscope, which combines a high-intensity light source, a slit-shaped beam of light, and a binocular microscope.(Figure2.1) The examination is conducted while the patient's chin rests on a support and the eye is carefully aligned with the instrument. The slit lamp allows ophthalmologists to view the cornea, iris, lens, and anterior chamber in detail, enabling the detection of various eye conditions.

Now, the fundamental operational idea was readily available. Several ways were employed to obtain the functioning principle, and the tests conducted on these methods will be discussed in depth in their respective chapters.The initiation of the mechanical component design for the laryngoscope was also necessary. In order to acquire knowledge and proficiency in the subject matter, a decision was made to commence the process of constructing a model of a conventional laryngoscopy apparatus using various methodologies. The objective was to ascertain the feasibility and efficacy of its implementation in the specific scenario under consideration.In order to obtain a 3D printed object, it was necessary to do a literature search on the topic. Various types of filaments provide distinct outcomes when used in a 3D printer, necessitating the implementation of diverse designs that account for variations in flexibility and stiffness.

Ultimately, the majority of these tests proved unsuccessful, leading to the abandonment of the respective proposals. However, the acquired information derived from these sources proved to be beneficial for the project in the long run.

2.1. PRODUCTION OF OPTICAL LENSES

The lens production industry underwent a significant transformation in the 20th century due to the implementation of advanced precision manufacturing techniques. The utilization of computer-controlled machinery and diamond turning methodologies has facilitated the production of lens forms that exhibit exceptional precision and intricacy. Furthermore, the advent of novel materials, such as specialty glasses and plastics, has significantly broadened the scope of potentialities in lens design and functioning.

In contemporary times, the creation of lenses has embraced sophisticated manufacturing techniques that seamlessly include meticulous engineering, the principles of material science, and state-of-the-art technology. Over time, these processes have undergone advancements in order to provide to the growing need for lenses of superior quality, with intricate patterns and remarkable optical capabilities.

Computer numerical control (CNC) machining is a frequently utilized technology in the manufacturing of lenses. The technique described in this study involves the utilization of computer-controlled milling or grinding equipment for the purpose of shaping lens blanks composed of optical materials, such as glass or polymers (Gibson et al., 2015). CNC machines utilize tools of high accuracy in order to achieve precise cutting and shaping of the lens surface according to the specified requirements. This methodology enables the fabrication of lenses with diverse geometries, such as aspheric configurations, hence augmenting optical capabilities.

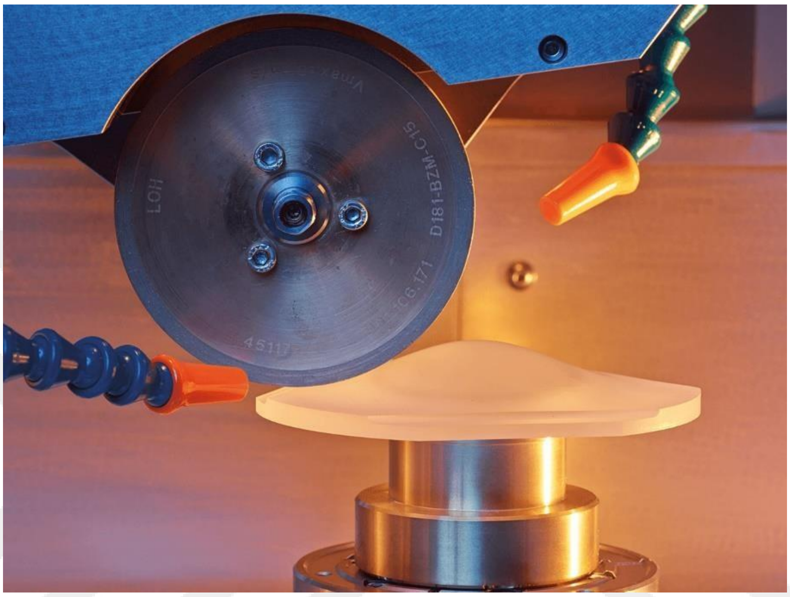


Figure 2.1.1: CNC machine producing optical lens.

Another widely recognized technique is precision molding, wherein molds are employed to form lenses by shaping molten materials. The technology of injection molding is extensively employed for the purpose of mass producing lenses (Gibson et al., 2015). During this procedure, liquid optical-grade polymers are introduced into a mold chamber that possesses the intended form of the lens. The cooling and solidification of the material occur within the mold, after which the lens is extracted, necessitating very minor subsequent polishing or finishing procedures. Precision molding is a manufacturing process that provides notable advantages such as enhanced repeatability, cost-effectiveness, and the capability to produce lenses with intricate shapes.

The process of additive manufacturing, commonly referred to as 3D printing, is now being investigated as a potential method for the creation of lenses. The approach described in the literature involves the incremental fabrication of lenses through the utilization of dedicated additive manufacturing equipment and materials with optical-grade properties (Gibson et al., 2015). Additive manufacturing facilitates the production of intricately designed lenses with a high level of customization, which may provide difficulties or expenses when employing conventional manufacturing techniques.

The field of nanotechnology has had a notable influence on the manufacturing of lenses. The utilization of electron beam lithography and nanoimprinting techniques enables meticulous manipulation at the nanoscale, hence permitting the production of lenses possessing distinctive characteristics (Chou et al., 1996). Through the manipulation of materials at the nanoscale, researchers have the ability to fabricate lenses that possess increased optical properties, including improved light transmission and surface functions.

In brief, the techniques employed in the manufacturing of lenses have undergone advancements to integrate meticulous engineering, state-of-the-art materials, and innovative technology. CNC machining, precision molding, additive manufacturing, and nanotechnology-based processes provide a wide array of methodologies for the production of lenses that exhibit remarkable optical performance and intricate patterns.

Technological developments have been the driving force behind notable advancements in lens manufacture witnessed in recent decades. The field of optics has evolved to encompass a range of approaches, such as the production of aspherical lenses, the utilization of diffractive optics, and the integration of nanotechnology. The aforementioned improvements have resulted in the emergence of sophisticated imaging systems, optical fibers, laser technology, and a multitude of other uses.After the process, the lenses are left under UV light for 24 hours to completely harden.

2.1.1. MSLA 3D PRINTER

The Stereolithography Apparatus (SLA) 3D printer is a type of additive manufacturing technology that use the photopolymerization process for the production of three-dimensional items. The utilization of this technology is prevalent throughout diverse sectors and has garnered significant attention owing to its capacity to manufacture complicated components with exceptional surface quality and high resolution.

The method of SLA 3D printing commences by utilizing a reservoir containing a liquid photopolymer resin that exhibits sensitivity to ultraviolet (UV) light. The process involves the gradual descent of a build platform into the resin, followed by the targeted exposure of particular regions inside the resin using a UV laser. This laser exposure is guided by a computerized design or CAD file. The resin undergoes solidification or polymerization upon exposure to UV radiation, resulting in the formation of a single layer of the item. Subsequently, the construction platform ascends, initiating a repetitive sequence wherein each layer is successively added until the entirety of the thing is fabricated.

The primary advantages of SLA 3D printing are in its capacity to fabricate intricately complex components with exceptional surface characteristics. Nevertheless, it is crucial to acknowledge that SLA printing is constrained by its reliance on UV-curable liquid resins, which may render it unsuitable for extensive manufacturing or scenarios necessitating distinct material characteristics, such as robustness or resilience to elevated temperatures.

The Stereolithography (SLA) technology use a laser to sequentially solidify the resin in the 3D printer tank, layer by layer. After the completion of each layer, the construction plate undergoes a descent in order to accommodate the subsequent layer. Hence, the aforementioned procedure is iterated till the ultimate component is acquired. In contrast, the Masked Stereolithography Apparatus (MSLA) is a modified iteration of SLA 3D printing. While the underlying idea of light curing the resin utilizing a light source remains the same, there are certain distinctions in the manner employed. In contrast to the utilization of laser beams for layer tracing, MSLA printers employ a bigger ultraviolet light source that is afterwards subjected to selective masking through an LCD screen in order to generate the desired pattern.

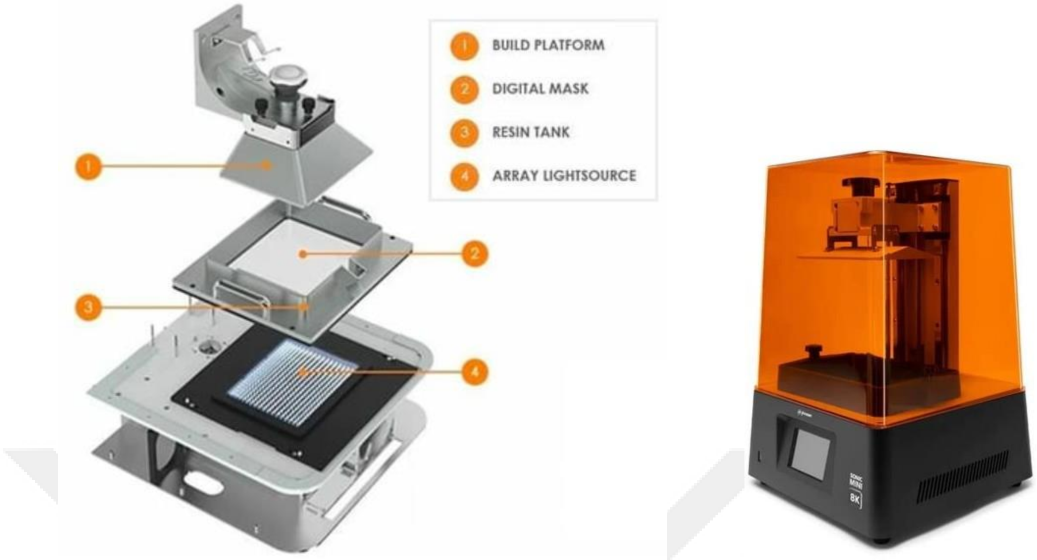


Figure 2.1.1.1: The makeup of an MSLA 3D printer

Having the highest resolution of 22 µm and 1152 ppi, the 3D printer has a 7.1” LCD screen and 18 cm Z axis. The most important point at this stage is that the resolution is of high quality. In addition, thanks to this device, we can print the layer gap formed during the production of the lens at the point of 0.01 mm.

With the 3D printer Phrozen 8K Mini purchased for this project and specified in the cost report, the next step was taken and the lenses were printed (Figure 2.1.1.1). Lens maker formula, whose focal length and dimensions were specified with the Lens maker formula previously mentioned in the interim report, came to a conclusion with the results of the experiments that lasted for a few months.

Within this particular context, the test process might be characterized as a form of iterative experimentation. Upon acquiring the printer for our project, a comprehensive exploration of various printing procedures was undertaken, with the aim of optimizing the device for lenses devoid of any preset configurations.

The rationale behind this phenomenon is in the superior resolution quality exhibited by the device in comparison to the majority of devices available in the market. Consequently, the formation of pixel images during the printing process on the lenses, which are comprised of layers generated by the UV rays emitted from the LED screen, is significantly reduced.

The use of lens design to provide support throughout the printing process has effectively mitigated any issues that might arise during printing.

During the course of the testing, it was seen that the complete fabrication of the lenses was not achieved as a result of several mistakes made by both the machinery and the human operators.

Both sources highlight a shared concern over the incomplete configuration of the parameters and the lens's inability to properly adhere to the printing surface.

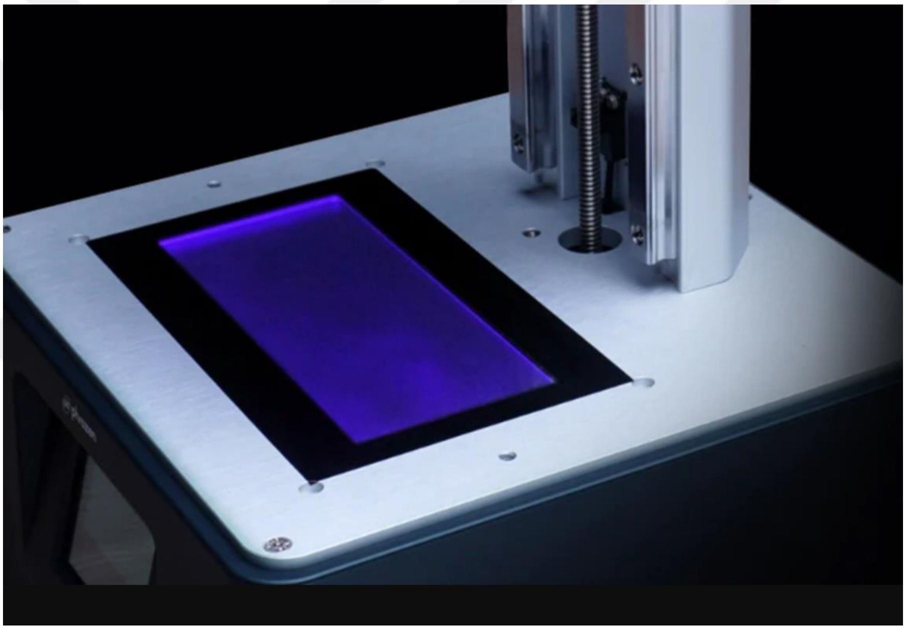


Figure 2.1.1.2: MSLA Printer UV LCD screen.

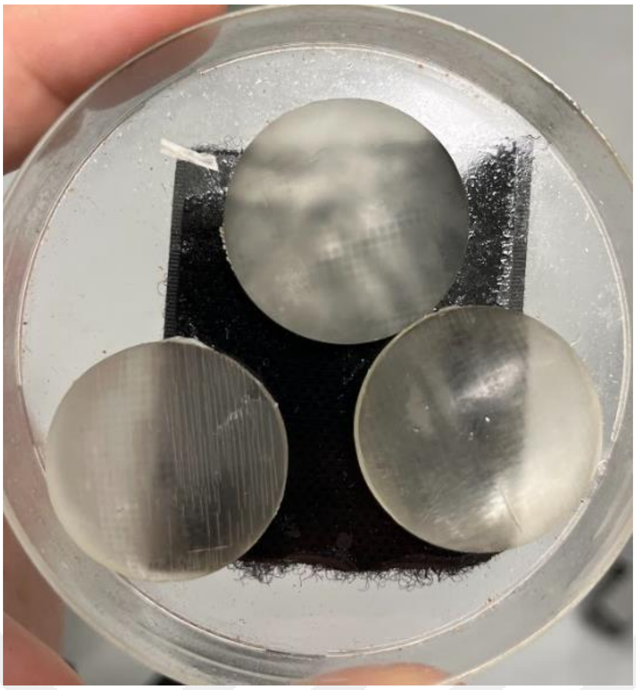


Figure 2.1.1.3: 3D printed lenses from Phrozen Sonic Mini 8K 3D SLA Printer

2.1.2. FLAT LAP MACHINE

The flat lap machine is a specialized apparatus employed in the field of lapidary work, encompassing the processes of shaping, grinding, and polishing various gemstones and other resilient substances. The apparatus comprises a planar spinning disc or wheel, commonly composed of metallic material, against which abrasive substances are placed to execute several operations within the lapidary procedure.

The principal objective of a flat lap machine is to generate planar surfaces on gemstones or other materials. Gemstone shape and grinding is a widely employed practice for the purpose of achieving desired forms, such cabochons (gems that are smooth, rounded, and polished), flat slabs, or faceted stones. The utilization of the machine enables meticulous manipulation and exactitude in the process of grinding, leading to the attainment of clearly delineated forms and a high degree of evenness.

The utilization of a flat lap machine is likewise employed for the purpose of eliminating rough surfaces and scratches from gemstones. The utilization of increasingly finer abrasives facilitates the process of mitigating flaws and achieving a refined, polished surface. The rotational movement of the machine, in conjunction with the abrasive substances, effectively erodes the material and progressively unveils the inherent splendor and transparency of the gemstone.

In addition, the flat lap machine has the capability to be utilized in the process of faceting gemstones. The process of faceting entails the exact cutting of geometric forms on a gemstone, resulting in the creation of many flat surfaces, commonly referred to as facets. Lapidaries are able to achieve precise cutting and polishing of complicated aspects by utilizing the machine's flat lap wheel, in conjunction with specific cutting laps and polishing chemicals.[10]

Flat lap machines are frequently utilized by lapidarists, jewelers, and hobbyists due to the numerous benefits they provide. These machines offer a regulated and uniform grinding and polishing process, which is essential for attaining the intended outcomes. Gem cutting and faceting necessitate the utilization of tools that enable the production of even, consistent surfaces and accurate angles. Flat lap machines provide a high degree of versatility, since they are capable of accommodating a wide range of sizes and kinds of gemstones or other rigid materials.[11]

Common manufacturing techniques, like as grinding and polishing, are employed in the production of optical components.

The selection of these components is typically contingent upon the specific segment of the electromagnetic spectrum that is desired.

The composition of the substance includes glass, crystal, or metal components. Injection molded optics, which are high-quality bulk optical components composed of polymers, have become increasingly popular due to their cost-effectiveness, particularly in the production of aspherical elements. Although these production processes have the potential to yield high-quality optics, their broad implementation is faced with many challenges.

Despite all of these issues, our project entails the production of lenses through the utilization of 3D printers available at our institution. Subsequently, we will proceed to fabricate those lenses.

Prior to the commencement of the polishing procedure, a series of distinct sandpapers are employed to prevent the occurrence of any surface irregularities that may necessitate sanding. The phenomenon being discussed, sometimes referred to as "different sandpaper," pertains to variations in the quantity of sand. The most effective approach to accomplish this procedure is to design our own lapping machine as per the specifications. Lapping fulfills specific criteria for dimensional precision and surface quality that are necessary for the production of items with such specifications. The possibility of comparing lapping to flattening or polishing arises due to the utilization of granular material in the lapping process. The lapping procedure is performed for each iteration.Consequently, it is possible to achieve surface areas of utmost sensitivity, with an accuracy level at the micrometer scale.

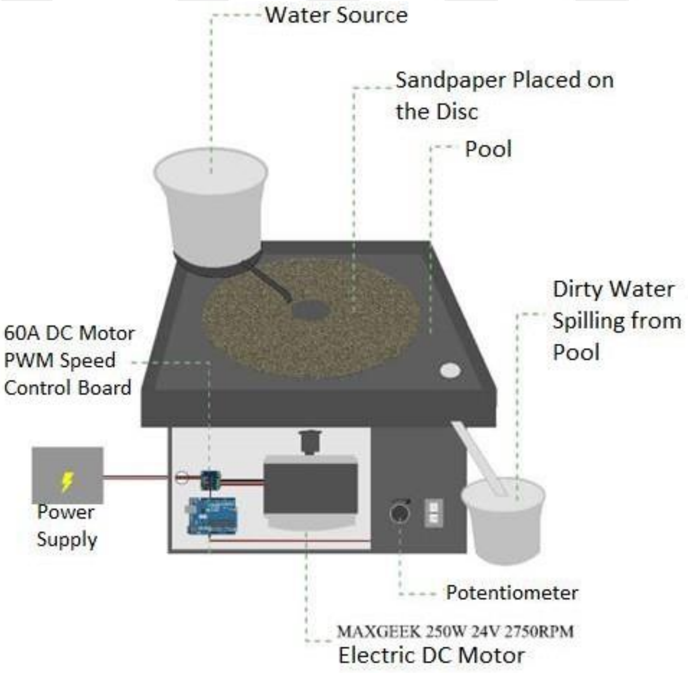


Figure 2.1.2.1: Flat lap machine schematic diagram and design.

The area covered by the project for us can bring the lenses to the desired transparency and shape “polishing” that is polishing and “griding” that is grinding (sanding) that should be applied ınstead of making it long and with a high margin of error by the hand method under normal conditions, this device It is aimed to speed up the work and reduce the margin of error.

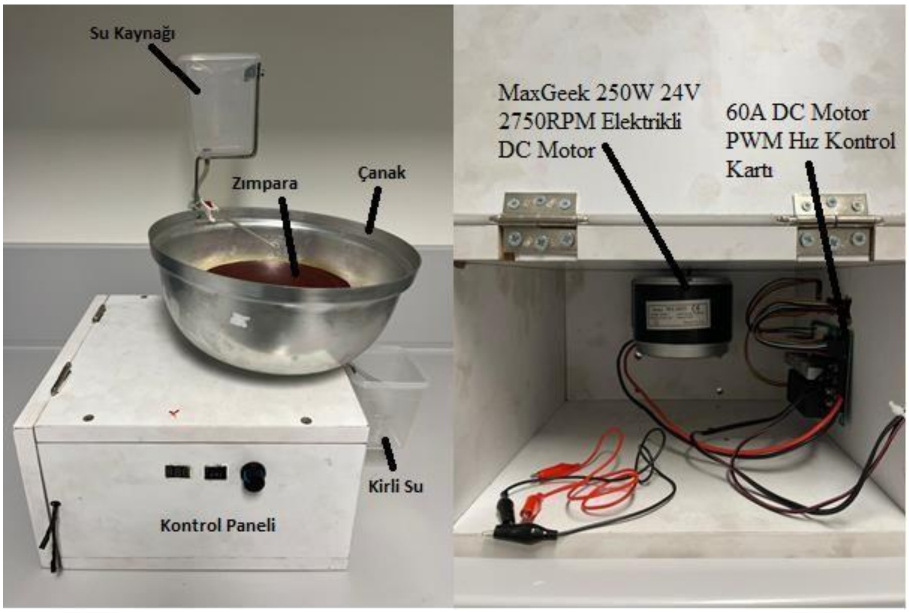


Figure 2.1.2.2: Flat lap machine parts explanation.

To explain the installation in detail and simply;

We also stated in the application form that the shape of the design and the materials planned to be used may change in the future as a result of the tests and experiments to be carried out. The installation of the outer structure is made of a waterproof wooden material, and the design has been improved, minimizing the risk of water leaking of the outer structure and leakage of water from any outside intervention to the engine.

- Water supply; It will be used in the sanding process and it has an important point in terms of facilitating the sanding process by allowing water to drip towards the center of the disc. In order to take advantage of the gravitational force of the water source, the source vessel is mounted in a high position with an iron rod above the bowl.

Figure 2.1.2.3: Flat lap machine Picture from behind to show water dump.

• Sandpaper placed on the disc; Thanks to our DC motor, which we plan to use, sandpapers with different values will be adhered by using disc-shaped plates and the disc will be rotated at certain revolutions.

• Dish; The place where the water mixture of the residues from the lenses worn with the help of water is poured. The reason why we made a design change here is that it has been observed that the water to be given by dripping on the rapidly rotating vertical can scatter around with the wastes generated during the sanding process due to the centrifugal force. In order to prevent this, a transition was made to the structure we call the bowl instead of the pool. The disc with sandpaper was raised with the help of a felt disc inside the bowl, and it also prevented water leakage into the engine.

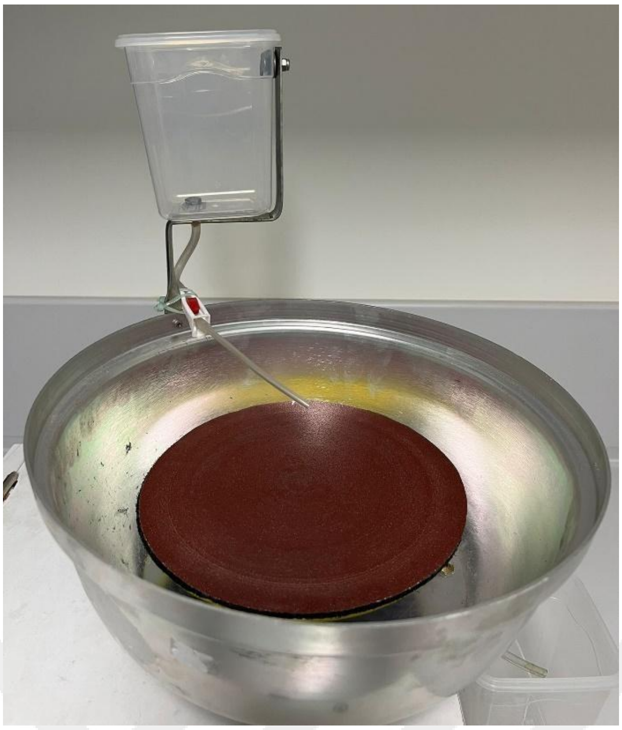


Figure 2.1.2.4: Flat lap machine Picture to show sandpapaer disc,water supply and pool.

- Dirty water spilling from the bowl; the place where the dirty water will be discharged into a container using a pipe with the help of a hole in the bowl.

- MaxGeek 250W 24V 2750RPM Electric DC Motor; For now, it is the engine that we consider sufficient for our machine in the first installation. DC motor is a class of rotary electric motor that converts direct current electrical energy into mechanical energy. The purpose of the motor is to provide the necessary work force for the replaceable disc, which is positioned to be in the air above the pool, to rotate at the desired revolutions. For this process, the motor will be connected to a motor driver module as shown in the figure and it will be operated with the help of an external power source. As stated, the motor has a rotational power of 2750RPM and works with 24V.

- 60A DC Motor PWM Speed Control Card***;*** *Purpose of PWM Motor Control Circuit**;*** converting signal information into suitable for transmission, providing power control, supporting special circuits such as solar battery charging units. Apart from these, it is used in the design of micro inverters used in communication systems, voltage regulator circuits, sound effects and amplifiers, solar energy systems and wind energy systems. This technique, which is Pulse Width Modulation, is a technique that takes place in special application areas such as Arduino or electrical machines, as well as more electronic circuits such as signal processing or signal transfer. In its simplest form, it can be defined as a signal modulation technique.

The purpose of our project is to control the speed of the motor and ensure that the disc rotates at the desired speeds. The purpose of choosing this card is that it has its own potentiometer, a cycle clock and modules that act as a switch for on-off and direction. In short, we can call the area where these modules are located. The range shown by the rev panel is between 0 and 100, allowing us to measure the value of the given power and convert it into numerical data. The key enables the disc to rotate clockwise and counterclockwise.

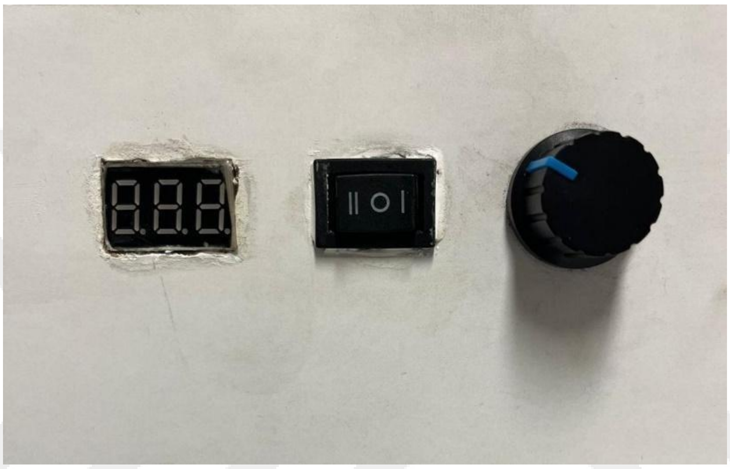


Figure 2.1.2.5: Picture of potentiometer,speed level index and switch to conrol start rotation from clock wise to anti clock wise.

• Potentiometer; a resistor that we plan to use to adjust the speed of the DC motor after the correct cable connections are provided. Potentiometer, also known as rheostat, is one of the resistor types. The characteristic of the potentiometer is that it is a controllable resistance. It is one of the basic elements of electronics and is found in many of the circuits that require control. If we consider that the potentiometer is a resistor in nature, we can use it to control current and voltage in electronic circuits, which will be used in our project to manually control the speed of the motor.

At these stages, firstly, the removed lenses are sanded to increase the number of grit. This process is carried out with water flowing from the water source.

Many tests have been carried out on the grinding machine to achieve the desired surface and smoothness. The speed required for sanding the device without damaging the lenses was determined as a result of tests and experiments. The motor in the machine has a power of 2750 rpm and creates more force than necessary for the lenses consisting of a resin-based raw material.

This process varies depending on the number of sandpaper used and the retention time of the lens. The more the lens passes through the sandpaper (depending on the increase in the grit number of the sandpaper) and the more sensitive and longer the processing time on each paper, the less the scratch rate and the more easily it reaches transparency during the polishing process. For the polishing process, the head on the machine was changed and the sponge head, which is used for pastry polishing, was installed. The speed of the machine is not very important for this process. Paste and polish materials are applied to the sponge and the lenses are prepared for the final process, polishing. The purpose of this process is to minimize the scratches formed during sanding with scratch remover paste and polish materials and to keep the surface as bright as possible. The sanding function adds a matte finish to the floor. When you want to replace this matte look with a glossy look, the polishing function will come into play.

Figure 2.1.2.6:The final state of the lens that comes out of the 3D printer, which has been sanded and polished.

2.1.3. EPOXY RESIN

Epoxy resins, also known as polyepoxides, belong to a category of reactive prepolymers and polymers that possess at least one epoxide group. The resins have the capability to undergo crosslinking reactions, which can occur either intramolecularly by catalytic homopolymerization, or intermolecularly with various co-reactants such as polyfunctional amines, acids and acid anhydrides, phenols, alcohols, and thiols. The co-reactant is typically referred to as either a hardener or a curative, whereas the process of crosslinking is commonly known as curing. Thermosetting polyepoxides are recognized for their favorable mechanical characteristics, as well as their exceptional resilience to elevated temperatures and chemicals. Nevertheless, the mechanical characteristics of the material are influenced by the ratio between the curative and polyepoxide when the curing process takes place. The presence of an excessive amount of amine typically results in diminished mechanical characteristics.[12]

In order to attain the most favorable performance characteristics, it is customary to cure the epoxies using stoichiometric or nearly stoichiometric amounts of curative. Similar to other categories of thermoset polymer materials, it is customary to combine various grades of epoxy resin and use additives, plasticizers, or fillers in order to attain the necessary processing characteristics and/or final attributes, or to save expenses. The process of combining different substances, such as blending, including additives, and utilizing fillers, is commonly known as formulating.

Besides polymerization, salient issues for epoxies include optical properties such as light transmission at various wavelengths. Light transmission values from 200 nm up to 5 µm are of particular interest to many optical engineers. Nearly all light-transmitting epoxies perform well from 350 nm to 2.5 µm. Above 2.5 µm, epoxies vary greatly in their ability to transmit light. Another optical property is index of refraction upon cure. This value normally ranges from 1.5 to 1.65.

Epoxies exhibit remarkable durability as electrical insulators, yet it is possible to construct them to possess conductivity. In their capacity as insulators, they exhibit exceptional dielectric strength, dielectric constants, volume resistivity, dissipation factors, and several other electrically insulative characteristics. The flexibility of epoxy is demonstrated by its ability to be formed as either thermally conductive and electrically insulative, or thermally and electrically conductive, thereby highlighting its wide range of applications.

Epoxies have remarkable chemical resistance. These materials demonstrate resilience in challenging conditions, such as when they come into contact with water, fuels, acids, bases, and other solvents, many of which possess aggressive properties.

Epoxy is a type of thermosetting polymer that is commonly used as an adhesive Resin is a man-made polymer that is produced by the chemical reaction of bisphenol A (BPA) and glycidyl ether. Bisphenol A (BPA) is a chemical molecule that is present in some types of polymers and resins.[13]

Epoxy resin finds extensive application in the field of construction due to its inherent qualities of strength, durability, flexibility, and resistance to elevated temperatures and chemical substances. Moreover, it is available in a diverse range of colors and finishes, enabling users to personalize it in accordance with their own preferences.According to the source provided, [14]

In order for epoxy systems to undergo the process of curing, it is vital that the resin and hardener engage in a chemical interaction. The process of mixing plays a crucial role in the utilization of epoxy. To ensure a smooth occurrence of the chemical reaction, it is imperative that the resin and hardener are uniformly distributed inside the mixture. The outcome is contingent upon effective mixing techniques. In combinations that lack homogeneity, issues related to curing might arise either locally or globally.

In the context of epoxy mixes, it is imperative to utilize either a graduated measuring cup or a precise scale. The utilization of oversized measuring cups or kitchen scales is not recommended. It is imperative to include epoxies using accurate measuring units at a precise and consistent pace. The addition of a higher proportion of hardener to epoxies leads to the incorporation of a combination of hardeners that contribute less to the desired slow curing process, resulting in an unfavorable accelerated setting and the formation of an unattractive gel-like texture.

The composition has two constituents, namely epoxy resin and hardener. Every resin system possesses unique mixing ratios. The application of the substance is prepared by thoroughly combining the ingredients in accordance with the specified mixing ratios.

Epoxy resins have notable physical and mechanical strength at completion of the drying process, and demonstrate remarkable resistance to various chemical substances.

In general, since the epoxy will dry after 24 hours, various studies are carried out to make the surface brighter. After first drying, it is sanded with water-based sandpapers such as 80-120-140-600-800-1200-1500-3000, respectively. After the processes are finished, the surface is cleaned from the remaining fine scratches by applying paste. (Figure 2.1.3.1)

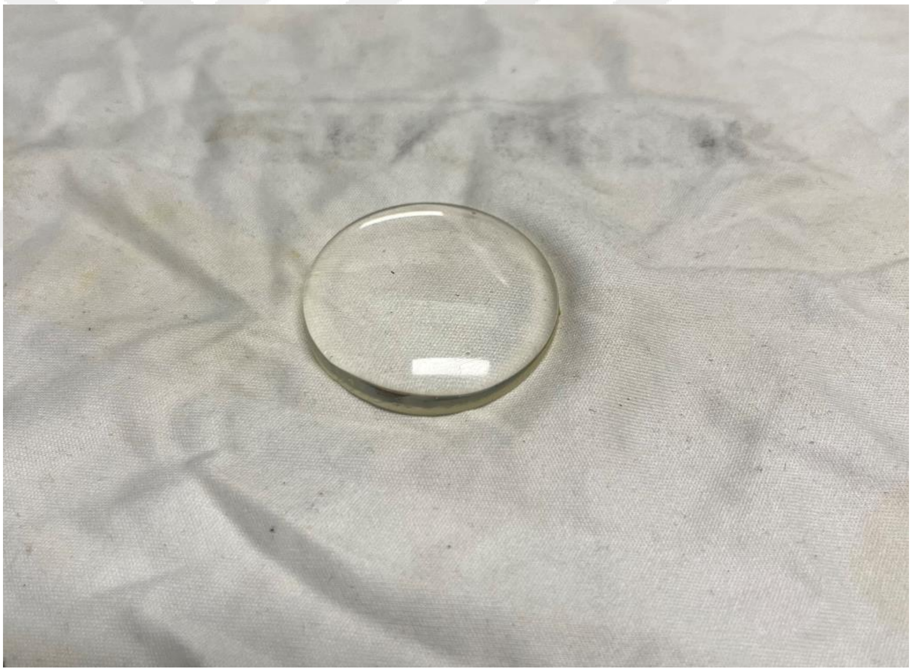


Figure 2.1.3.1. Epoxy lens that has undergone sanding and polishing processes.

However, working with sandpaper with a low grit can leave deep and permanent scratches behind while sanding the surface deeper. Another purpose of using these papers with low sand counts is to take the dried air bubbles on the surface, which remain in the epoxy resin and appear during drying after casting, more easily.

At this stage, we saw that the best solution was to remove the air inside the epoxy resin. Thus, we prevent air bubbles that may occur on the surface and prevent deep scratches that may occur by starting with a low grit number in the sanding process. To remove the air in the epoxy resin, the desiccator of our oculus in the Nanobiotechnology laboratory was used

As optical adhesives, the average refractive indices of conventional epoxy resins are in the range of 1.50–1.56. [14]

2.1.4. RTV2 SILICONE MOLD

Silicone molds are utilized as a production material, where silicone is employed as the primary substance for mold creation. These molds are made by the casting process, and subsequent silicone molding is conducted. Despite its appearance as an ancillary entity, it serves as the fundamental catalyst for the emergence of the resultant product. Errors can arise in any items that are produced if they are not processed properly. In short, it is imperative to meticulously plan and execute silicone molds in a manner that minimizes errors.

The utilization of silicone molding techniques has significant value across several sectors. The production process encompasses a critical stage that holds significance in terms of both material and quality. In contemporary practice, there has been a notable inclination towards utilizing RTV2 silicone molds in the process of silicone molding.

The utilization of RTV2 mold silicone offers several benefits in terms of both cost-effectiveness and quality, owing to its distinctive technical characteristics. Due to its diverse range of applications and adaptable nature, it is well recognized for its ease of use across several industries, spanning from the culinary field to the construction industry. The acronym RTV is an abbreviation for "Room Temperature Vulcanizing" in the English language.The user's text is already academic and does not need to be rewritten.

In the Turkish context, the utilization of RTV denotes the process of formation (curing) taking place at ambient temperature. The numerical designation "2" employed in the naming of RTV2 silicone rubbers signifies the presence of a dual-component chemical composition inside the product. RTV2 is composed of catalysts and base materials that possess cryogenic characteristics. RTV2 silicone rubbers provide significant advantages in several operations, including copying, replication, coating, and printing transfer from models, owing to their technological structure.

The present study employed silicone molds characterized by chemical characteristics indicative of moderate hardness. The process of preparing mold silicones is rather straightforward, but, the subsequent casting and application stages provide significant challenges.

RTV2 mold silicones are composed of two primary constituents, namely silicone and catalyst. The catalyst is introduced into the silicone matrix at a concentration of 2% by weight, and immediate mixing is required. The challenging aspect of this task has been completed, since the absence of a precise and consistent blend would hinder the proper occurrence of the hardening process and result in a lack of uniform fluidity. [15]The mixture is placed in a desiccator for a duration of 10 minutes in order to mitigate the formation of air bubbles. The developed combination exhibits desiccant properties, leading to the drying of the material over time. Prolonged storage of the mixture results in its solidification. This method has been acquired through extensive long-term testing and experimentation. Later, the mold silicone mixture coming out of the desiccator is transferred into the determined container and the object to be reshaped is placed with it, in which case these lenses are used in the project. (Figure 2.1.4.1.)

Figure 2.1.4.1. Recesses and epoxy casting of lenses molded from mold silicone.

2.1.5. DESICATOR

A desiccator is a device used to safeguard moisture-sensitive items by preventing the ingress of moisture, hence ensuring the dryness of the enclosed material.Laboratories are utilized for experimental purposes.The user did not provide any text to rewrite. Typically composed of glass, these objects possess an aperture located at the uppermost part of their enclosure. Furthermore, it is employed in vacuum operations through the utilization of a rubber stopper and glass valve affixed at this location. To facilitate the manipulation of a vacuum environment, a solitary-stage vacuum pump was affixed to the desiccator. After that, prepared epoxy resin was put into the desiccator and after the pump was started, it was kept until air bubbles came out. (Figure 2.1.5.1) This process varies between about 20-30 minutes. The epoxy resin starts to dry 30 minutes after mixing, which is sufficient for us.

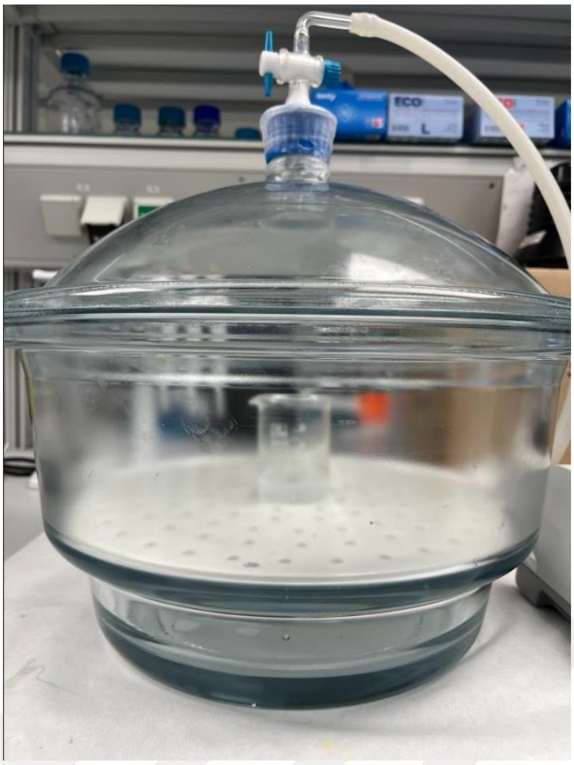


Figure 2.1.5.1. Transparent epoxy resin weighing 15 g placed in the desiccator.

Air bubbles begin to disappear from the surface approximately 20 minutes after they rise to the surface. After the surface is completely free of air bubbles for the remaining 10 minutes, the compressed air in the desiccator is slowly removed and then the lid is opened. The reason for this is that the lid cannot be opened due to the pressure caused by vacuuming inside. The epoxy resin stored in the beaker is taken and then poured into the places of the lenses whose mold has been removed. Under normal conditions, the drying time is considered to be 24 hours, but since sanding will be applied to the epoxy lenses produced in this project, the temperature formed in the environment deteriorates the structure of the lenses and causes them to lose their hardness. For this reason, the drying process was determined as at least 48 hours.

2.2. DETERMINING THE DESIGN

The type of lens we designed and wanted to test for the first lens production was determined as a plano convex (convex) lens. The reason for this is that one of the features of the lens, having a flat surface, will be an advantage for us, as it will be easier to manufacture. If we produce a production with the desired optical properties with this lens type, it will be our aim to ensure that our biomicroscope can function with a single lens. If a plano-convex lens of desired dimensions is produced in a lab environment, it can lead the production of other lens types. For now, it has been decided that it will be the best to proceed with this lens in terms of teaching us the production process.

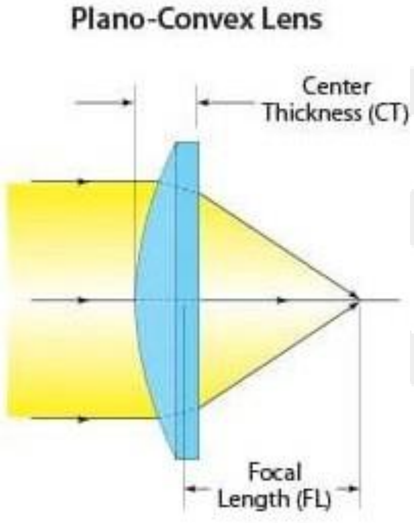


Figure 2.3.1. Working principal of plano-convex lens schematic.

Plano-convex lenses are optical components characterized by a positive focal length, consisting of one surface that is spherical in shape and another surface that is flat. These lenses have been specifically engineered for applications involving infinite conjugate (parallel light) usage or for basic viewing purposes in non-critical scenarios. These optical lenses are well-suited for versatile focusing applications.

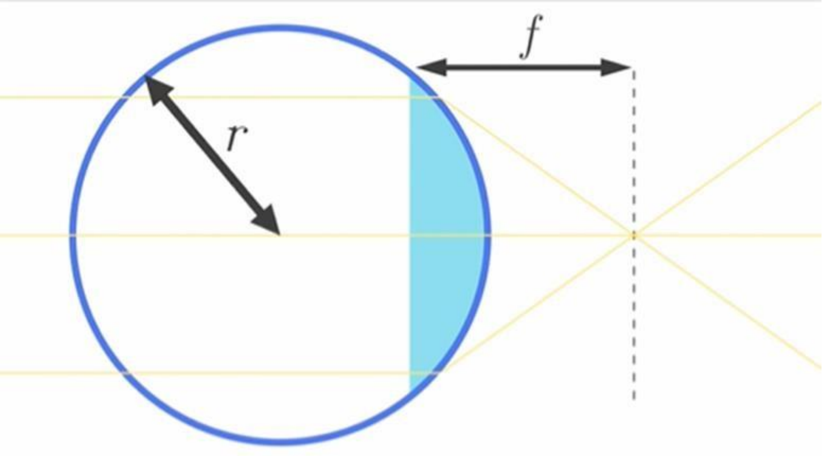
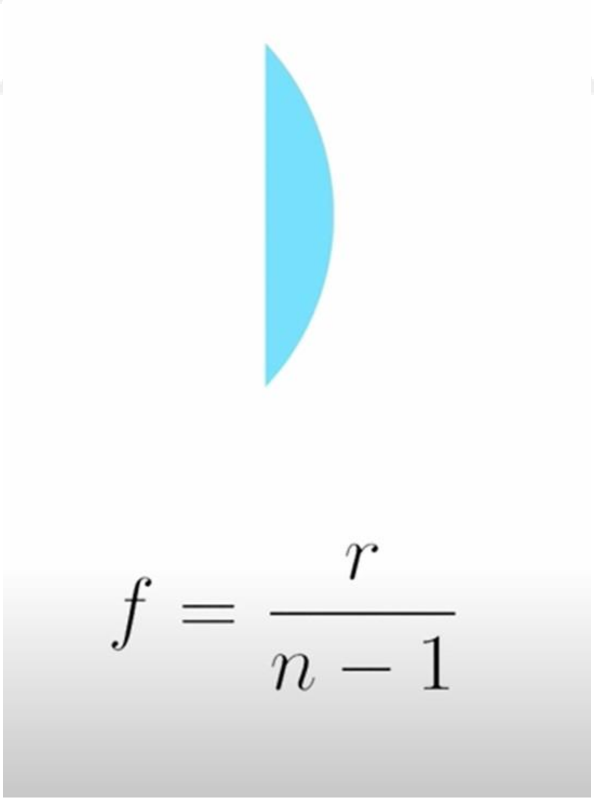


Figure 2.3.2. The relationship between diameter of lenses and focal length of it.

We can describe the concept of focal length for the lens as the center point where the incident light rays are collected. Likewise, the light passing through the lens is collected in a certain center. The focus, the imaginary point, is a point that light rays form at the point where the object converges. Although conceptually a point, the focus physically has a spatial dimension, called a fuzzy circle.



$$f = \frac{r}{n-1}$$

Figure 2.3.3. Formula for a optical lenses focal length dependent on material refractive index and diameter of lens.

In order to determine the dimensions of the lens, we provided the drawing in the desired dimensions by taking into account the focal length and diopter value. According to the researches made for our study, which should be used in eye examination and focused on a single lens, the diopter size used by other brand slit lamp biomicroscopes was seen as 20. The focal length of a lens with 20 diopters is calculated as 5 cm with the help of formulas. This distance can be simply defined as the distance between the slit lamp that the doctor will hold in his hand and the patient's eye. The radius of the lens is calculated as 2.45 cm, again based on optical formulas. The item specified for the lens is calculated with the index value of the plexiglass, which is planned to be cut in the CNC machine we deem appropriate as calculations and initial experiments. The index value is a parameter that varies according to the material used and has different index values according to the density and light transmittance of the material.[16]

The diopter, also known as the opticste, is a unit utilized to quantify the refractive power or optical power of a lens or mirror. The reciprocal of the focal length, denoted as 1/f,

The measurement of myopia and hyperopia in the field of ophthalmology is often denoted in diopters. The power of a lens has an inverse relationship with its focal length. The relationship between focal length and power is such that as the focal length decreases, the power increases. The equation $P = Y = 1/f$ represents the relationship between power (P) and convergence (Y), where f represents the variable. The numerical value and units of power and convergence in lenses are equivalent. The reciprocal of the focal length, measured in meters, corresponds to the magnitude of the lens power, expressed in diopters. The power of a convex lens exhibits positive convergence, while the power of a concave lens demonstrates negative convergence. The phenomenon being referred to is the ability of a lens to collect or concentrate light.[17]

Lenses are specifically engineered to align with their designated regions of application. When there is a need for significant refraction of light, the design of the lens takes into consideration its geometric shape, as well as the selection of thickness and refractive index.

Due to the composition of glass and plastic derivatives, it is possible for the refractive indices of the lenses to exhibit variation.

The Lens Maker's Formula establishes a correlation between the focal length of a lens and the refractive index of the material it is made of, as well as the radii of curvature of its two surfaces.

Lens makers utilize this technique to produce lenses with certain optical power by employing glass materials with a particular refractive index.[18]

$$\frac{1}{f} = (\mu - 1) \times \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Where,

f	The focal length of the lens
μ	Refractive index
$R_1 and R_2$	the radius of the curvature of both surfaces

This formula is applicable to both concave and convex lenses and provides valuable insights into the behavior of lenses and their ability to converge or diverge light.

Using these formulas, the focal length of a lens with a diopter value of 20 was calculated as 5 cm, and the radius of a plano convex lens was calculated as 2.45 cm according to the lens maker formula.

2.2.1 FIRST DESIGNS IN FUSION 360

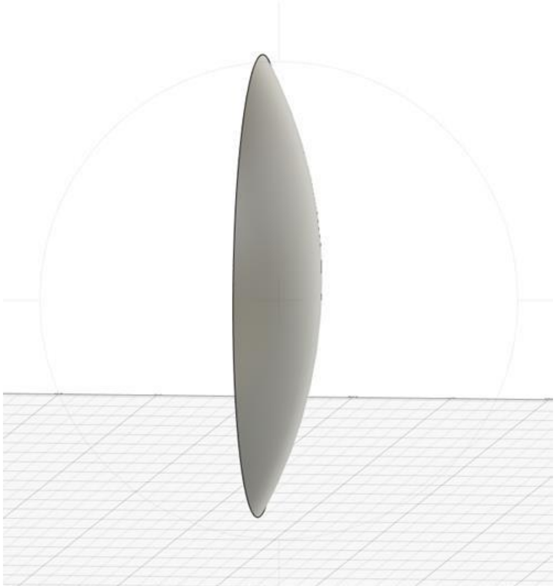


Fig. 2.2.2.1: First drawing in the Fusion360.

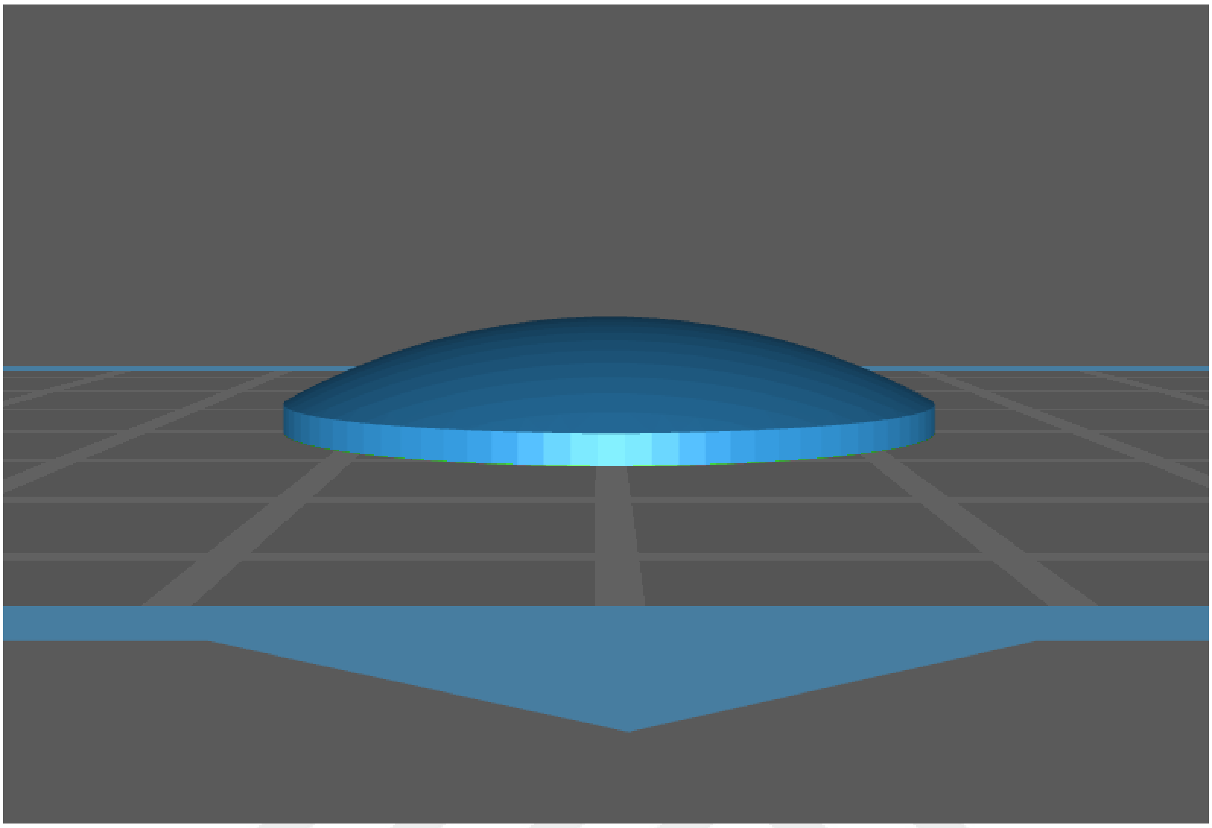


Fig. 2.2.2.2: 3D schematic before printing lens.

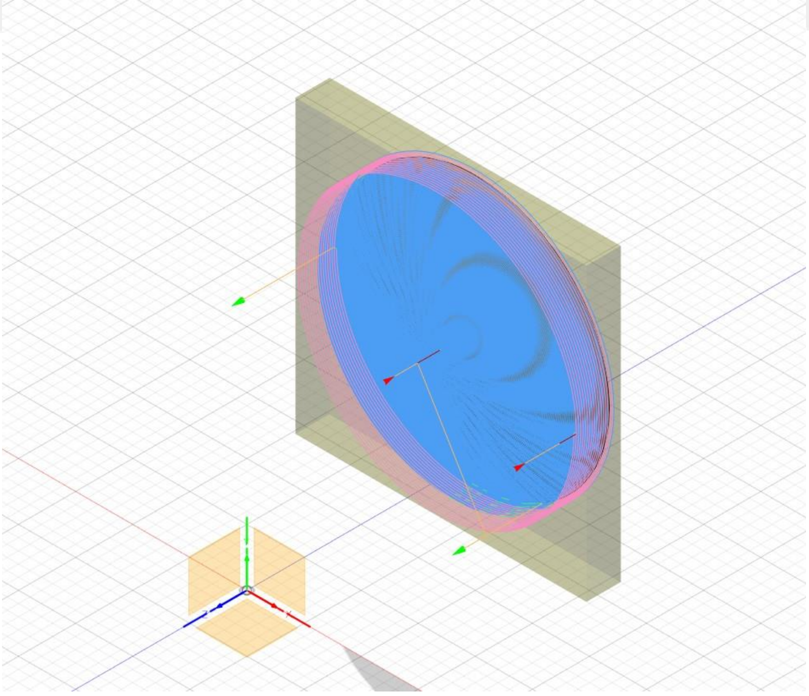


Fig. 2.2.2.3: Simulation for determining the layers between gaps for printing.

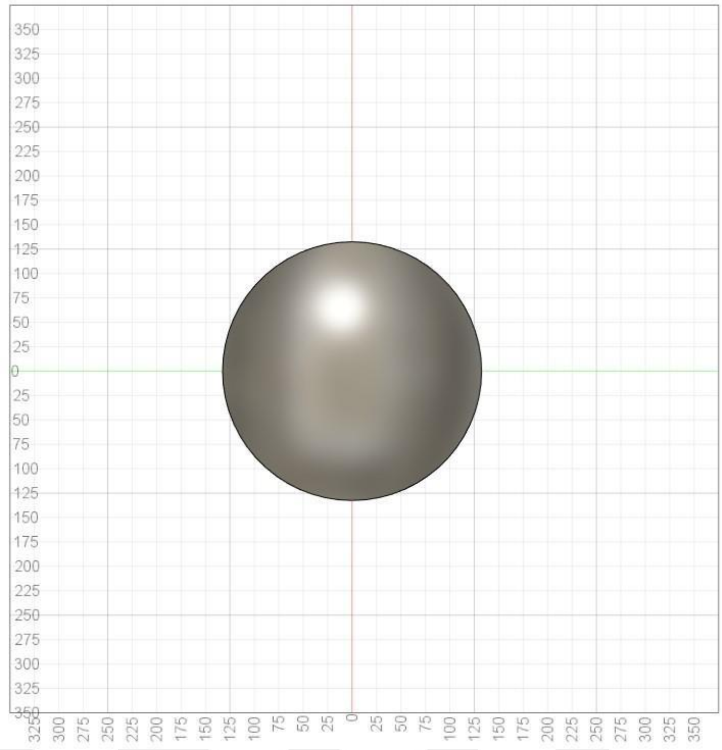


Fig. 2.2.2.4: Top view of designed 20 diopter optical lens from Fusion 360.

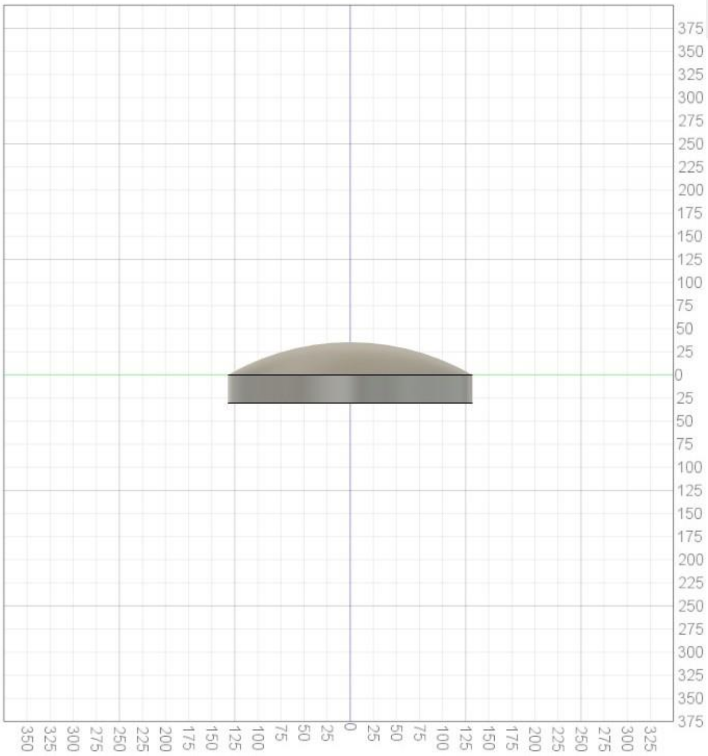


Fig. 2.2.2.5: Side view of designed 20 diopter optical lens from Fusion 360.

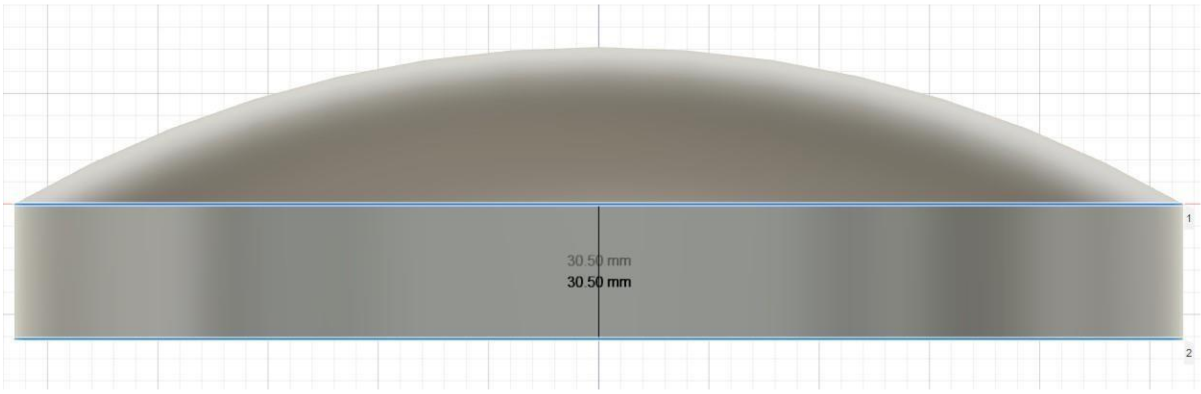


Fig. 2.2.2.6: Side view to show height of optical lens to seat position 30.50mm.

2.3. OPTICAL TESTS

These tests are basically examination of light and optical properties. Differences between crystal material and epoxy material are widely seeming in this tests. In the first place, the tests of the lenses that came out of the 3D printer were carried out. The main purpose of the tests is to look at the light refraction tests of the lenses. For this, the lenses were fixed on the optical table at Istanbul Bilgi University and their light refraction properties were examined. However, the transparency rate of the lenses from the 3D printer was not included in these tests because it was not at the desired level.

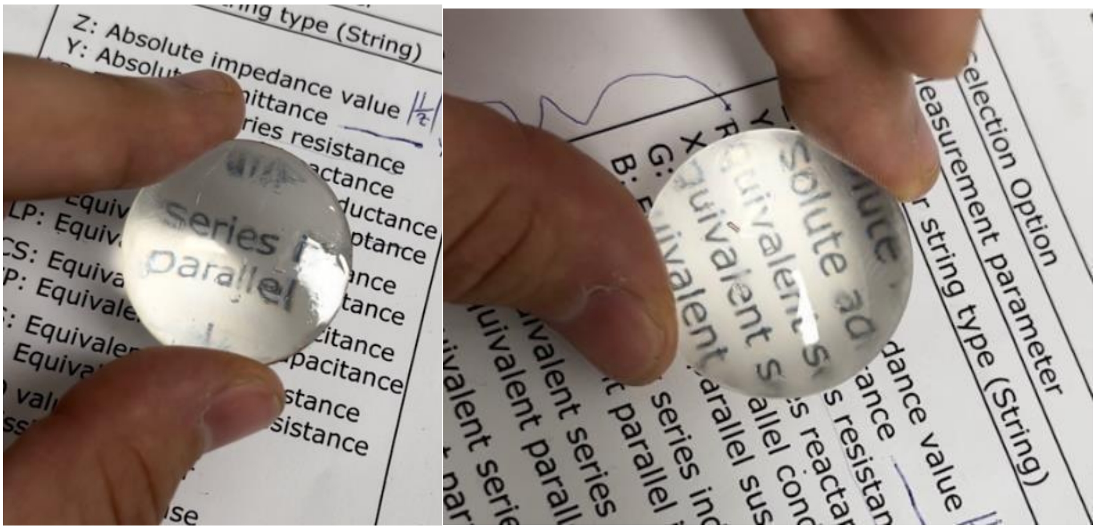


Fig. 2.2.3.1: First 3D printed lens came out from Phrozen Sonic Mini 8K Printer.

Looking at the chemical properties of the lenses coming out of 3D printing, it was predicted that such problems would be encountered, because the hardening of the lenses under UV rays after printing causes a decrease in transparency. Main reason for this problem is because of solvent content of epoxy based 3D printer solution.

Solvents are chemicals that can dissolve or disperse other compounds in order to generate a homogenous mixture. Solvents can have a variety of impacts in the context of epoxy materials, depending on their chemical qualities and interactions with the epoxy resin.

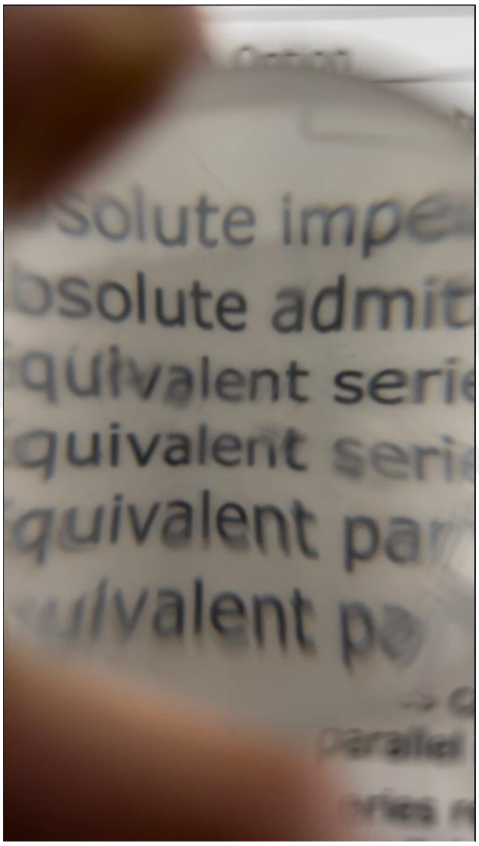


Fig. 2.2.3.2: Printed lenses transparency test under 5cm to show quality of reflection.

It is critical to highlight that the selection and usage of solvents must be carefully evaluated, since they can have both good and negative impacts on epoxy materials. Depending on their compatibility with the individual epoxy formulation, some solvents may have an effect on the curing process or the mechanical qualities of the cured epoxy. Furthermore, the use of unsuitable or excessive solvents can result in poor adhesion, decreased strength, or surface flaws.

Furthermore, solvents can be hazardous to one's health and safety due to their flammability or potential for skin and respiratory irritation. When dealing with solvents and epoxy materials, it is critical to observe safety requirements, wear adequate personal protective equipment, and maintain proper ventilation.

Due to their solvent content, these materials are not resistant to yellowing.

Epoxy based lenses are more resistant to this problem because of solvent content. Generally epoxy can be more resistant to sunlight and temperature.[19] Next approach for this situation is more reasonable considering of 3D printed lenses. So these optical tests are for compare crystal material based lenses and epoxy based lenses.

For this approach we are took examples form Istanbul Bilgi University optical laboratory. These lenses coming from Network Corp. and our main purpose is simulate their transparent and surface properties. So that we can compare and observe the accuracy of the path we follow when we produce our own lens. These two types of lenses differences basically their chemical components and atomic structures. Also because of their different refractive indexes their focal length also would be different. For comparing these two lenses we tested their light reflaction. At 5 cm , we tested their behavior of focusing the light.At Fig.2.2.3.2, their behavior can be see clearly and show us their similarity. This results show that we can produce different types of lenses if their refractive indexes approximately close each other. So that we can miming a original lens and produce it much cheaper and easier than using factory production methods.

3. DESIGNING EXPERIMANTAL SLIT LAMP BIOMICROSCOPE

In this chapter, the determined design for the slit lamp biomicroscope will be discussed in detail. Basic hand held biomicroscopes have different kind of style and shape. Their system requirements an optical system with varied of specific lenses. In this situation we are looking for using just one lens and direct approach for patient. In this way production of lenses will be reduced and size of the will be much smaller. In marketing this kind of biomicroscopes can be found but accessibility of these device very hard. Because of their high price and avability for less developed countries these devices not reachable for every hospital.Main reason is making specific optical characteristic lens is difficult and expensive. Also making these kinds of devices portable is another challenge. We designed a handheld portable prototype for show possibility of producible this device. Inspiration of this device is suitable for electric circuit which is inside of the device.This circuit purpose is create a light source for during eye examination. Circuits parts kept simple although it can be improvised. Circuit made of 9V battery , button , 10 K resistance and led light. Design schematics and circuit diagram will be given later in this report.

3.1. PREPERATION OF LENS

This chapter will be approach preparation mixture of epoxy and silicone mold.3D printed lenses designed respectfully Lens Maker Formula. For this design lens characterizations are 5cm focal length which doctors will be approach patient from this distance and 20 diopter magnitude. These printed lenses will be pattern for epoxy based lenses. 3d printed lenses molded with RT2 silicone mold. After molding is done lenses removed from silicone than epoxy mixture filled with in it. Approximately 2 days later epoxy would be toughened and after that grinding and polishing process will be started which is done by our production flat lap machine.

3.1.1. CASTING AND MOLDING

In this chapter preparation of mixture epoxy and RT2 silicone mold will be explain. Previously chapters, definition of silicone mold and epoxy resin was explained. In this project RT2 silicone mold was used for pattern.3D printed lenses dip in silicone mold and after that they been removed for pouring the epoxy.

For preparation of RT2, this substance yields high-quality rubber molds with fine detail and little shrinkage. Depending on the intricacy of the form, they will manufacture hundreds of castings. The inclusion of a catalyst activates this self-releasing liquid rubber, which is then poured over the former and cured at room temperature. RTV20 is a soft silicone that has been condensation cured.

In mold making works, the surfaces of the model, for this case it’s our 3D printed lenses, to be molded should be cleaned of dirt such as oil and dust. Mold release agent should be applied in case the silicone sticks to the model. Mold protective products must be used when molds are taken from models on concrete, wood, porous and absorbent surfaces. The mold model is prepared and placed in the support mold in the most appropriate way.

After the silicone package is opened and mixed thoroughly, the desired amount is taken from it and put into a clean container and weighed. The lid of the package should never be left open. Silicone(100gr) and catalyst(2gr) ratios are measured and mixed thoroughly. Appropriate volume container should be used considering the swelling of silicone during vacuuming.

In order to get rid of the air bubbles formed during the mixing and reaction of the silicone, the air inside is vacuumed by placing the container in a desiccator. During this process, the volume of silicone can swell up to 5 times. Care should be taken to overflow the captain. It is recommended not to exceed 2 bar pressure during vacuuming and not to exceed 15 minutes.

In order to prevent the formation of air bubbles during casting, the silicone should be poured from a single point at the top of the model and at a constant speed. For Intricate and Complex models, it is recommended to apply a thin layer with a brush first. The air bubbles formed are removed with compressed air. After 5 minutes, the entire silicone is poured over the model.

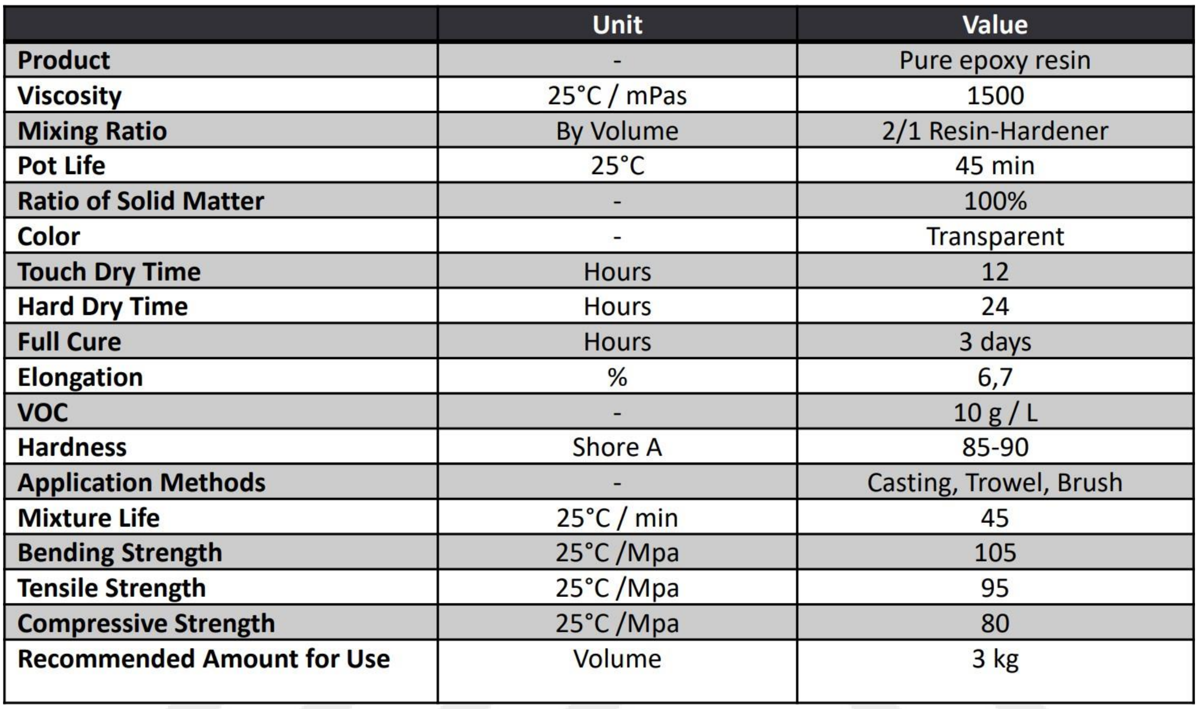
Molding silicones are of two types, condensation-freezing and addition-freezing. Condensation-freeze silicones freeze for 6 to 15 hours at room temperature. Addition-freeze silicones freeze within 24 hours at room temperature and the setting time can be shortened by heat.

After the silicone freezes in the specified time, the support molds are removed. When removing the silicone mold from the 3D printed lenses, care should be taken to remove it without using sharp and pointed tools. After leaving the 3D printed lenses, it is recommended to leave the silicone mold in the open area for 2-3 hours at room temperature. Silicon molds resting in the open air can be cast more and the molds last longer.

In this way we can produce more than ones 3D printed lenses with epoxy based.

For preparation of epoxy we used Purepoxy-130 from PURYAP Yapı Kimyasalları ve Makine Sanayi Tic.Ltd.Şti. .According to their technical documents Purepoxy at 50% relative humidity and 23 °C is an estimated approximation, subject to potential variations due to fluctuations in environmental circumstances, particularly alterations in temperature and relative humidity. The data provided was computed for planar surfaces.
It is recommended to either let the PUREPOXY-130 resin and hardener to reach ambient temperature, which ranges from 24 to 27°C, or to provide heat to facilitate the process. This process will enhance the fluidity of the mixture, facilitate the escape of entrapped air, and mitigate the occurrence of bubble formation. Combine two units of resin with one unit of hardener in a container that is both dry and clean. Utilize either a paint stir stick or a mixer to agitate the mixture for a duration of 2 to 3 minutes. Following the initial stirring process, proceed to transfer the mixture into a comparable empty mixing vessel and continue to stir

for an extra duration of 1 to 2 minutes. Introduce the ingredients into the mold. It is recommended to allow a duration of 15 to 20 minutes before proceeding to apply a lighted propane torch or a heat-blowing drier at an inclination of 45 degrees over the designated surface.



	Unit	Value
Product	-	Pure epoxy resin
Viscosity	25°C / mPas	1500
Mixing Ratio	By Volume	2/1 Resin-Hardener
Pot Life	25°C	45 min
Ratio of Solid Matter	-	100%
Color	-	Transparent
Touch Dry Time	Hours	12
Hard Dry Time	Hours	24
Full Cure	Hours	3 days
Elongation	%	6,7
VOC	-	10 g / L
Hardness	Shore A	85-90
Application Methods	-	Casting, Trowel, Brush
Mixture Life	25°C / min	45
Bending Strength	25°C /Mpa	105
Tensile Strength	25°C /Mpa	95
Compressive Strength	25°C /Mpa	80
Recommended Amount for Use	Volume	3 kg

Table. 3.1.1.1: Technical specifications of Purepoxy-130 taken from technical documents.

The epoxy resin, consisting of components A and B, should be mixed in a ratio of 2 parts of component A to 1 part of component B in order to get a high level of transparency. The resins are combined within a static mixer, located in an appropriate container, in predetermined quantities. The process involves pouring prepared resins into pre-cleaned silicone or polyester casting molds at an ambient temperature ranging from 20 to 25 degrees Celsius. It is worth noting that lower ambient temperatures might prolong the drying period of the result. This particular product is suggested for utilization in applications ranging from 1 to 2 centimeters. The duration required for the drying process is 24 hours.According to the findings of our test, it is recommended that the drying time for our epoxy-based lenses falls between the range of 24 to 48 hours.The rationale behind this phenomenon is that the process of removing epoxy-based lenses is followed by the use of grinding and polishing techniques using a flat lap machine, which inadvertently results in deformations to the lenses. Due to the increasing temperature during the application process, deformation occurs. Therefore, it is important to ensure that the epoxy-based lenses hardener possesses sufficient resilience to remain unaffected by this issue.

3.1.2. GRINDING AND POLISHING

After removing our epoxy based lenses from their mold , for better transparent and brightness and also make sure for the reduce surface roughness lenses should be grinding and polishing.

Grinding and polishing are critical steps in the lens manufacturing process to achieve the desired shape, smoothness, and optical performance. These processes not only ensure that the lens meets its intended design and specifications but also contribute to delivering clear, sharp images with minimal optical aberrations and reflections.

It's important to note that modern lens manufacturing often employs computer-controlled machinery and automation to ensure precision and consistency throughout the process. Advanced techniques and technology have significantly improved the efficiency and accuracy of lens grinding and polishing, resulting in high-quality lenses used in various optical applications.

As already mentioned produced lenses grinding by our manufactured flat lap machine respectively 800-1200-1500-2000-3000.Experiments show us by looking ratio of sandpapers if increase ,the results would be much promising. Determination of surface roughness dependet on grinding process.Surface roughnees and micro level pictures will be shown later parts in this report.

For polishing materials chosen by wax materials.This process basically for cleaning and shinning surface after grinding part.Material selection choose easily accessible and cheap for cost efficiency. Benefits and drawbacks of these selections will be mentioned in discussion part.

3.2. MECHANICAL SYSTEM

This project came out from idea that possibility of making low cost and portable hand held biomicroscope.For this goal, limited resources was used.Mechanical structure of biomicroscope made out of PLA from 3D printer in İstanbul Bilgi University. This design kept simple thanks to our one lens biomicroscope approach.Researchs show that this kind of optical systems can be imitated.[20] As already explained in previous chapters, for materials using slit lamp biomicroscope should include a special prism and light source for eye examination.These kind of prism hardly found and also very expensive so this project didn't include prism.Main reason is showing the idea of design a portable biomicroscope can be done.In mechanical design, properties of electric circuit be placed. It is designed as a circuit replaceable battery and easy to disassemble.As a light source , basic white led was chosen for simulate the work of light source from modern slit lamp biomicroscope.

To make easy the battery replacement and also long durability , 9V battery was chosen.At the under part battery placed and design of under shaped respectively for battery shape. For design each circuit part measurements by caliper and calculated for making compact and height of the device approximately 14 cm which is good for hand held.

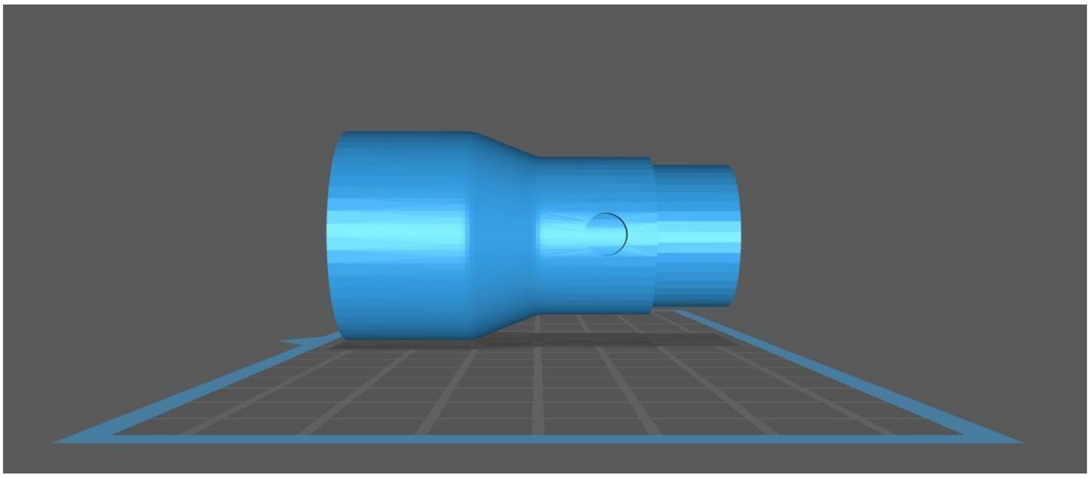


Fig. 3.2.1: Middle part design of slit lamp biomicroscope to show switch button side.

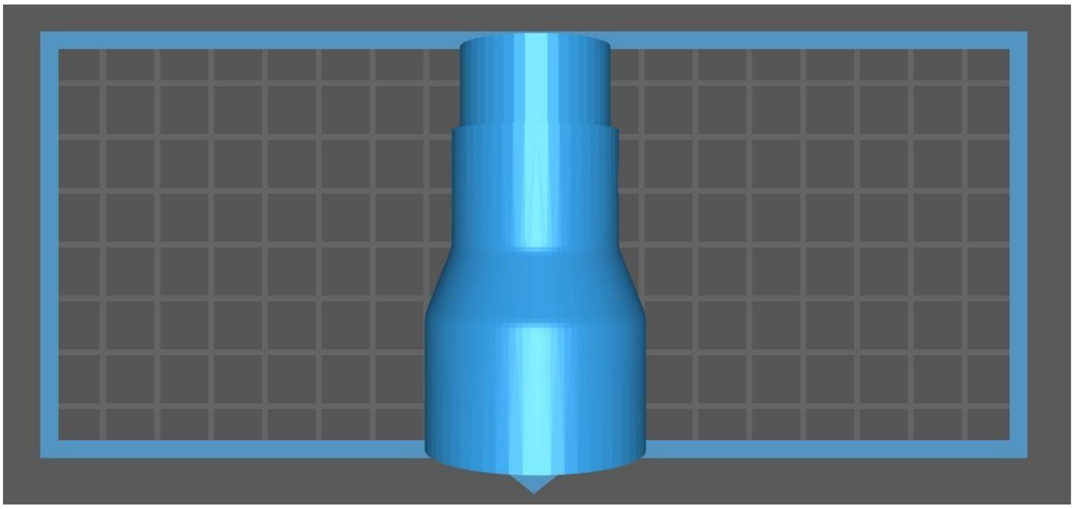


Fig. 3.2.2: Middle part design of slit lamp biomicroscope screenshot from top view.

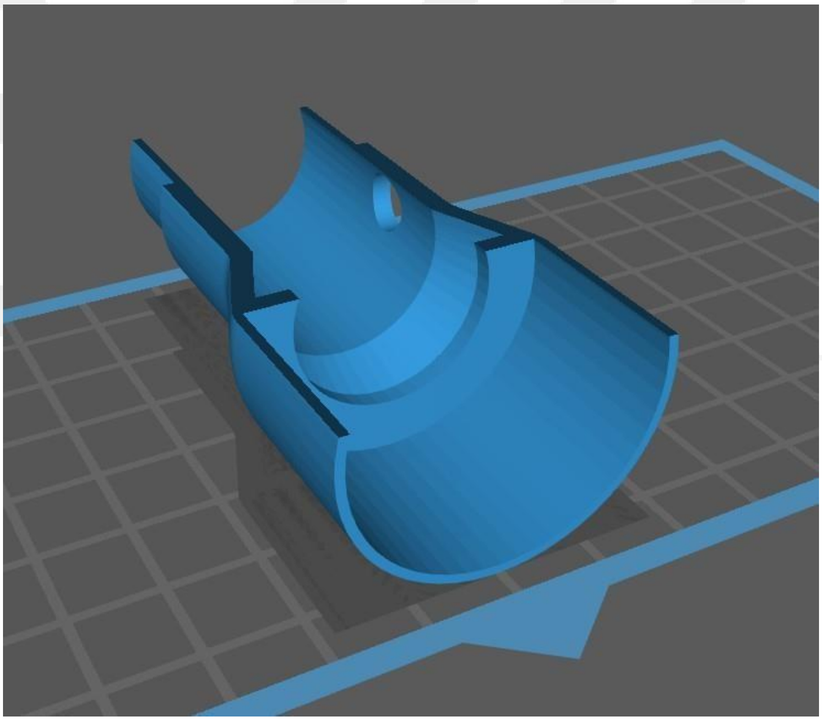


Fig. 3.2.3: Middle part design of slit lamp biomicroscope screenshot inside view.

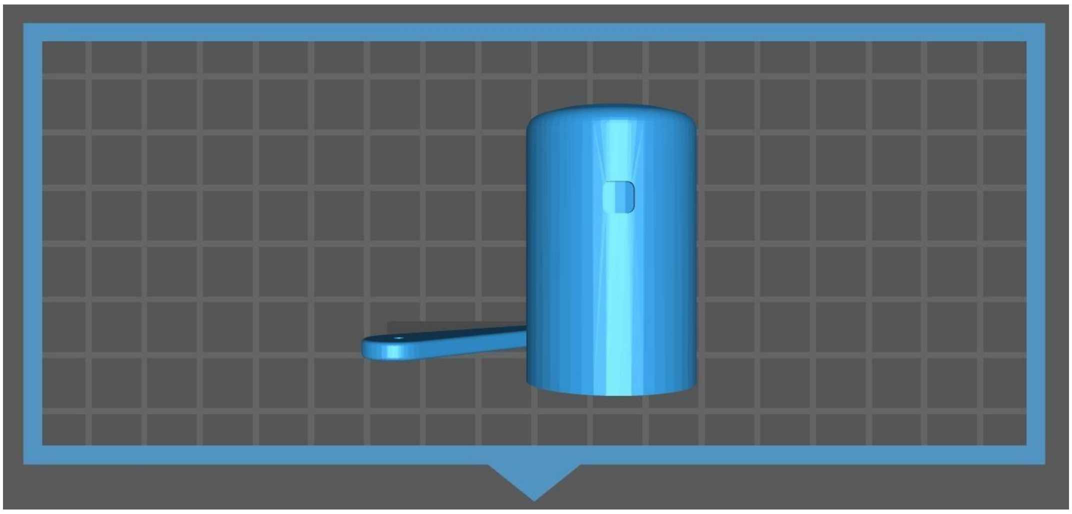


Fig. 3.2.4: Upper part design of slit lamp biomicroscope screenshot from top view.

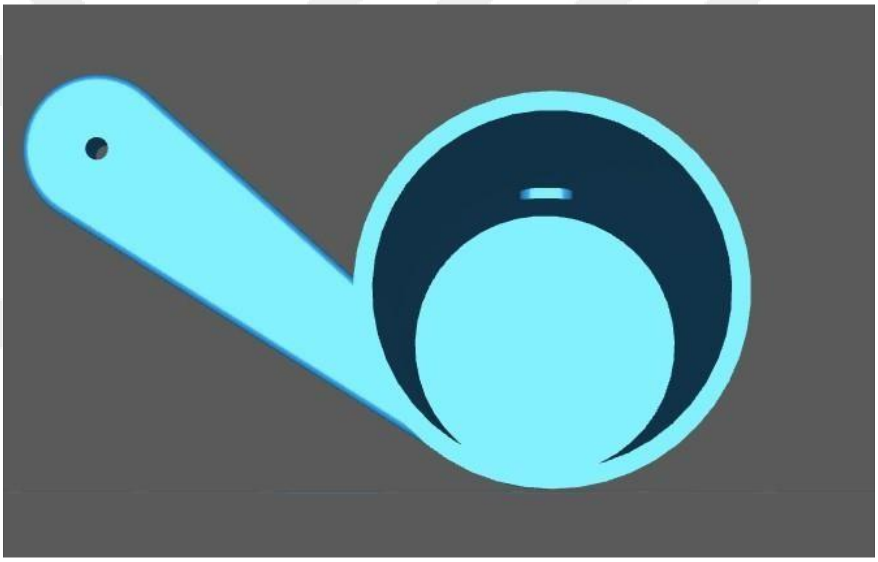


Fig. 3.2.5: Upper part design of slit lamp biomicroscope screenshot show inside view.

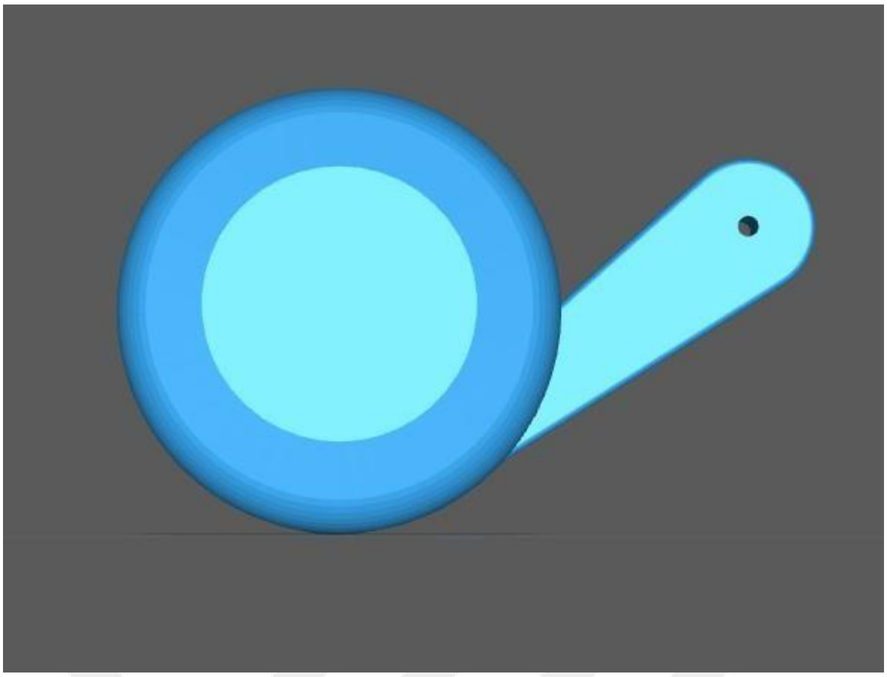


Fig. 3.2.6: Upper part design of slit lamp biomicroscope screenshot overhead view.

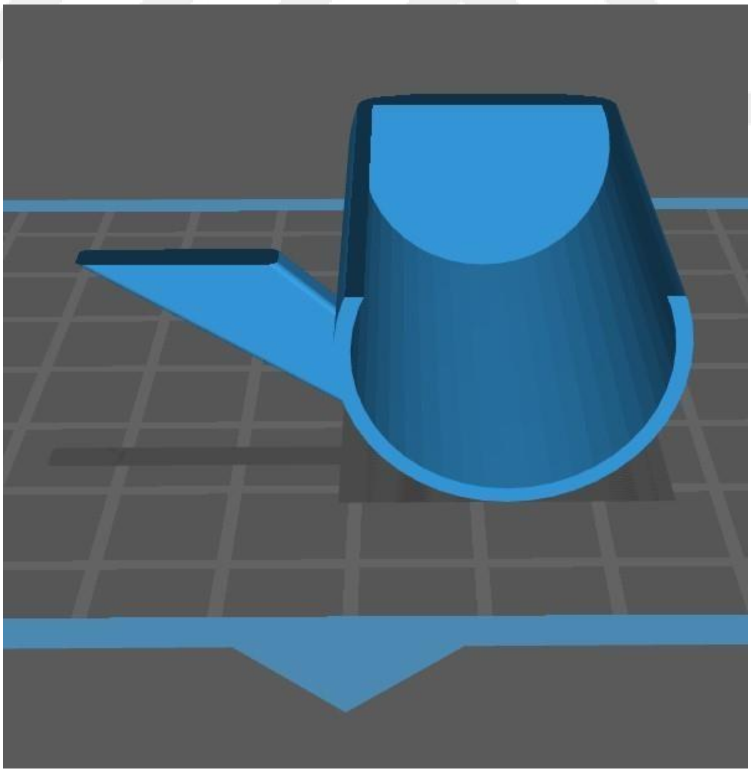


Fig. 3.2.7: Upper part design of slit lamp biomicroscope screenshot inside view.

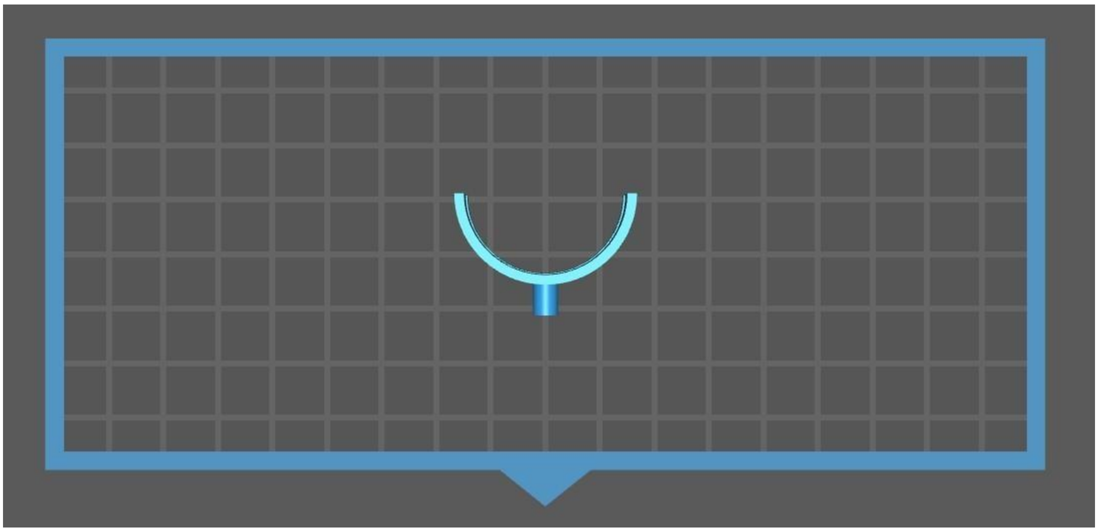


Fig. 3.2.8: Slot for optical lenses designed for placed on upper part.

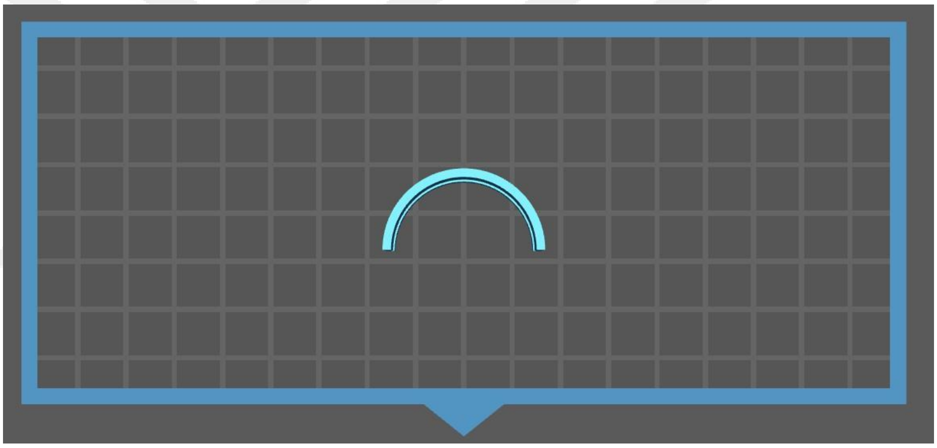


Fig. 3.2.9: The top part of slot to immobilize lenses.

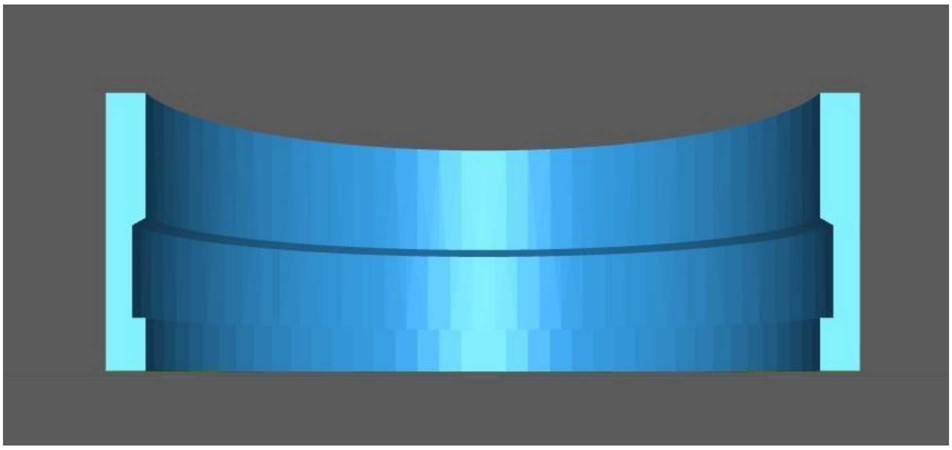


Fig. 3.2.9: Inside of slot designed a groove to place optical lenses.

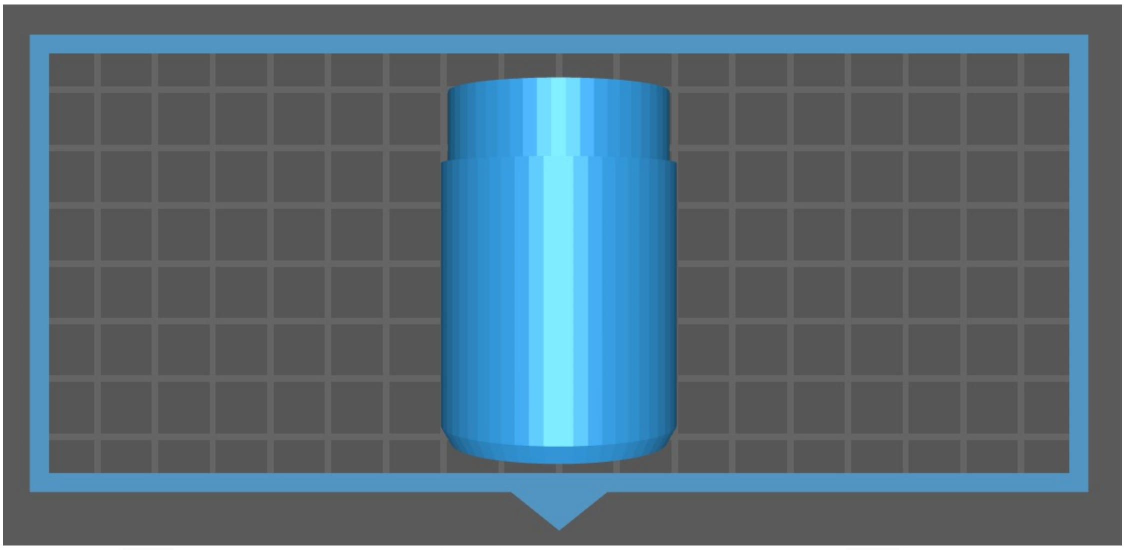


Fig. 3.2.10: Under part of system for battery bed.

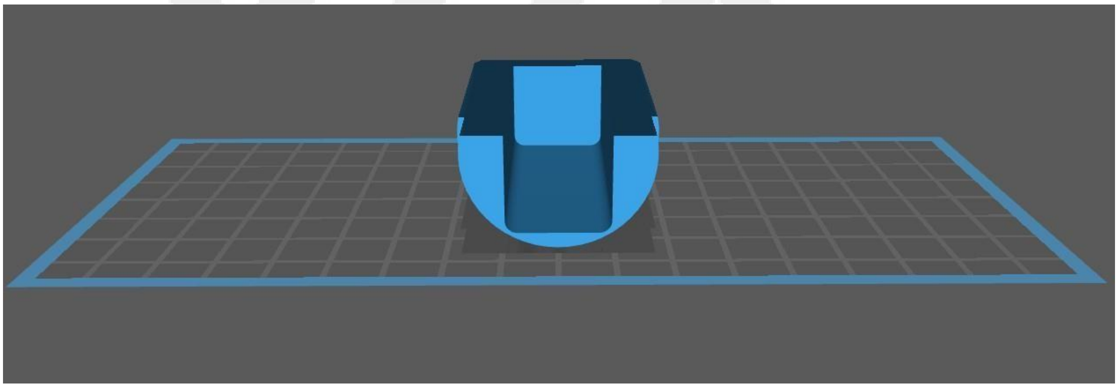


Fig. 3.2.11: Inside view of battery bed.

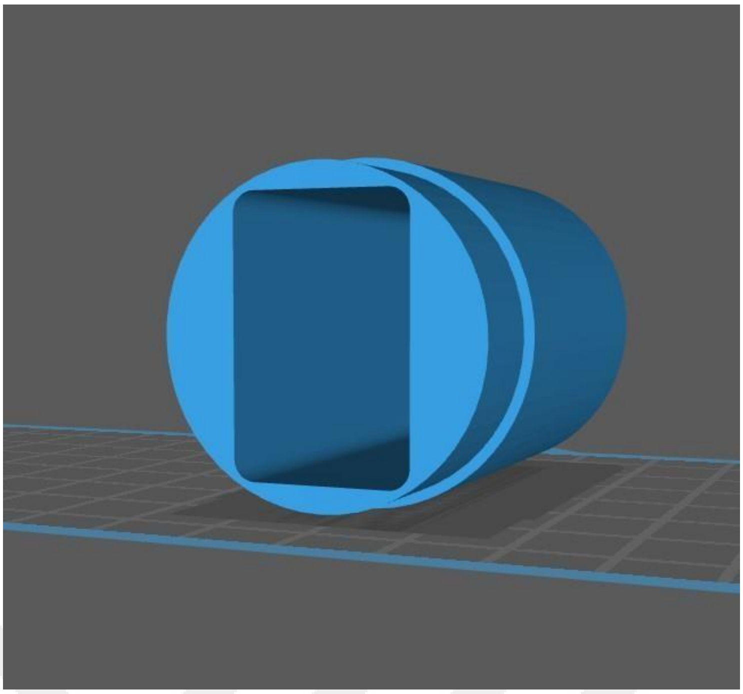


Fig. 3.2.12: Under part of system designed by dimension of 9V battery.

3.3. PROTOYPE FOR SLIT LAMP BIOMICROSCOPE

After the printing the mechanical system next part was the assembling the biomicroscope.The electric circuit solder than perched inside of the system.System basically designed for the turn on the led light and also replaceable battery.Also optical lens space designed for replaceable so lenses can be changeable though to eye examination process.The space for the optical lenses mentioned previous chapter with figures.By making prototype prove us this biomicroscope can be manufactured in portable size.

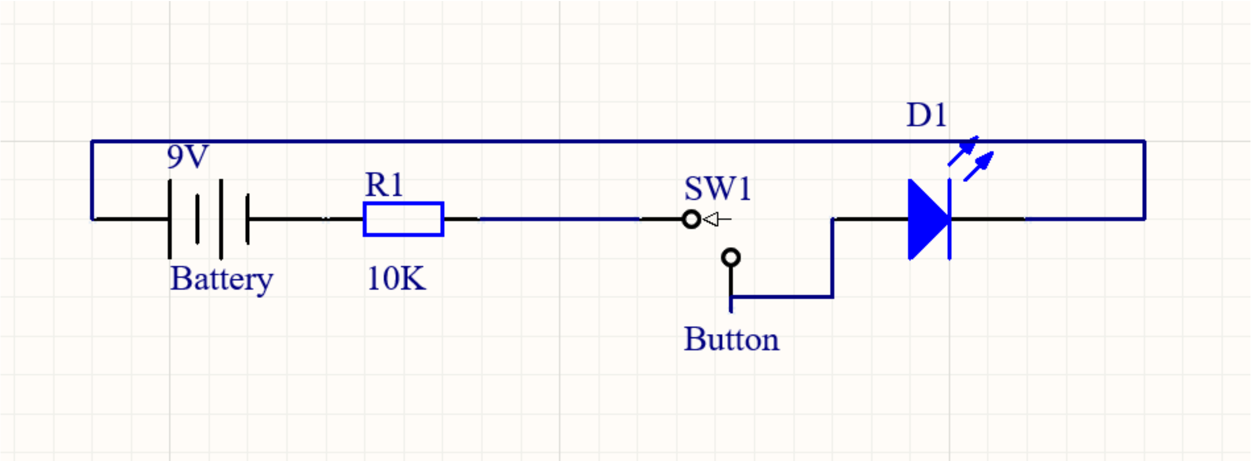


Fig. 3.3.1: Basic electric circuit diagram for biomicroscope.

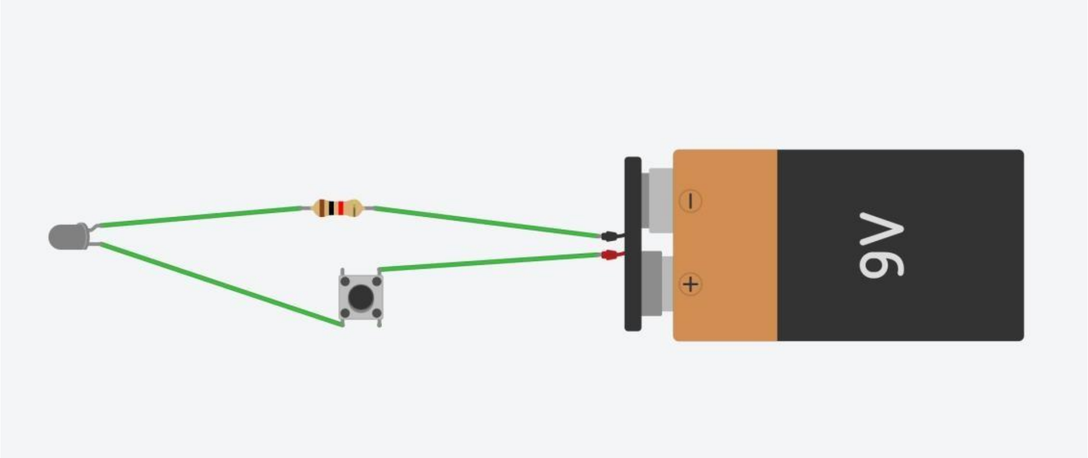


Fig. 3.3.2: Electric circuit schematics.

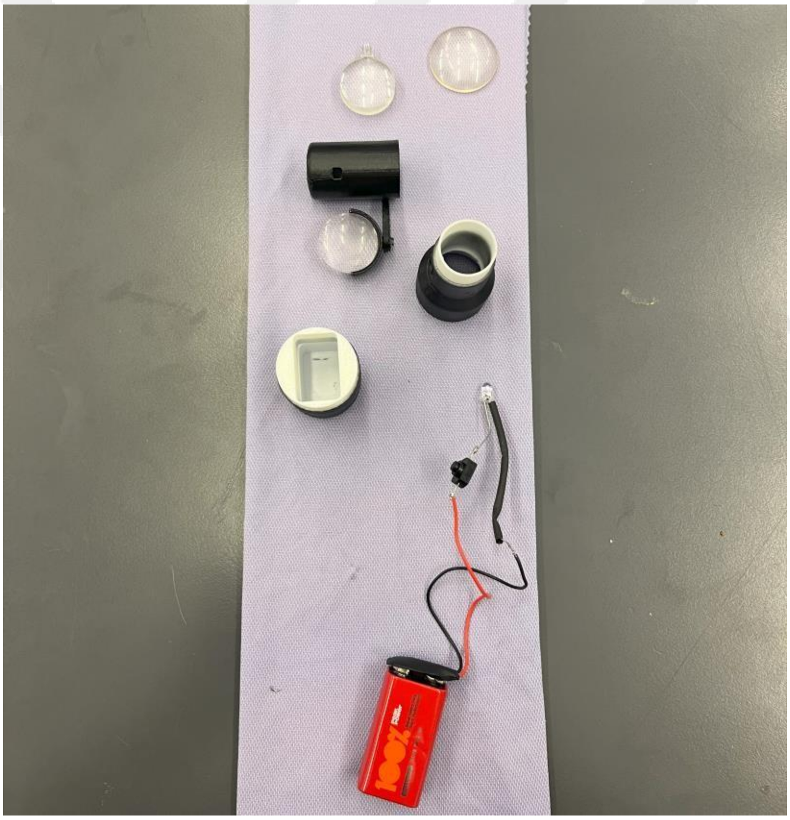


Fig. 3.3.3: Biomicroscope parts and lenses with electric circuit.

Fig. 3.3.4: Assembled state of biomicroscope.

4. EXPERIMENTS OF OPTICAL LENSES

Optimization process was required to make the experiments in the cleanroom. With the scientific data we obtained from these tests, we learn the accuracy of the research and the data we can compare. These tests were carried out in a clean room at Boğaziçi University. The purpose of the tests is to compare the surface topographies of the original lenses and the copy lenses and look at the similarity ratios.

4.1. SURFACE TOPOGRAPHY AND CLEAN ROOM TESTS

Clean room tests made under the Boğaziçi University Biomedical Engineering Institute Cleanroom.In these tests HIROX 3D Digital Microscope and Bruker DektakXT Profilometer units has been used.

The Hirox 3D digital microscope is an innovative imaging device that has been created by Hirox Co., Ltd., a prominent Japanese corporation. The microscope in question integrates optical microscopy with digital imaging and computer processing techniques, hence enabling the acquisition of high-resolution and three-dimensional imaging capabilities. The device is specifically engineered to acquire minute features of diminutive entities and surfaces, providing a thorough comprehension of their topographical characteristics and structural composition from various perspectives and depths. The microscope's software possesses a user-friendly interface that facilitates the analysis and measurement of the obtained three-dimensional pictures. Consequently, this feature renders the microscope very advantageous for a wide range of scientific and industrial purposes, such as materials science, manufacturing, medical research, and electronics. The Hirox 3D digital microscope is a very adaptable imaging tool that contributes to several sectors by offering non-destructive capabilities such as the creation of 3D models and the capacity to execute virtual cross-sections. This technology is valuable for research, quality control, and inspection operations.

Fig. 4.1.1: HIROX Digital Microscope

A profilometer is a specialized apparatus employed for the purpose of quantifying and examining the surface topography of objects or materials at a microscopic scale. The technique involves utilizing a measuring probe to scan across a surface and record height fluctuations, therefore offering accurate data pertaining to surface roughness, texture, and profile.

Profilometers are frequently employed in several domains such as research, production, and quality control, with the purpose of evaluating the surface properties of components, coatings, and materials. The data acquired by profilometer measurements serves as a valuable resource for engineers and scientists in their pursuit of process optimization, product quality assurance, and a comprehensive understanding of surface performance and behavior across diverse sectors.

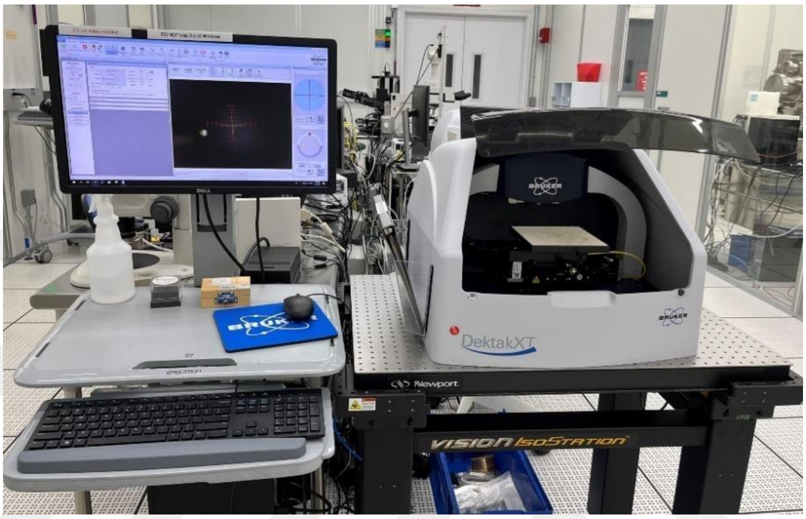


Fig. 4.1.2: Bruker DektakXT Profilometer.

These test show us in micrometer levels both epoxy based and original lenses surface for comparison figures results are clearly show that topographic resolutions for both lenses remarkable. Results shows that how essential grinding part is for lens production.HIROX images for both lenses side by side shown in figures.

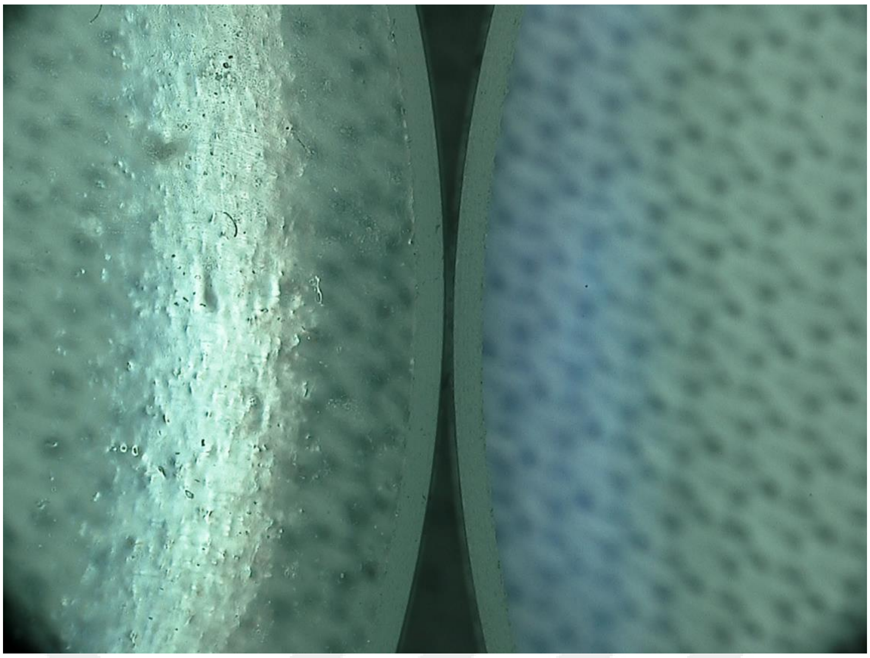


Fig. 4.1.3: Side by comparison between Epoxy based lens and Newport PAC052 Achromatic Lens

In the figure it can be clearly see that surface images clearly show that epoxy based lenses surface more rough than original. This results was expected. Because of techniques used on both lenses different than other. Manufacturing this kind of optical lenses made by advanced CNC machines and sensitive cutting techniques. It should be not forgotten that epoxy based optical lenses produced in laboratory environment.

Microscopic images taken under micrometer levels. To understand the behavior of surface roughness after grinding and polishing process for lenses these images taken.By looking coordinate system we estimate that if the pinks upper that zero under microscopic levels this results shows us that surface roughness exits in topographic images.

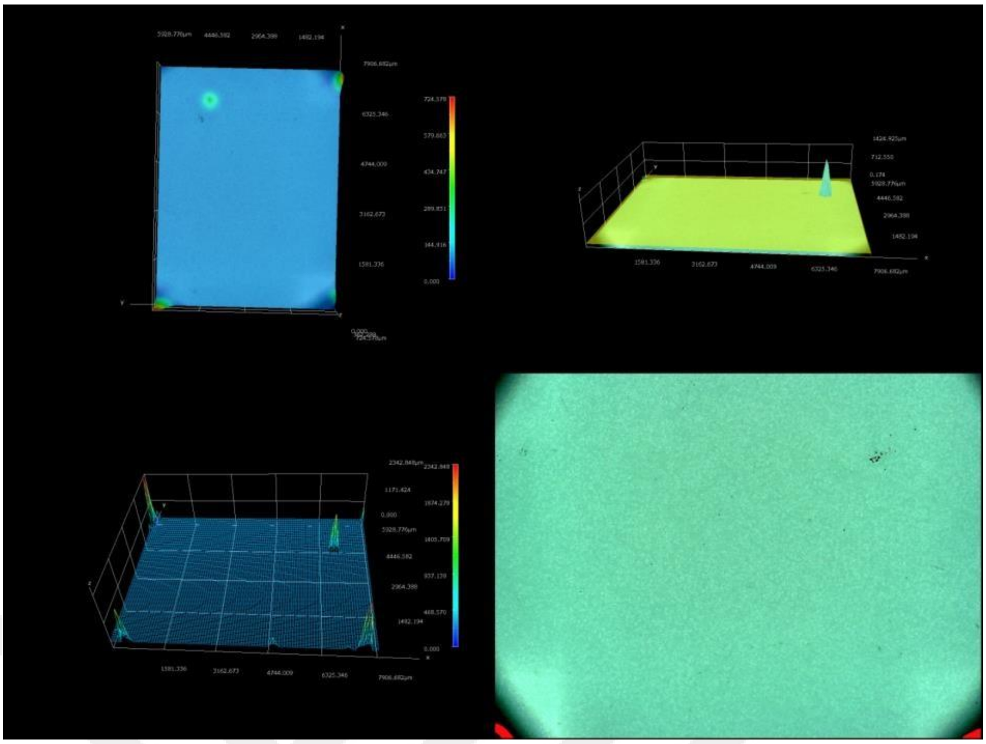


Fig. 4.1.4: PAC052 original lens area measurement topographic figure.

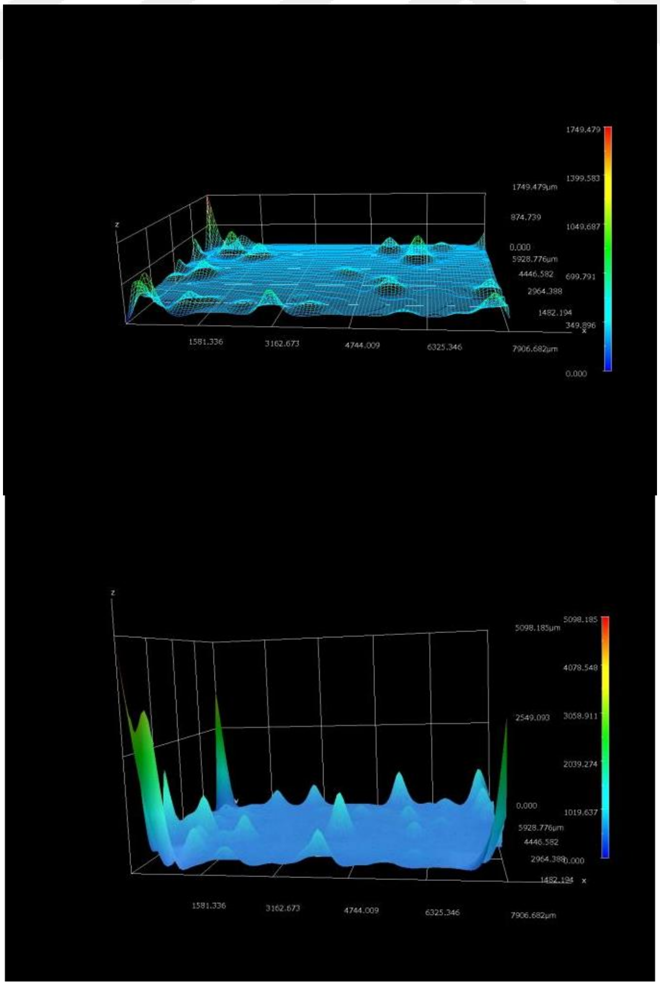


Fig. 4.1.5: PAC052 epoxy lens area measurement topographic figure.

Microscope measurements shown us topographic images of both original and epoxy based lenses to comparison. Of course measurements can not be absolute accurate because of both lenses can not be placed as exact same place.On the other hand this images also shown us how close epoxy based lenses surface area from original lenses.

Between 5000 to 8000 μm values these topographic images taken under the microscope.Working with microscope theses parameters shown clear image.

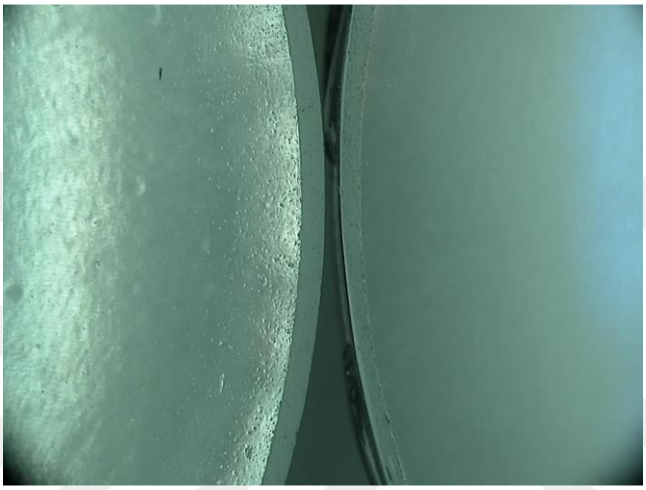


Fig. 4.1.6: Side by comparison between Epoxy based lens and Newport PAC046 Achromatic Lens.

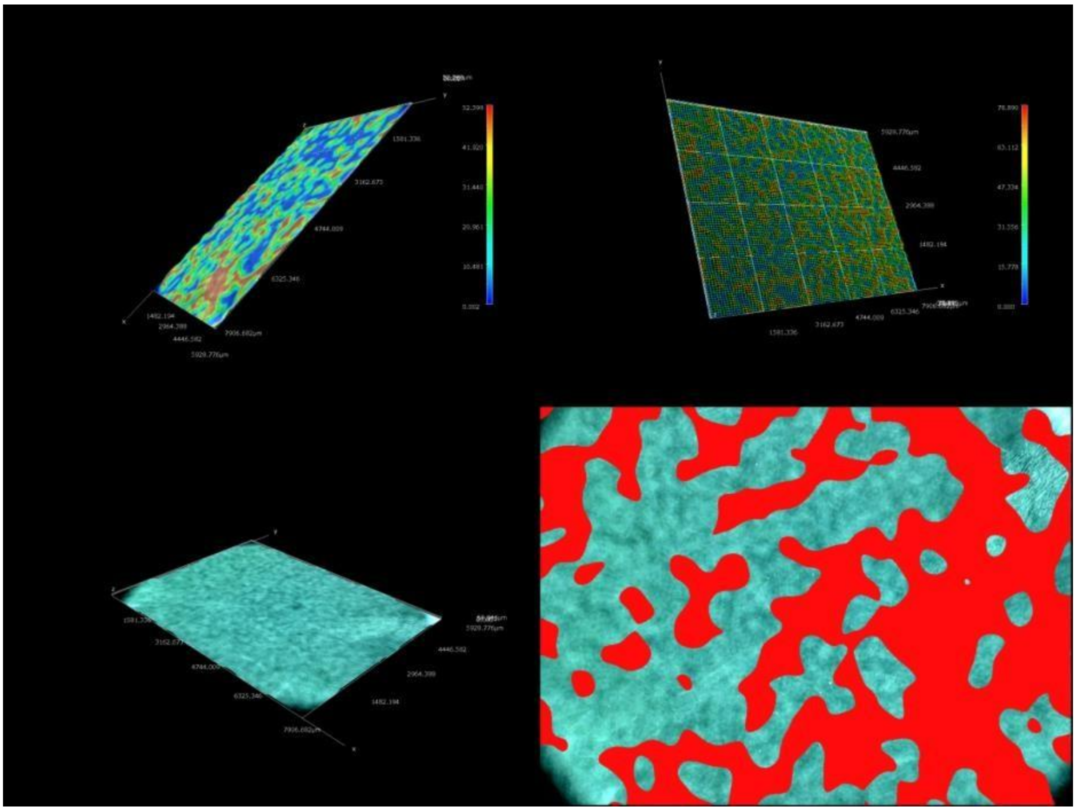


Fig. 4.1.7:PAC046 original volume measurement in microlevels**.**

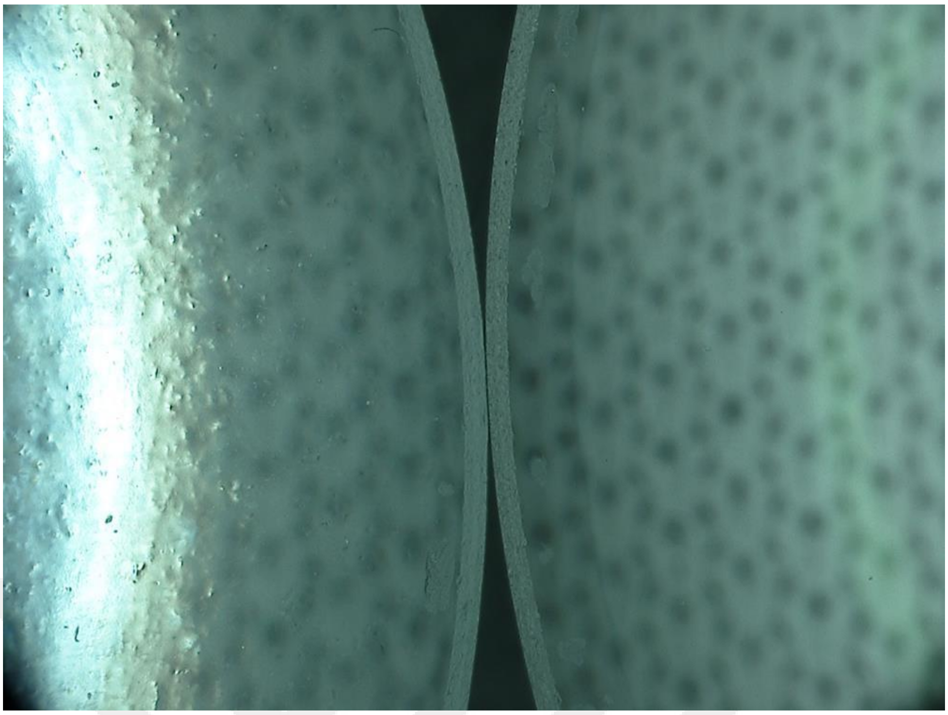


Fig. 4.1.8: Side by comparison between Epoxy based lens and Newport PAC040AR.14 Lens

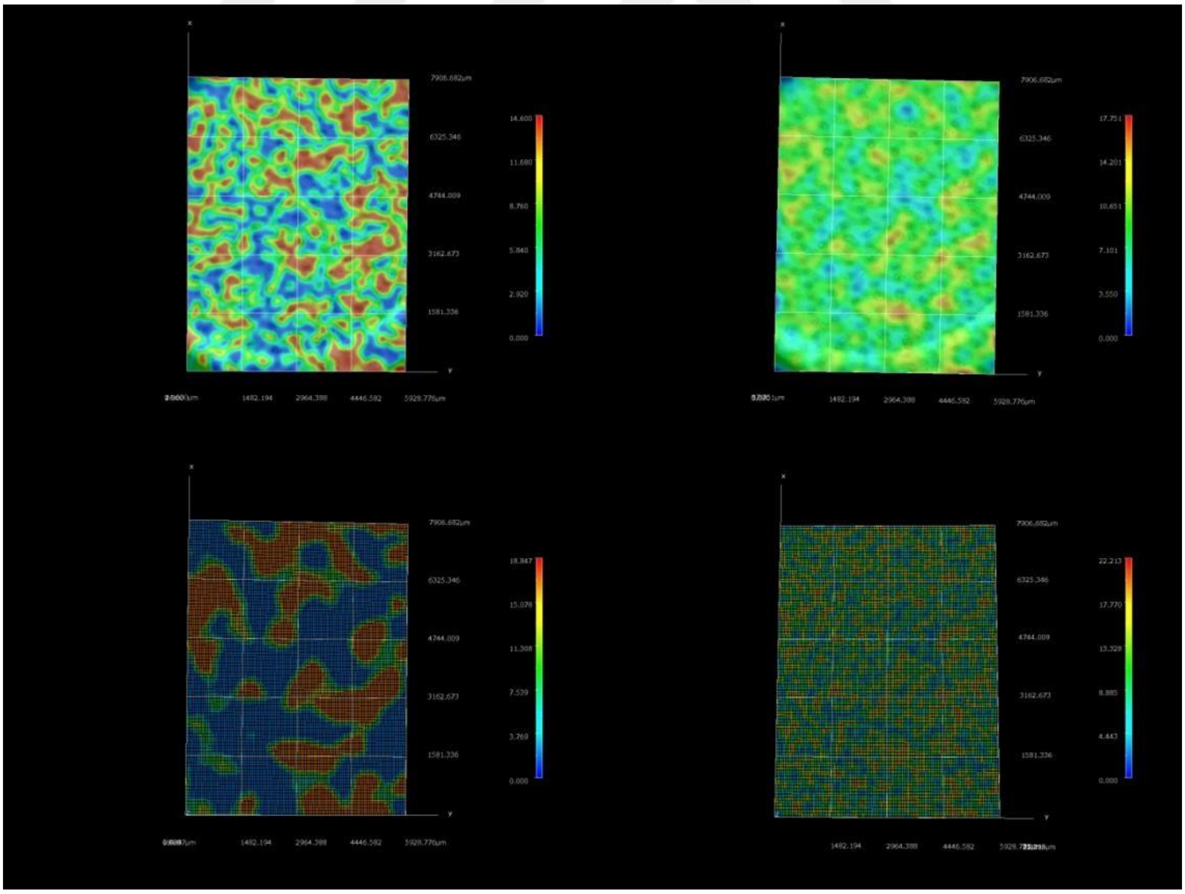


Fig. 4.1.9: PAC040AR.14 Epoxy based copied lens volume measurements by surface.

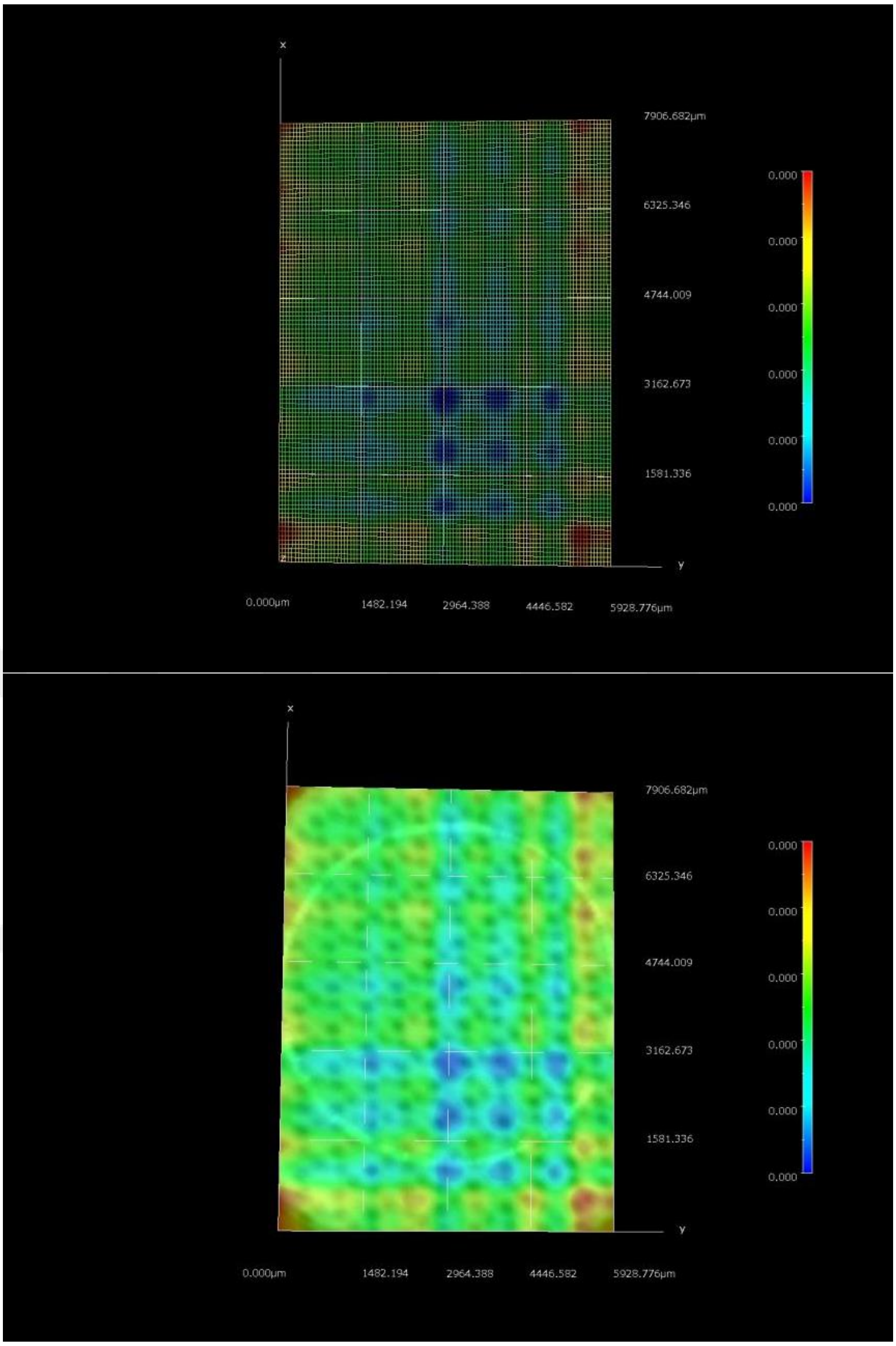


Fig. 4.1.10: PAC040AR.14 original lens volume measurements by surface.

Although these results give information about surface of both lenses, comparison for roughness profilometer devices will be more appropriate.

On the other profilometer device cant detect same spot for both lenses. Replacement for lenses doing by hand with operator. So that we cant make sure coordinate the same spot on epoxy based and original lenses.As Fig.4.1.11. shows that surface roughness for both lenses upper graph is for original and down graph is for epoxy based lenses.

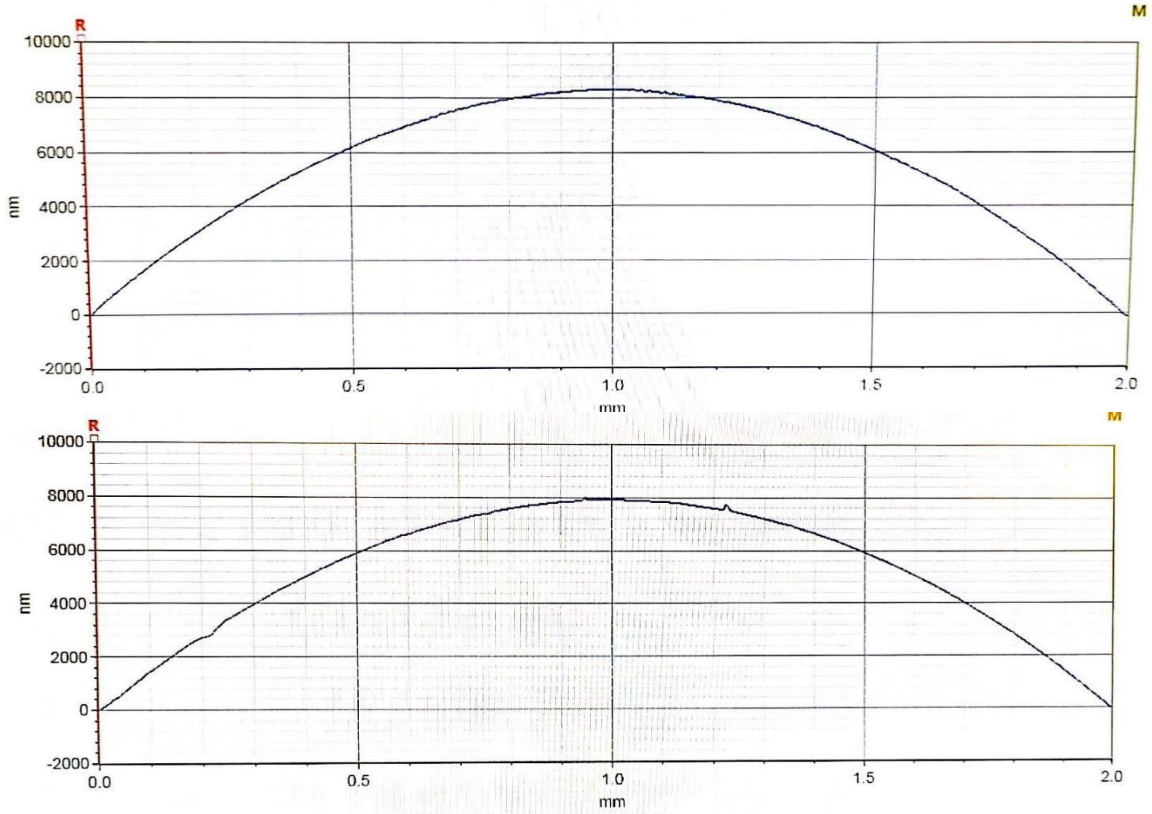


Fig. 4.1.11: PAC046. Profilometer results under 10000nm.

By looking at the graphs after polishing and grinding process epoxy based lens surface decline clearly seen. As a result of grinding surface area become much lower compare to original which was expected. Also surface roughness of epoxy based lens in some can clearly see but compare to original it is to small which is good for us.To comparison,both graph’s standard deviation taken and calculated results for original lens was 2323,80 and for our epoxy based lens was 2271,82 which were quit close results. The significance of standard deviation lies in its ability to provide insight into the dispersion of values within a certain dataset.

4.2. OPTICAL TABLE TESTS

Optical test made in İstanbul Bilgi University at Microsystems Lab. using optical table.Experiments on the optical table compared the manufactured lenses to their originals.The lenses made from epoxy were observed to collect and distribute light around a focal point ,focusing a spot similar to the original lenses.These can be seen clearly in figures.The performance of some lenses,both copies and originals was very similar.The epoxy lenses and original lenses,both positioned at a height of 50mm. These lenses exhibit similarities in terms of spot size and focal length,although the epoxy based lenses show slight dispersion due to the techniques and different material chemical properties which is already mention previous chapters.Overall , the performance of the lenses is comparable ,but epoxy lenses cannot match %100 precision of factory made lenses which is an expected result for us.

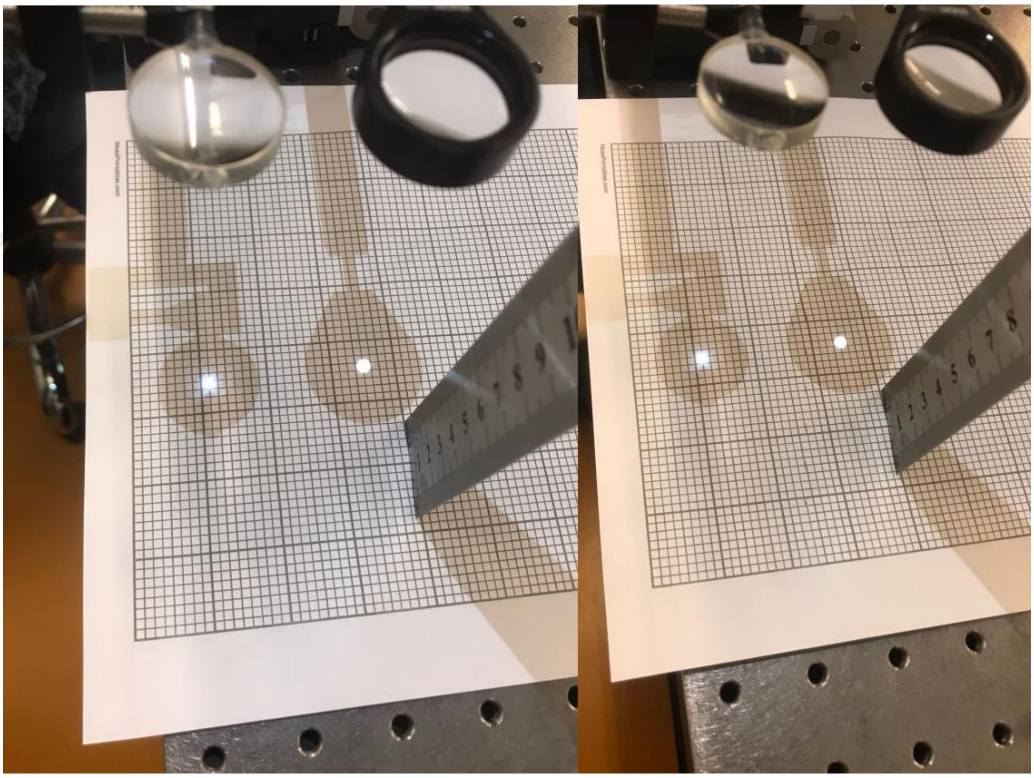


Fig. 4.2.1. From 5cm above both copied and original lens focal length tests at optical table.

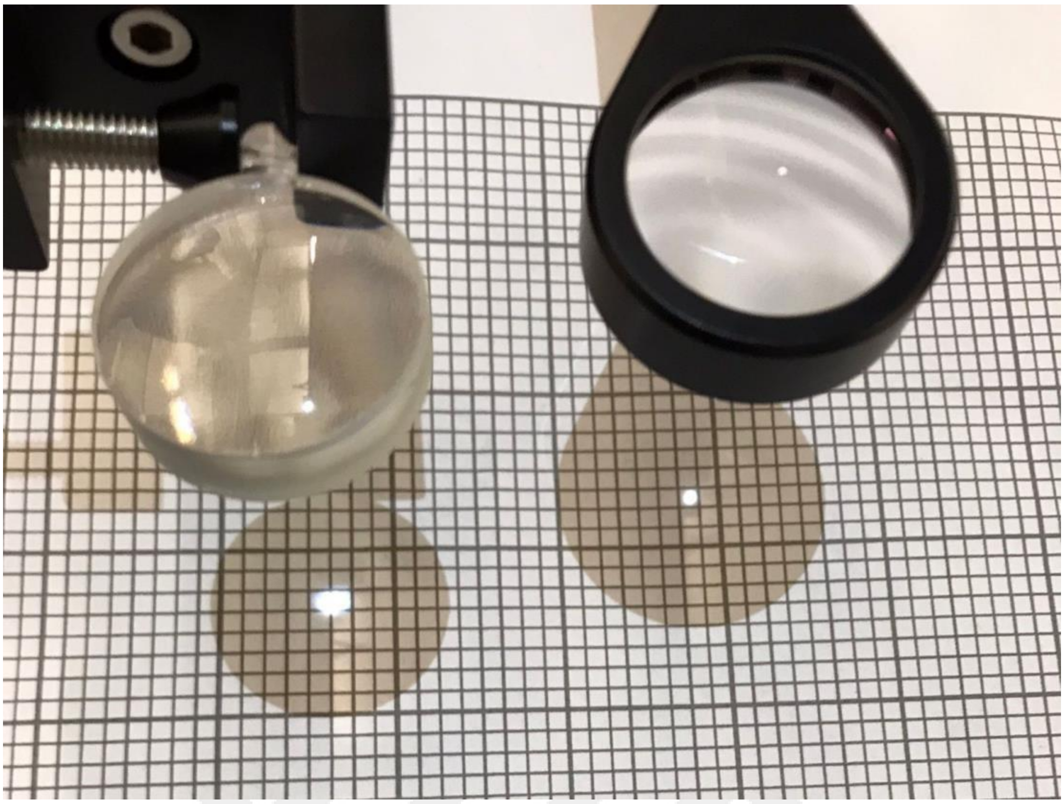


Fig. 4.2.2: PAC040AR.14 original lens and epoxy based copied lens focusing the light under 5cm.

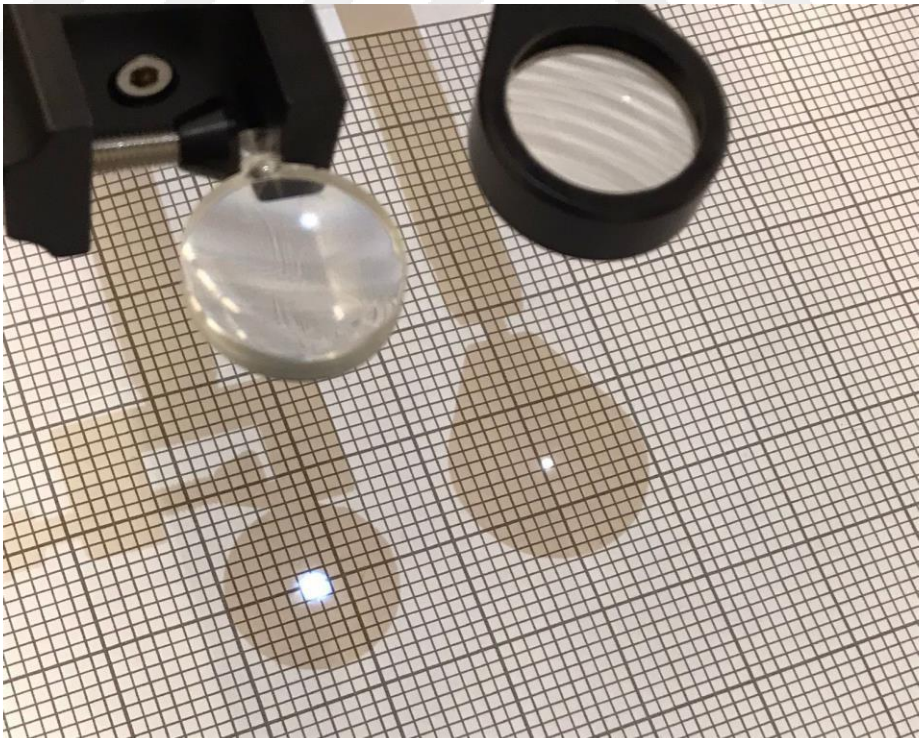


Fig. 4.2.3: PAC052 lens and epoxy based copied lens focusing the light from flint side.

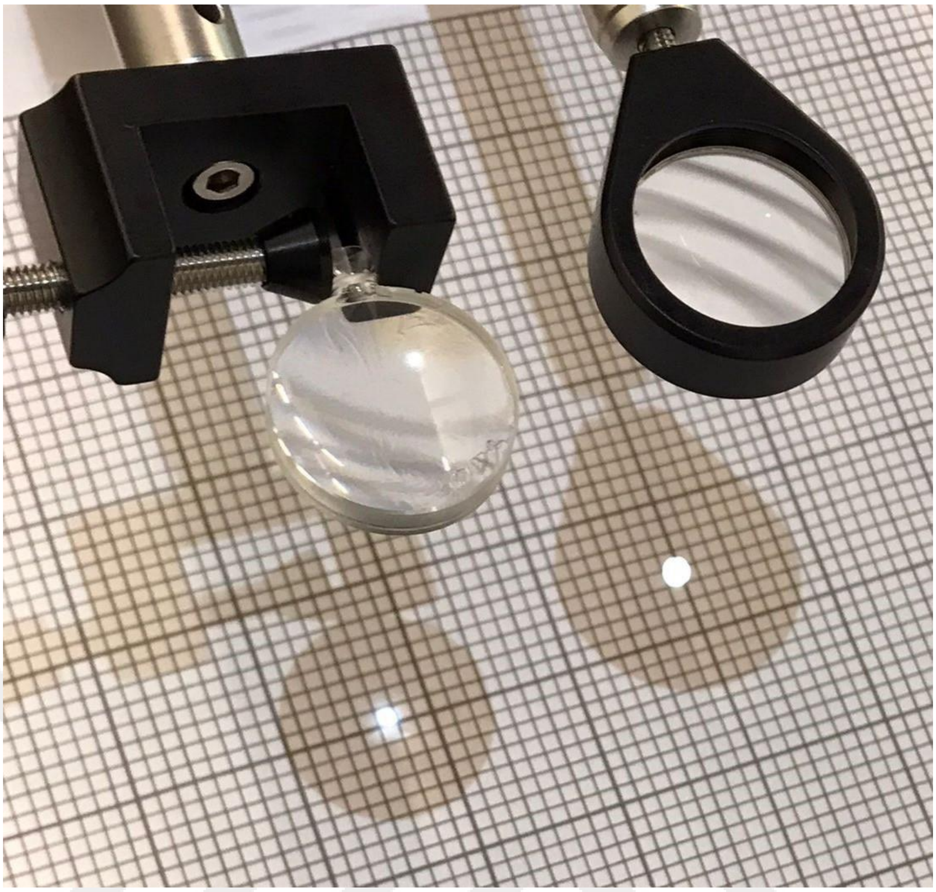


Fig. 4.2.4: PAC052 lens and epoxy based copied lens focusing the light from crown side.

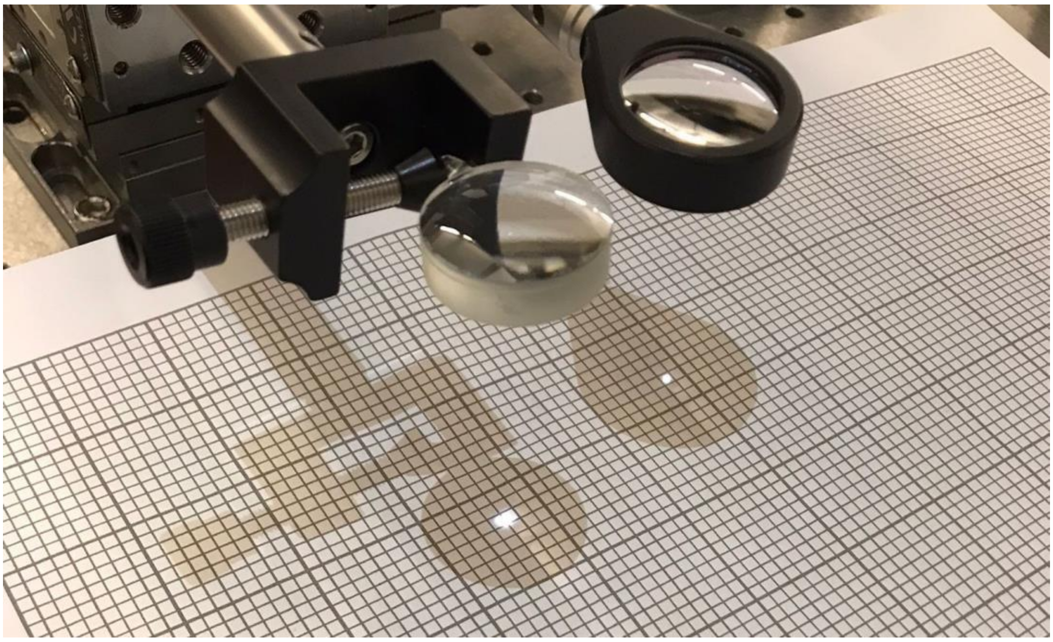


Fig. 4.2.5: PAC040AR.14 original lens and epoxy based copied lens focusing the light above 5cm.

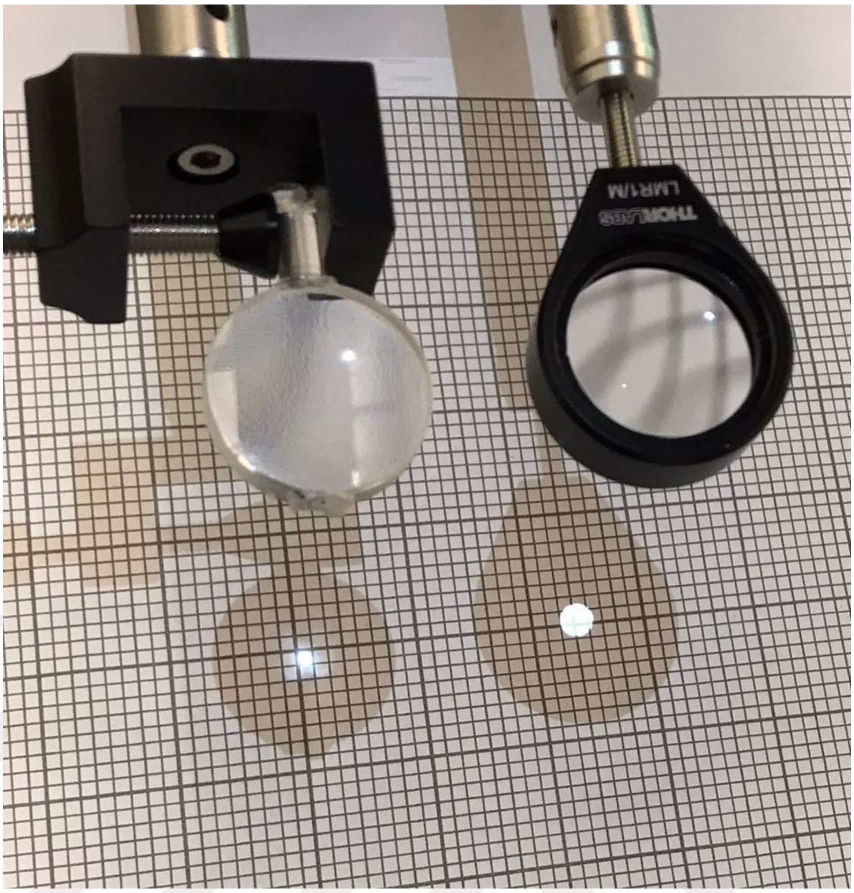


Fig. 4.2.6: PAC046 original lens and epoxy based copied lens focusing the light from crown side.

5. CONCLUSION

Throughout this report, steps that were taken to design and fabricate a suitable lens for slit lamp biomicroscope and the methods used while accomplishing the task hand were discussed in detail. In the next few chapters, cost analysis and the results for this project will be discussedin detail too but still, it is worth to note that cost of this whole prototype is not more than $100. Which is more than two thousand percent cheaper than the standard slit lamp biomicroscope in the market.

On the other hand this approach just for simulate the slit lamp biomicroscope which is main reason for us because of try to find a new design and fabrication method for lens production .

Fig. 5.1: Finished prototype design.

Also, it must be noted that this design works with replaceable battery and optical lenses.Standart slit lamp biomicroscopes optical lenses include inside of the device.Which is good for protection of lenses and system but useful for adaptation.In the market there are some slit lamp biomicroscope have portable versions like our design.Our stand out is making our own lenses different from standard manufacturing methods and also different material usage.So these points make our project remarkable so that can be achieve lots of features to the optical lens production.

5.1. RESULTS

As a result, the main purpose of the Phrozen Sonic Mini 8K 3D printer purchased for this project is now the printing of lenses whose radius and dimensions are drawn using the Lens Maker formula in the FUSION 360 program. Its dimensions are designed based on the this formula.

Fig. 5.1.1: First manufactured epoxy based lenses.

In this figure shown us(Fig. 5.1.1) where we are came from for this project.As you can see in this figure from up to down these lenses shown;came out from mold first time,after grinding and after polishing respectvily.These lenses diameter approximately 4 cm produced for tests and designed by Lens Makers formula in Fusion360.

Achromatic lenses manufactured by Newport Corporation are used for our reference to some of the lenses found in the laboratory. The aim here was to be able to compare all these methods and their fabrication with an original lens.

The results show that the lenses we can make show a perfect similarity when compared to the originals (Figure 5.1.2).

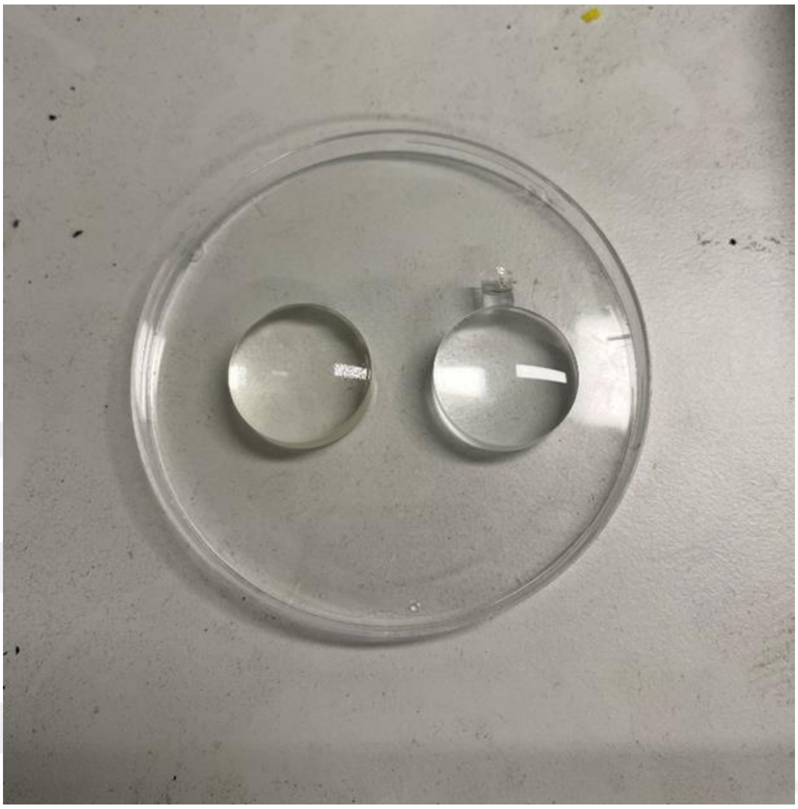


Fig. 5.1.2: Left side Newport PAC040 lens and on the right side our copied epoxy based lens.

It has been proven that lenses can be made using epoxy resin, and its ability to refract light and show optical properties just like glass or crystalline lenses with Assoc.Prof. Yiğit Dağhan Gökdel, optical characterizations will be made and a design will be made for the Slit Lamp Biomicroscope project. This study has proven that this microscope can do this job with only one lens. With a design that is tangible and easy to carry, a single lens with optical properties that we produced has been mounted, and this device has become portable with a light source .

The production of lenses with desired optical properties, which is one of the main objectives of this study, has now become a project that can be used in many areas. Small diameter lenses containing more than one optical material can be used in desired areas in medical technology. More sample lenses and prototypes from the test results can now be seen in our laboratory at the Nanobiotechnology Center.

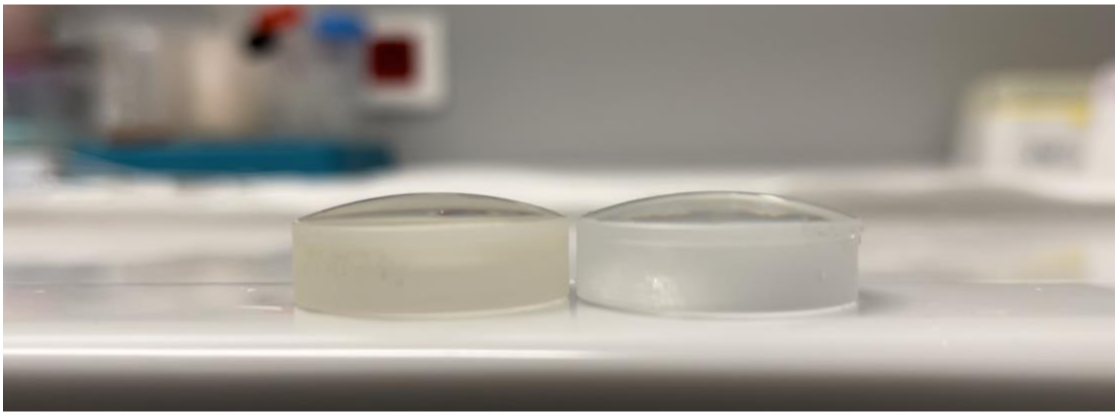


Fig. 5.1.3 Comparison of convex lenses. (Original on the left, epoxy lens on the right)

Since two different lenses are made of glass material and resin-based materials, the refractive indices of the lenses are different from each other, and therefore their optical properties are also different from each other. Optical comparisons and tests of these lenses will be made at İstanbul Bilgi University.

The most important result we got from this study shows that we can produce exactly the same concavities of the outer surface and lenses.(Figure 5.1.3)

5.2. DISCUSSION, FUTURE WORK AND CONSTRAINTS

Regarding the future of the project, some improvements are thought to be done. Many improvements were already made when compared with the first prototype and first state of the system.

Due to the epoxy choice , by looking cost and obtainable in the market , results shows that material not resistant to heat. Under certain circumstances like temperature higher than 40 centigrade Celsius material start to dissolve. Also to be exposed UV lights more than enough gives material yellowish surface. Because of solvent inside of epoxy to cause this problem.By purchasing low content of solvent this problem can be resolvable.These kind of epoxy based materials can be found in the markets but due to the price issue it should be purchasing by large amount of units. This situation makes our project cost much higher.

Just one optical lens about 5 grams. With 1,5 kg our methodology make approximately 300 units of optical lenses. By looking this results indicate productivity of lenses can be increase by amount of epoxy polymer.

Regarding to the examination and experiments by HIROX microscope indicates production of epoxy based lenses requires cleanroom environment. Under micro sizes shows that even the equipment while making mixtures for epoxy must be applied in cleanroom environment due to the containment.

Other requirements such as prism and special light source make remarkable improvements for our design. These parts are also expensive due to the USD.

Also, material research hasn’t been done in this part of the project because this part was mostly about creating a working prototype rather than a ready to use one. Detailed research regarding the materials that can be used for a biomedical device such as this one will made in order to make sure that the biomicroscope that will be produced will be more than just a prototype at the end of the project.

After deciding the material that will be used, fabrication process will be altered to suit the needs of that material. That will be the last phase of the project and it is aimed that a perfectly working product including all the systems that were previously worked upon will be produced.

Among the future contributions of the project is that it pioneers the production of optics, which is primarily needed in the medical sector. The production of special glasses used by dentists during examinations and the production of lenses on glasses that serve as magnifying glasses can be given as examples for the future among the contributions that this project can provide.

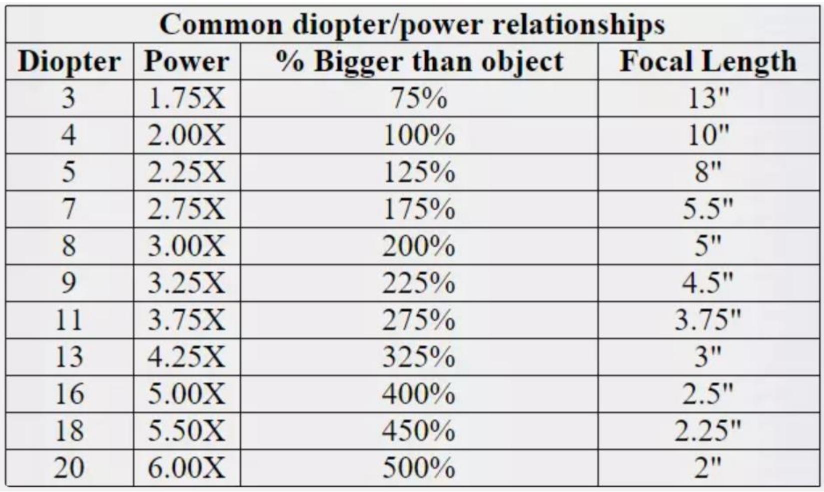
Another important point is that these lenses are made using epoxy resins that are easily accessible on the internet, which are very cheap in terms of budget. In the case of keeping the spectrum wide in terms of cost, higher quality lenses that are resistant to temperature and UV rays can be produced in production. However, it can be said that the use of special production resins with a refractive index will be more successful in terms of transparency and light transmittance, although the cost is high.

We have shown that we can produce our own optical lenses in the laboratory environment, which is the main purpose of this project. In the future, we have paved the way for studies on designing lenses with desired optical properties and making them usable in the desired area and project.

The term "diopter" pertains to the curvature of the lens. As the value of the diopter increases, there is a corresponding increase in the thickness of the lens and a higher curvature. As the degree of curvature intensifies, the trajectory of light rays is altered in a manner that results in a more extensive coverage of the viewer's retina, hence giving rise to the perception of an enlarged object. The term "powers" pertains to the degree by which an object is magnified when observed through a magnifying lens. The representation of power is commonly denoted by the symbol X.

Acoording to E-TAY Indistural Com.;

Magnification = (Diopter / 4) +1



Common diopter/power relationships

Diopter	Power	% Bigger than object	Focal Length
3	1.75X	75%	13"
4	2.00X	100%	10"
5	2.25X	125%	8"
7	2.75X	175%	5.5"
8	3.00X	200%	5"
9	3.25X	225%	4.5"
11	3.75X	275%	3.75"
13	4.25X	325%	3"
16	5.00X	400%	2.5"
18	5.50X	450%	2.25"
20	6.00X	500%	2"

Table. 5.2.1: Diopter/Power relationships according to E-TAY Indistural Com.[21]

By looking this table and our calculations we can easily come up with the idea of making objects bigger than 500% approximately with our produced lenses which is our field of view percentage.

As seen in the figure below, current design fits the portable standards right on. It was not possible to print this design and try this on a medical area because of the conditions of missing parts, but this is the number one priority for this project which is designing a lens prototype.

Fig. 5.2.1: Final design to handle of hand held portable slit lamp biomicroscope design.

5.3. SOCIAL, ENVIRONMENTAL AND ECONOMICAL IMPACT

This project is expected to impact the area of biomedical in an optimistic way. Economically, this project will make the biomicroscope market a lot more active than it is today in the countries that are not using USD as a currency. Also, it should create some kind of a rivalry in the biomicroscope market and might lead to cheaper and more advanced versions.

Also, it should decrease the laziness of going through the procedure of eye examination because this way the success rate for the procedure will increase caused by the easiness of eye examination .

It will also be a meaningful step in the medical and technological field which might lead to a better education in the medical schools. Also these project proves making and designing desired optical lenses with various areas.

5.4. STANDARDS

It’s really important to follow certain standards when doing an engineering project. Also, because that this is a biomedical device with electronic components inside, following standards will be followed closely.

Engineering standards for the IEEE and IET such as IEEE 1073 will be followed. Also, because this is a medical device, ISO 13485, ISO 10993-1 and IEC 62366-1 international standards will be followed closely. Also, this device will be first released in Turkey, which means EU and TR standards will be followed closely as well. These standards can be examplified as: EN ISO 13485:2012, EN ISO 14971:2012, BS EN ISO 13485:2012, BS EN ISO 14971:2012 and TS EN ISO 13485.

5.5. COST ANALYSIS

Cost analysis for the hardware and the materials that were tested and discarded will not be included in this page for the sake simplicity. Only the cost that was created during the development and the fabrication of the prototype at hand will be included.

Materials	Costs
YapıKimya Ultra Transparent Epoxy 1,5 Kg	24.52 USD
RTV2 20SHORE Silicone Mold 1Kg	21.22 USD
Grinding and Polishing Components	55.00 USD
Total:	100.74 USD

Table 5.5.1: Cost Analysis

As it can be seen from the table above, total cost of the biomicroscope prototype at hand is quite cheaper than the most common devices at the market.

All the Newport optical lenses prices change between 60-80 USD for each.Just for 100 USD can be manufactured over 300 unit optical lenses.By this account, production method we choose is more efficient and economic than standard optical lens manufacturing.

REFERENCES

[1] Liu, J., & Hartmann, P. (2021). Recent advances in precision optics manufacturing: Towards freeform surfaces and microlenses. Advanced Optical Technologies, 10(1-2), 47-66. doi: 10.1515/aot-2021-0016.

[2] Sihota, R., & Tandon, R. (2008). Parson's Diseases of the Eye (21st ed.). Elsevier.

[3] Nema, H. V., & Nema, N. (2019). Textbook of Ophthalmology. Jaypee Brothers Medical Publishers.

[4] Chou, S. Y., Krauss, P. R., & Renstrom, P. J. (1996). Imprint of sub-25 nm vias and trenches in polymers. Applied Physics Letters, 67(21), 3114-3116. doi: 10.1063/1.115840

[5] Gibson, I., Rosen, D. W., & Stucker, B. (2015). Additive Manufacturing Technologies. Springer.

[6] Kanski, J. J., & Bowling, B. (2015, May 26). *Kanski's Clinical Ophthalmology: A Systematic Approach*. Saunders.

[7] Groet, G., Luxexcel: 3D Printing: Combining Prescription Power and a Waveguide into a Lightweight Lens. SPIE AR VR MR. Vol. 11764. 2021: SPIE.

[8] Huang, W. and X. Zhang, 3D Printing: Print the Future of Ophthalmology. Investigative Ophthalmology & Visual Science, 2014. 55(8): p. 5380-5381.

[9] Hu, S., et al., Portable Handheld Slit-Lamp Based on a Smartphone Camera for Cataract Screening. Journal of Ophthalmology, 2020. 2020: p. 1-6.

[10] Hahn, R. S., & Virden, J. W. (1977). Precision flat lapping and polishing machines. Precision Engineering, 12(2), 61-66. doi: 10.1016/0141-6359(90)90072-Y

[11] Doebeli, M., & Rohrer, H. (1998). Method for the fabrication of micro-optical structures in semiconductor substrates. US Patent No. 5,721,351.

[12] Aktitiz, S., Aydın, K., & Topcu, A. (2020, December 31). Stereolitografi (SLA) Tekniği ile Basılan 3 Boyutlu Polimer Yapılarda İkincil Kürleme Süresinin Mekanik Özelliklere Etkisi. *Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, 949–958. https://doi.org/10.21605/cukurovaummfd.868895

[13] Akyüz, S., Yarat, A., & Egil, E. (2011). Bisfenol-A içerikli dental materyallere güncel yaklaşım. *Clinical and Experimental Health Sciences*, *1*(3), 190–195. http://www.ejmanager.com/mnstemps/56/56-1325063217.pdf

[14] Su, W. F., Fu, Y. C., & Pan, W. P. (2002, September). Thermal properties of high refractive index epoxy resin system. *Thermochimica Acta*, *392–393*, 385–389. https://doi.org/10.1016/s0040-6031(02)00124-7

[15] Du, S., Xie, B., & Luo, W. (2019). Development and applications of liquid silicone rubber. Express Polymer Letters, 13(6), 585-600. doi: 10.3144/expresspolymlett.2019.54

[16] Shao, G., R. Hai, and C. Sun, 3D Printing Customized Optical Lens in Minutes. Advanced Optical Materials, 2019. 8: p. 1901646.

[17] Huang, Y., et al., Design of a High-Performance Digital Slit-Lamp Microscope with FiveSwitched Zoom. Applied Sciences, 2020. 10(8): p. 2757.

[18] Hecht, E. (2002). Optics (4th ed.). Pearson Education. ISBN-13: 978-0805385663.

[19] Sommer, A.C. and E.Z. Blumenthal, Implementations of 3D printing in ophthalmology. Graefe's Archive for Clinical and Experimental Ophthalmology, 2019. 257(9): p. 1815-1822.

[20] Willis, K., et al., Printed optics: 3D printing of embedded optical elements for interactive devices, in Proceedings of the 25th annual ACM symposium on User interface software and technology. 2012, Association for Computing Machinery. p. 589–598.

[21] www.mymagnifier.com/en/faq/E-TAY-faq-003.html