DAS Departamento de Automação e Sistemas
CTC Centro Tecnológico
UFSC Universidade Federal de Santa Catarina

Development of an Adhesive-Dispensing-Unit for precision application purposes in the production of wafer scale micro-optical components

Monografia submetida à Universidade Federal de Santa Catarina

como requisito para a aprovação da disciplina:

DAS 5511: Projeto de Fim de Curso

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Florianópolis, janeiro de 2013

Development of an Adhesive-Dispensing-Unit for precision application purposes in the production of wafer scale micro-optical components

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Esta monografia foi julgada no contexto da disciplina
DAS 5511: Projeto de Fim de Curso
e aprovada na sua forma final pelo
Curso de Engenharia de Controle e Automação Industrial

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Abstract

The continuously growing demand for small and precise glass optics for miniaturized optical systems in demanding applications require adequate production technologies for such optical components made of specialized glasses.

The Wafer Level Optics research project (WLO) aims at the utilization of a wafer-based manufacturing approach via precision glass moulding. This approach promises an effective way to harness adequate scale effects, leading to two major advantages: firstly the wafer-based manufacturing enables the by far more cost effective production of hundreds of optical elements in just one manufacturing step. Secondly it would also facilitate subsequent process steps, since e.g. the handling and alignment of the elements can be undertaken on waferlevel as well.

From the metrological point of view, the ostensible difficulties lie in the exact alignment of the wafers to one another. At this point the wavefront-based alignment of an optical system promises to be highly suitable for the alignment of an entire wafer with a necessary accuracy in the $sub - \mu m$ range. The imperativeness of the need for such tight tolerances is deducted by the effects, that even slight imperfections in the alignment process have on the optical function of a system.

However, the precision and optical function of a micro-optical system is not only dependant on the accuracy of the alignment, but also on the capability to cement the aligned wafer to one another with high accuracy and within in a well determined position. In order to achieve a good bonding result it is critical to adjust the properties of the adhesive to the targeted bonding process.

After the adhesives have been physically evaluated the second major task involves the actual application process and the developement of an adequate appliance.

It will be necessary to design, construct and assemble an integrated device, capable of holding the micro drop application nozzle / system and moving the wafer on an automated basis. For automation purposes it will be furthermore necessary, to design a accompanying LabView programme, in order to control and monitor the application process.

Resumo Estendido

A crescente demanda por produtos opticos pequenos e precisos para sistemas opticos miniaturizados em várias aplicações exigentes necessitam de uma tecnologia de produção adequada para esses componentes feitos de vidros especializados. Enquanto as tecnologias de ponta utilizam um processo de retificação, polimento ou de corrosão demorada e cara, o inovador projeto de pesquisa Wafer Level Optics (WLO) se foca em uma abordagem baseada em placas via modelagem precisa em vidros. Essa abordagem promete um meio efetivo de aproveitar um efeito de escala adequado, levando a duas grandes vantagens: primeiramente, a produção em nivel de placas permite uma produção menos custosa de centenas de elementos opticos em apenas um passo de produção. Segundo que também facilita outros passos subsequentes, desde, por exemplo, o manuseio e alinhamento dos elementos podem ser feitos em escala de placas também. Ainda que esse método de produção ja é uma tecnologia de ponta nas industrias de litografia e semicondutores e também é usado largamente na produção de componentes opticos de plástico, sua transferência para a produção de componentes micro-opticos de vidro ainda apresenta várias dificuldades cruciais ainda não resolvidas e alguns problemas operacionais.

Do ponto de vista metrológico, as dificuldades se encontram no alinhamento exato entre as placas. Nesse ponto, o alinhamento por frentes de onda de um sistema optico promete ser altamente adequado para o alinhamento de uma placa inteira com a precisão necessária no nível de $sub - \mu m$. A grande necessidade para pequenas tolerâncias é devido aos efeitos, que até as pequenas imperfeições no processo de alinhamento têm na função optica do sistema.

Entretanto, a precisão e a função optica de um sistema micro-optico não é apenas dependente da precisão do alinhamento, mas também da capacidade de colar as placas alinhadas entre si com grande precisão e numa determinada posição. Para atingir um bom resultado na união é de grande importância ajustar as propriedades do adesivo para o processo de união escolhido. Na cadeia desse processo rigoroso, o projeto Wafer Level Optics considera que a união das placas alinhadas precisa der considerado simultaneamente com o procedimento de alinhamento propriamente dito. Para atingir um resultado ótimo de união, as propriedades físicas do adesivo precisam ser combinadas com o processo de colagem e dos requisitos dependentes. Portanto a

escolha de um adesivo adequado está fortemente ligado com o projeto do aparelho de alinhamento, já que o método de secagem do adesivo é altamente influenciado pelo procedimento de alinhamento.

Depois do adesivo ser avaliado fisicamente, a segunda maior tarefa envolve o processo de aplicação e o desenvolvimento de um dispositivo adequado. O adesivo será aplicado externamente atravéz de um sistema de tecnologia de microgotas, permitindo gotas bem pequenas no nível de 20pl com uma frequência máxima de 6kHz. Essas características são usadas para projetar um processo de aplicação dinâmico, em que a placa é movida em uma mesa xy em altas velocidades sob o sistema de despejamento.

O processo de aplicação tem o objetivo de realizer um procedimento automatizado, no qual a placa colocada no sistema receberá a quantidade exata de adesivo nas posições exatas entre os elementos micro-opticos. Por isso, será necessário projetar, criar e montar um aparelho integrado, capaz de conter o bico e o sistema de aplicação de micro gotas e mover a placa nas direções necessárias. Isso também inclui a escolha e integração de um outro equipamento, como a mesa xy. Para o propósito de automação, será também necessário deselvolver um programa em LabView, para controlar e monitorar o processo de aplicação.

A placa contendo as gotas de cola será posteriormente colocado em um equipamento para alinhamento, onde depois de um processo preciso de alinhamento, o adesivo será secado.

Contents

Capítulo 1: Introduction

The project described in this document is a part of a greater project called Wafer Level Optics. The next section will introduce the project as a whole and the section after that will specify which parts of the Wafer Level Optics project was developed by the project described in this document.

1.1: The Wafer Level Optics project

The Wafer Level Optics project aims to develop precision glass molding techniques for the replication of micro-optics at wafer level. It is foreseen that the molding of multiple micro-optics on one glass wafer, stacking these to optical systems, bonding them and then dicing them will become the norm for micro-optics manufacturing in future.

1.1.1: Motivation

As the latest studies approve, the European photonics industry is steadly growing. In the last years the growth was substantially higher than the GDP growth for the EU25 countries. Sectors like production technology, medical technology and live science earn 26 percent of the total EUR 43.5 billion turnover [2] , as Figure 1.1 shows.

Micro optical components and systems often serve as an important enabler for innovative products in the laser, life science or biotechnology market. At this point the role of glass micro optics becomes more and more important. advantages of ultra precise optical components made of glass eg are their resistance against environmental impact, their biocompatibility and their capability of being used in high power applications. The ongoing miniaturization and the continuously growing quantities are only two issues which led to a change in optics manufacturing within the last decade. Direct manufacturing techniques such as grinding and polishing could no longer meet the requirements of the demanded micro optical components, so the precision glass moulding was set up to keep step with the technical developments in optics design. By applying this manufacturing technique large quantities of ready-to-use and highly precise optics can be produced.

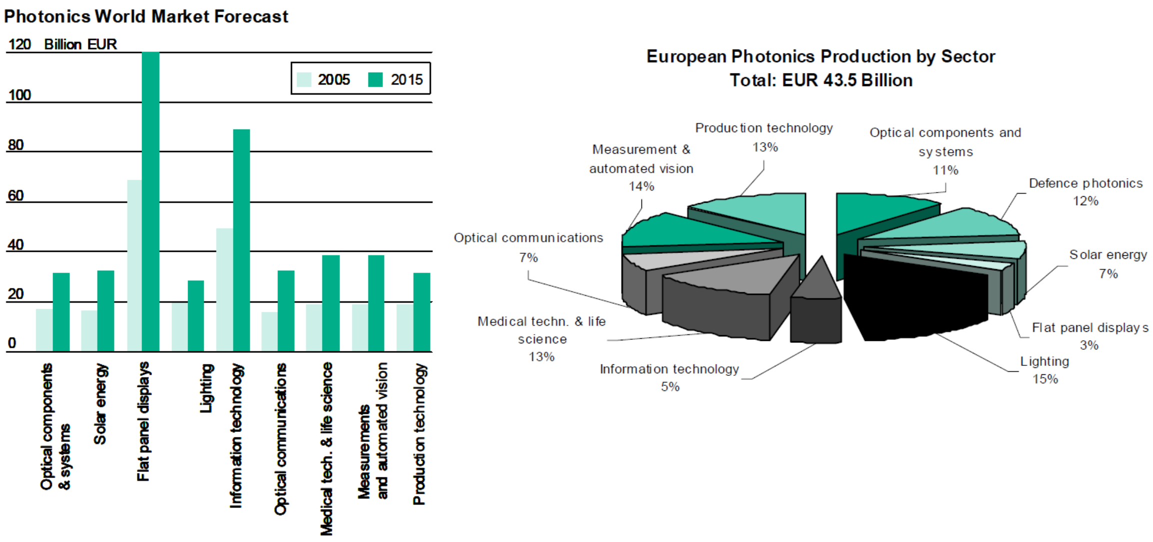


Figure 1.1: European photonics production by sector [2] and photonics world market forecast [2]

Producing micro optics needs different nano and micro manufacturing process. The mould substrate material is a powder based material each particle size of 200nm and less. The accuracies requested for the micro optics are typically in sub-micron range which results in manufacturing processes driven in the same magnitude of precision.

Beside the ongoing trend of miniaturization the integration of those small micro optical lenses to highly precise optical system demands for innovative solutions. Here the semiconductor industry is a leading example:

The manufacturing of thousands of computer chips on one silicon wafer enabled an enormous reduction of manufacturing coasts and at the same time lowered the handling complexity as well as the system integration coasts. Derived through this example the motivation of the Wafer Level Optics project is to build up the same economies of scale for the precision glass moulding process. Moulding multiple micro optics on one glass wafer, stacking those wafers to optical systems, bond and finally dice them will be the future alternative for micro optics manufacturing, Figure 1.2. Thus the current process chain for precision glass moulding will be scalable such as optics manufacturer will be enabled to either mould small series of micro glass optics but also, using the same equipment, answer the high volume demands of certain market segments. While the necessary process technology for the manufacturing of polymer optics on wafer scale is already in an advantage stage, there is currently no intelligent manufacturing platform available that permits the replicative manufacturing of glass optics on

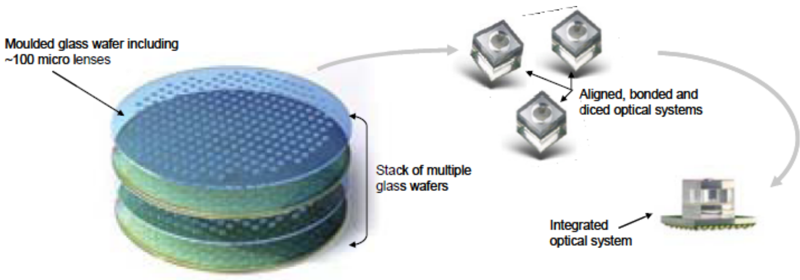


Figure 1.2: Mains principle of WaferOptics approach

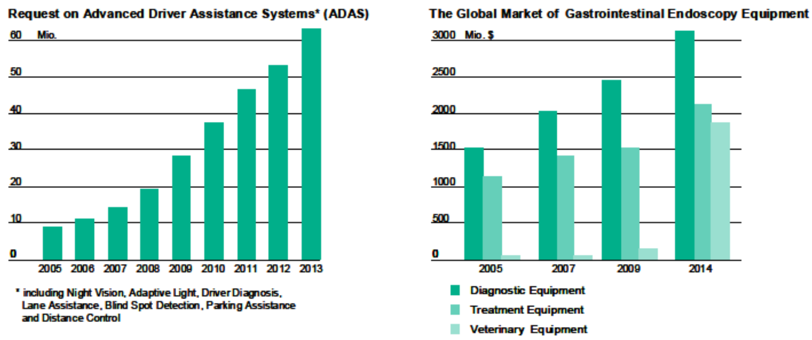


Figure 1.3: Perspective worldwide needs of ADAS [3] and endoscopy equipment [4]

wafer scale.

While the consumer electronic market is nearly completely kept by Asian optics manufacturer, technologies such as laser or medical science where Europe holds the market leadership show growing demands in terms of micro optical components. Medical instrumentations containing imaging sensor or cameras such as endoscopes for example consists of complex optical systems with multiple glass optics. Similarly the increasing distribution of advanced driver assistance systems (ADAS) where cameras are often used for parking assistance (front and rear camera), safety issues (blind spot detection or lane keeping/change assistance) or in form of optical sensors (rain detection sensor) deliver additional markets for micro optical glass components, Figure 1.3. Since most of these products are linked to a 10-20 year warranty or should keep their functionality over the whole product life cycle, the use of polymer optics is clearly limited.

Despite the strong market leadership of the Asian competitors for high volumes glass optics used for consumer goods like DVD-players and digital cameras e.g. a rising success of moulded glass optics in smaller quantities but therefore with higher grades of complexity can be observed in Europe. Industries and branches such as lase technologies or life science record a permanently growing demand of sophisticated glass optics. Of course production costs and handling efforts of these optics should be as low as possible. To meet these demands precision glass moulding in most cases is the only technology to apply. Those optics manufacturer who have the machining and measurement equipment necessary to successfully replicate glass micro optics in their production portfolio often invested multiple million Euros to build up these facilities. Investments coast that can only be overcome by steady innovations and intelligent and scalable production platforms. Here WaferOptics will contribute in order to assure a long therm workload for the machining equipment and enable the optics manufacturer to be highly flexible in yeald and efficiency.

To meet the abovementioned market needs by innovative approaches using state of the art machining equipment the overall goal of the project Wafer Level Optics to develop a completely new and efficient production process for glass optics with sub-micron accuracies.

Today micro-optical components can be manufactured by precision glass moulding as already mentioned. But the current technology only allows the replication of one (conventional process) to 20 (multi-cavity process) single optical elements within in moulding cycle, Figure 1.6. Since optical system often consists of three or even more different single optics, all aligned very precisely, large efforts are needed to assembly the optical systems. In addition, up to three iterations, must be passed before the moulded optic exactly meets the required specification. Each of this iterations contains the costly manufacturing of the mould and moulding try out to individually design the moulding process. To overcome there iterations FEM [1] process simulation is used.

The Wafer Level Optics idea represents the future solution for the manufacturing of micro optical systems. Instead of moulding one to 20 single micro optics using the same number of single mould pair, the Wafer Level Optics approach is to manufacture a large monolithic mould with 100 or even more dingle cavities having a diameter of up to 4". This mould will then be taken to replicate large glass wafers so that finally 100 or more precise micro optics are on one single wafer. Since the single optics are perfectly aligned on the glass wafer it is possible to stack different glass wafers, align them, bond them and finally dice them into multiple optical systems. These systems now are ready to be integrated in the desired products such as endoscopes, camera modules or sensor systems.

The Wafer Level Optics approach contains two major advantages for the manu-

[1] FEM (finite element method) is a methos for dividing up a very complicated problem into small elements that can be solved in relation to each other.

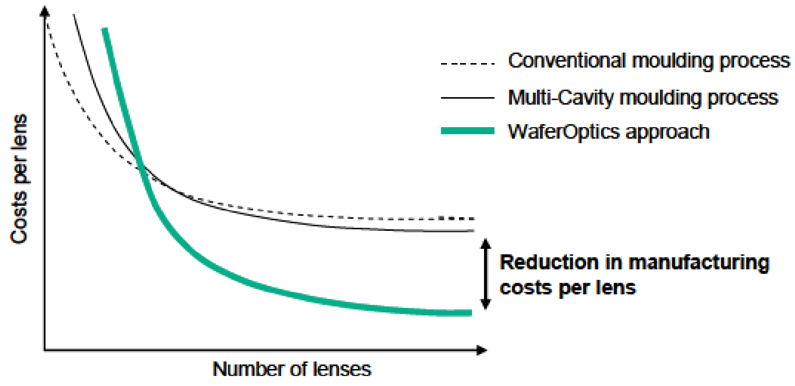


Figure 1.4: Estimated coast reduction of moulded micro optics applying Wafer Level Optics approach

facturing of micro optics:

- First, the costs for producing 100 single moulding tools is much higher than the estimated costs for the manufacturing of one monolithic mould. In conclusion the costs for the lenses can be decreased, Figure 1.4. But today, there is no manufacturing process capable to produce there moulds and replicates wafer scale glass optics.
- Second, the handling effort linked to the assembly of every small optical components will be essentially reduced due to the fact that no each optic but only the whole wafer needs to be handled.

Since the idea of the Wafer Level Optics project also intents to simulate the moulding process and the alignment process, two also completely new features for wafer scale optics, further reductions in costs are estimated due to efficient process layouts based on the a-priori information.

To conclude, the Wafer Level Optics project and the developments witch will be accomplished will significantly improve the position of European optics manufacturer towards their foreign competitors. Not only the leadership in Europe‘s strong markets like life science, automotive or laser technology will be essentially strengthened but also already lost markets such as camera module production or optical sensor manufacturing can be step by step re-conquered. All enabled through this new, efficient and scalable approach of optics manufacturing and the know how built up in this project.

1.1.2: State-of-the-art

Glass optics manufacturing in Europe was and in parts still is characterized by a direct manufacturing of the single optical components. The technologies applied here are grinding ans polishing. With this approach, Europe has reached a leading position in fabricating high precision optics. Typical representatives companies wich should be named here are Carl Zeiss (GER), Boostec (F) or Leica (GER). However, since each optic is manufactured individually, the drawback of this proceeding is that only small quantities can be manufactured. A comparison which shows the difference between the European market and the Asian one is the following: While a highly developed company as Leica Microsystems, providing high nd microscopes for the (bio)medical and life science branch is fabricating 70.000 optics per year, the Japanese opto-electronic fabricates much more than 1 million per month. The reason for this difference is that the Asian manufacturers consequently focus on replication technologies. With this approach they have gained a leading position in the large optics market such as digital cameras, mobile phones or other consumer goods.

<u>Precision glass moulding</u>

Within the last years Europe is facing a dramatic change in the optics market. Other branches, such as the medical technology, bio technology or even the ”old” industries automotive and machine building require more and more optical components as already shown above. But these markets need much higher quantities of complex shaped optics. With the current approach, a direct manufacturing of the single lenses or even the moulding of single lenses, the needs cannot be satisfied. In order to avoid that there branches will be also taken over by Asian companies, the European SMEs, that are currently the technology provider in optics manufacturing, have to get the necessary knowledge in order to serve the markets with the necessary optics products.

In the past years, the glass moulding technology was step by step established in Europe. Companies such as Aixtooloing (GER), Fisba (CH), and Kaleido (DK) apply this technology to fabricate moulds and optics in a large scale. In the precision glass moulding technology an already polished glass part (”Gob”) is put into a heat resisted mould and heated up to a glass specific temperature (usually between 300 and 800 C). Afterwards, the gob is pressed into the desired shape. After cooling down the system the ready to use glass optic can be taken out of the mould, Figure 1.5. The cycle time ranges between 15 - 30 minutes. A higher quantity can be reached by using multi cavity moulds or by separating the process (heating-pressing-cooling) into

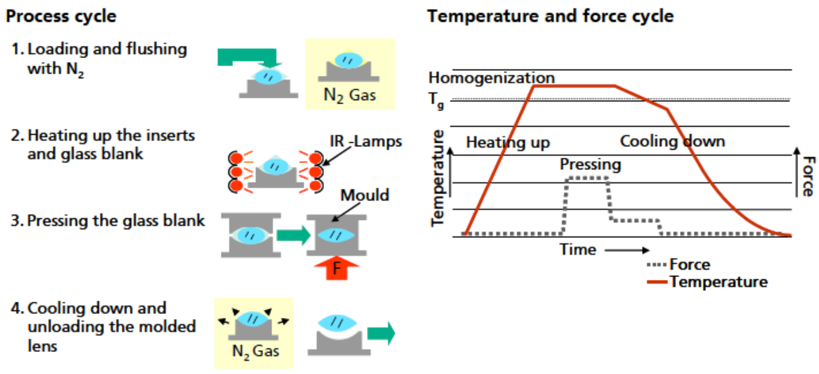


Figure 1.5: Process cycle of the precision glass moulding process

several steps. By doing this, piece times of less than one minute can be reached. The main advantages of this technology is that complex shapes, such as spheres or free forms, can be manufactured in a reproducible way and high accuracies. To enhance the efficiency of the glass moulding process the Fraunhofer IPT developed a method to simulate the moulding process. Thus, it is possible to precast the shrinkage of the glass lens during the cooling phase and initiate an a-priori correction by adapting the mould geometry. Since the mould manufacturing process is the most time and cost consuming process the simulation is a large benefit for the whole process chain because the iterating characteristic of the mould making process can be extremely reduced.

Considering that in the future optics as parts of car sensor systems or medical devices need to sustain certain environmental stresses such as heat, scratches or chemicals, glass will be the material of choice. Its properties in terms of hardness, heat and chemical resistance as well as its high refraction index which will allow smaller construction space is ideal for multiple applications. Therefore adequate manufacturing techniques capable to meet the market requests such as high volumes in combinations with high precision are absolutely necessary. The precision glass moulding and specially the moulding of wafer scale glass optics like addressed in the Wafer Level Optics project can and will be the main enabler to preserve and even enhance the European competitiveness in optics manufacturing.

Wafer scale optics manufacturing

In order to further increase the output and also facing the market demands of a further miniaturization and functions integration, a new approach, called wafer scale moulding, ws derived. Here, a glass wafer is put into the mould. The mould in the case has 10 or even more than 100 cavities. Thus the yield of on moulding cycle is increased.

Wafer scale manufacturing in general was first established by the semiconductor industry. Here, the silicon wafers gained more and more in diameter to ideally use the economies of scale during the manufacturing process of thousands of computer chips.

In optics manufacturing polymer optics can already be fabricated in a wafer scale level [6]. Since polymer optics are moulded at lower temperatures (200 - 300 C) the moulds do not have to resist intense conditions. Therefore non ferrous metals or aluminium are mostly used as mould materials. The big advantages of these materials is their machineability by diamond cutting processes. By applying ultra precision diamond turning or milling moulds up to a diameter of 200mm can be machined and subsequently used to cast wafer scale polymer optics [6]. This process is already driven to perfection so that the economies of scale can be used and cheap micro optics and micro optical systems can be fabricated.

Another approach to produce wafer scale optics is the so called glass on polymer technique [8], which can also be manufactured in wafer scale. Here, also a glass wafer is put into the moulding machine. But instead of moulding the glass, polymer is injected so that the multi polymer optics are casted on the glass wafer. Since the moulding temperatures here also do not reach critical values the moulds can be manufactured of non ferrous metal or aluminium as described.

Since glass is moulded at higher temperatures (350 - 800 C) [5] and the moulds need to be harder and more resistant against chemical and thermal influences, ultra fined grained ceramics or tungsten carbide is used as the mould material [7]. Its brittleness and hardness qualifies grinding as the ideal machining process. Hence, a ultra precision grinding process is applied to manufacture the moulds with the requested accuracies and surface finish. The process is yet not only established for large monolithic moulds. Here, the goal of the Wafer Level Optics project is to develop the grinding process to be able to machine hundreds of cavities (diameter 1 - 5mm) in one single 4” wafer scale mould, Figure 1.6.

Regarding the mould material, the state-of-the-art are ultra fined grained ceramics of tungsten carbide. These materials can be manufactured already in industrial scale. Since for the moulding of single optical elements the thermal expansion of the mould is not that critical, it will be for wafer scale optics. In conclusion there is a need to adapt the existing materials or develop new ones which show thermal expansion coefficient close to those of the moulded glasses.

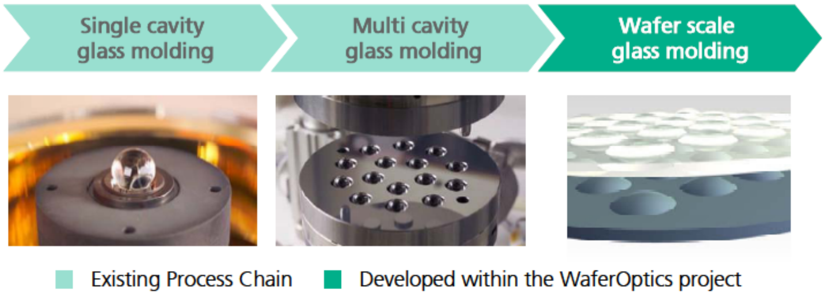


Figure 1.6: Scalability of the precision glass moulding process

Optics alignment and assembly

At present the adjustment of the optical elements takes place with wafer level optics and the basis of mechanical reference marks at the extents of the wafer. The accuracy of this procedure is in the range of some microns - but this alignment uncertainty already impairs the quality of the optical function. The negative influence of the alignment uncertainty rises as the refractive power of a lens rises. Miniaturization in modern systems if often achieved by designing lenses with a high refractive power. Therefore a substantial reduction of the optical quality due to misalignment can be stated as great challenge.

The state of the art procedure of the alignment of several optical elements is the centering which is performed with an autocollimator defining de de-centering of the optical axis of each component when rotating them. Based on this data corrective actions are performed iteratively. But this procedure cannot be performed concerning wafer scale optics since the rotations of several wafers around the local optical axis of any lens of the wafer is not suitable.

This problem can be faced by directly measuring the optical function and using this measurement data for an active alignment of the optical surfaces. A suitable method for the evaluation of the optical function is the wave-front sensor according to Shack-Hartmann principle. This technology combines two advantages: it supplies a 3D evaluation of the wave front with a very high dynamic range, i.e. it can detect rather huge misalignment, and it runs in real time, enabling a fast alignment. The wave front data in combination with the design data can ideally be used for the determination of the corrective displacement and at the same time for an inline quality assurance. After the alignment the wafers need to be fixed by an UV-hardening adhesive to avoid any possible shifts before the wafers are finally cemented.

1.2: Current Project and Document Organization

This chapter has presented the project as a whole and introduced and explained the concept of wafer level optics.

The current project is the part of the Wafer Level Optics project that was developed in Fraunhofer IPT and described in this document.

The part of the Wafer Level Optics project described in this document was the development of an adhesive dispensing unit for precision application purposes in the production of the wafer scale micro-optical components.

Throughout this project, many tools and devices were used. These tools and devices will be described in detail in Chapter 2.

All the process of designing and development of the automated adhesive dispensing device will be described in Chapter 3.

The strategies created for dispensing the adhesive on the wafers are going to be presented in Chapter 4, as well as their LabView algorithms.

Chapeter 4 will also present the tests and validation of the strategies.

The last chapter will show the conclusions and the future perspectives for the project.

Capítulo 2: Tools Used

As mentioned in the previous chapter, many tools were used for the development of the automated adhesive dispensing unit. These tools will be described in detail in this chapter. The tools used are the following:

- Micro-drop System: tool used to dispense the adhesive.
- Positioning System: Thorlabs XY Controlled Stage used to position the wafer for the adhesive dispensing.
- LabVIEW, data acquisition package DAQ-mx for LabVIEW and DAQ data acquisition card: tools used to perform the communication between the PC and the micro-drop device.
- Autodesk Inventor: software used to design the adhesive dispensing device.

2.1: Microdrop System

The system of microdrops is formed by a drop dispensing nozzle and a control unit that controls the functions of the shooting of the drops. The system also consists of peripheral components such as the miniature camera system. [12]

2.1.1: Operation

Microdrop Technologies dispenser systems are based on piezo driven printing technology. It functions according to the same principle as an ink-jet printer with a piezo-electrical print head. The liquid is fed through a capillary tube. To emit a droplet, a mechanical impulse is imparted to the liquid column by a piezo ceramic. At the nozzle tip a micro fine droplet is generated, which departs from the dispenser head at high speed.The micro dispenser system is for non-contact dispensing of liquids in single droplets of volumes ranging from 20 to 380 pl. It is possible ro dispense liquids in single droplets or in a series of drops with viscosities of 0.4 to 10000 mPas. Electronic control of the dispenser heads ensures a high level of dispensing precision as to volume, timing and placement. The procedure can be observed with the help of an integrated stroboscopic LED. [12]

Figure 2.1: Standard micro dispensing system with touchscreen [12]

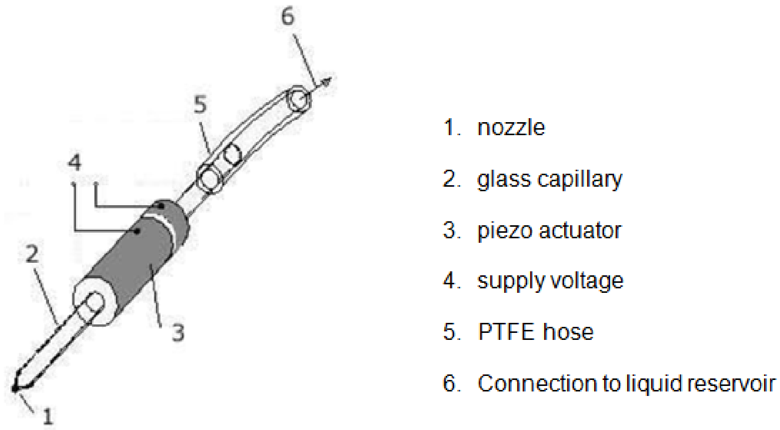


Figure 2.2: Droplet generator [12]

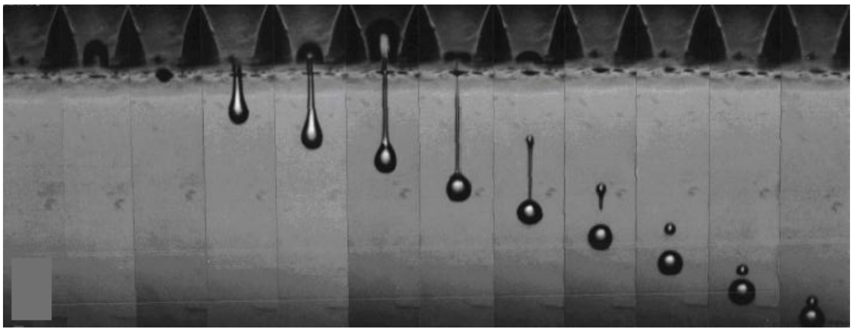
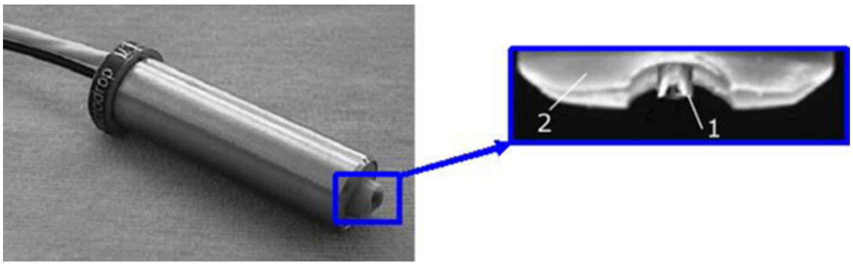


Figure 2.3: Different stages of the formation of the drop

The core of the micro dispenser system consists of a glass capillary (2 Figure 2.2) surrounded by a piezo actuator (3 Figure 2.2). The glass capillary is formed to a nozzle (1 Figure 2.2) at the end. The opposite end of the glass capillary is connected with the liquid reservoir by a PTFE hoe (5 Figure 2.2). The piezo actuator is supplied by the supply voltage (4 Figure 2.2) with short electric pulses which are converted into short pressure pulses. These pressure pulses expand from the glass capillary through the liquid to the nozzle. The liquid is accelerated with a force up to 100000 g. The liquid reaches a flow velocity of up to 10 m/s generating a liquid jet which ejects from the nozzle. The liquid is very quickly decelerated due to pressure loss and has a typical velocity in air of 2 to 3 m/s. The ejection of the liquid causes an immediate decrease of the the pressure in the glass capillary followed by a immediate deceleration. As a result of the inertial force and supported by surface tension, a small volume of liquid separates and forms a droplet. The rest of the liquid ir retracted into the nozzle and oscillates there until frictional loss leads the liquid to rest. Due to capillary forces in the nozzle, the ejected volume of liquid is automatically refilled from the liquid reservoir. [12]

The picture 2.3 shows this process in a photo sequence. The liquid first oscillates inwards and then it is accelerated forcefully. A droplet with a tail is generated. In the course of the process the tail becomes thinner and finally breaks off. The drop volume is dependent on the liquid, the nozzle diameter and the drive pulse parameters such as voltage and pulse width. Nozzle diameter between $30\mu m$ and $100\mu m$ are available. Reproducibility of the ejected drop volume is very high with a variation of less than 1 percent when all parameters remain constant. It is possible to dispense single droplets and a series of drops with frequencies of up to 6000 Hz. The droplet diameter ranges between $35\mu m$ and $90\mu m$. When applying triple pulses, the droplet diameter can be reduced down to about 50 percent of the nozzle diameter. [12]



1. Nozzle tip
2. Protective housing

Figure 2.4: Dispenser Head

2.1.2: Parts

The system if formed by 3 parts:

- Driver Electronics
- Dispenser Head
- Miniature Camera System

Driver Electronics The driver electronics triggers the dispenser head and generates the drive pulse for the piezo actuator of the dispenser head, which is then converted into pressure pulses. In addition, signals are generated for operating a strobe diode. These signals are synchronized with the droplet generation.

Dispenser Head

The figure 2.4 shows a dispenser head with a zoomed out nozzle tip (1 Figure 2.4) made of glass. The nozzle tip is the most sensitive part of the hole micro dispensing system. It must be handled with greatest care. The nozzle tip is surrounded by the protective housing (2 Figure 2.4) which is made of PEEK. The protective housing avoids destruction of the nozzle tip in case of a collision of the dispenser head with an obstacle. Four notches in the nozzle area of the protective housing enable a better observation of the nozzle during droplet generation. The dispenser head is designed cilindrically. The outer protective cover is made of stainless steel. The upper end of the dispenser head has a diameter of 12 mm and serves as limit stop when assembling the head into a vertical or horizontal holder. The micro dispenser head used comes with a heatable holder applied for dipensing liquids with viscosities in the range of 0.4 to

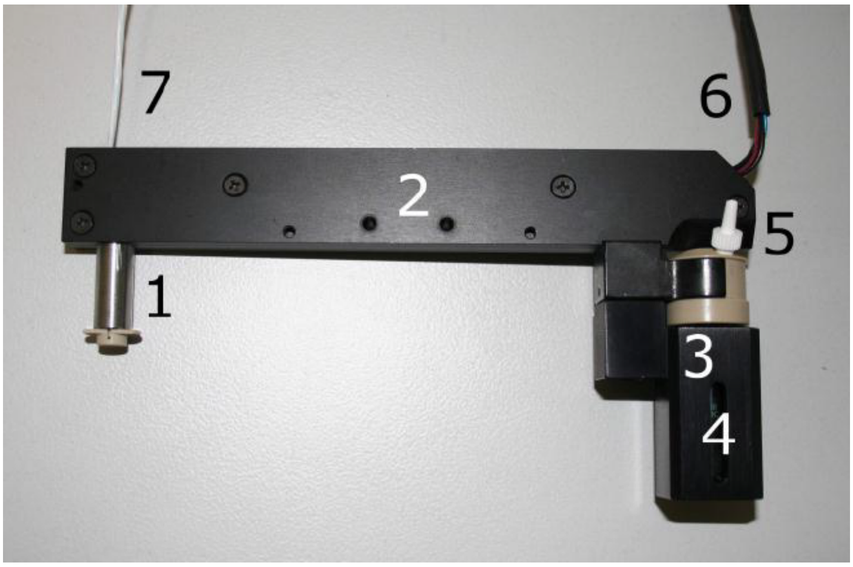


Figure 2.5: Micro dispenser head with completely heatable vertical holder

10000 mPas. In addition to the nozzle the complete dispenser head with supply hose and storage volume is heated. The heating range is between 25°C and 100°C.

The figure 2.5 shows a micro dispenser head (1 Figure 2.5) assembled in a heated vertical holder (2,3 Figure 2.5). The length of the vertical holder is 170 mm. The storage bin holder (3 Figure 2.5) of the heatable vertical holder contains a slot (4 Figure 2.5) for visual fill level control. One heating element and a PT-100 for temperature regulation are integrated in the heated holder. The electrical connections (6 Figure 2.5) for the heating element and the PT-100 lead to the heater control unit. The electrical connection (7 Figure 2.5) for the dispenser head is connected to the dispenser head connection at the driver electronics.

Miniature Camera System

The miniature camera system is an important optional supplementary system for the observation of the droplet generation and for the visual quality control of the dispensed droplets. The system consists of:

- Strobe diode with holder clip (Figure 2.6)
- TFT LCD monitor (Figure 2.7
- CCD camera (Figure 2.8

The strobe diode contains a LED assembled in the holder clip. It generates short flashes synchronous to the driver electronics. As a reult, the droplet generation

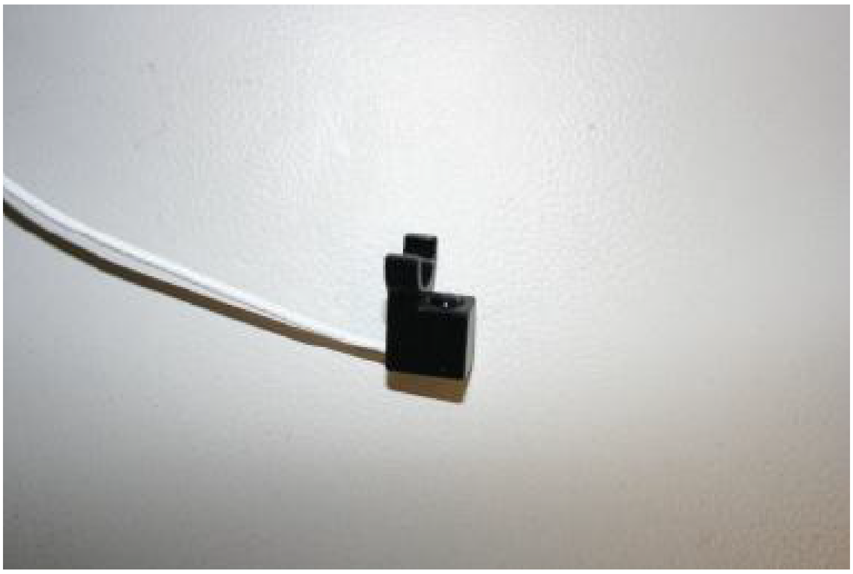


Figure 2.6: Strobe diode with holder clip

Figure 2.7: TFT LCD monitor

Figure 2.8: CCD camera

is optically frozen and thus can be visualized by the CCD camera.

2.2: Positioning System

Since the drops dispensing nozzle is fixed, it is the positioning system task to position the wafer so that the adhesive drops are positioned precisely. The positioning system consists of an XY positioning stage and a driver.

2.2.1: XY positioning stage

The stage is integrated with brushless DC servo motor with optical linear encoders that enables scanning speeds of up to 250 mm/s. It have a low-profile design that eliminates the external motor housings that create mechanical clash points and impede access to the sample. It's build with a closed-loop active feedback that ensures correct positioning with a resolution of $0.1\mu m$ and a bidirectional repeatability of only $0.25\mu m$, and a fully user configurable S-curve acceleration/deceleration profile that allows fast, smooth positioning without vibration or shock.

2.2.2: DC Motor Controller

The DC Motor Controller is ideal for motion control applications demanding operation at high speeds (hundreds of mm/s) and with high encoder resolution (¡100 nm).

Figure 2.9: XY Stage

Figure 2.10: XY Stage motor controller

The controller offer two channels of high-precision motion control for a wide range of applications. This controller is integrated into the apt family of products. It offers standard control and programming interface, allowing easy integration into automated motion control applications. The controller is capable of being reprogrammed in-field.

2.3: Data acquisition package for LabVIEW

The purpose of a DAQ (data acquisition) system is to measure a physical phenomenon such as light, temperature, pressure, or sound. A DAQ system includes the following building blocks:

- Transducer
- Signal
- Signal Conditioning
- DAQ Device
- Driver level and application software

With these five building blocks, it is possible bring the physical phenomenon desired to measure into the computer for analysis and presentation.

2.3.1: Transducer

Signal acquisition is the process of converting physical phenomena into data the computer can use. A measurement starts with using a transducer to convert a physical phenomenon into an electrical signal. Transducers can generate electrical signals to measure such things as temperature, force, sound, or light.

2.3.2: Signal

With the help of a transducer, it is possible to convert a physical phenomenon into a signal. Not all signals are measured in the same manner, so it is needed to categorize the signal as digital or analog. After categorize the signal, there are different types of information possible to obtain from it, which are state, rate, level, shape, and frequency.

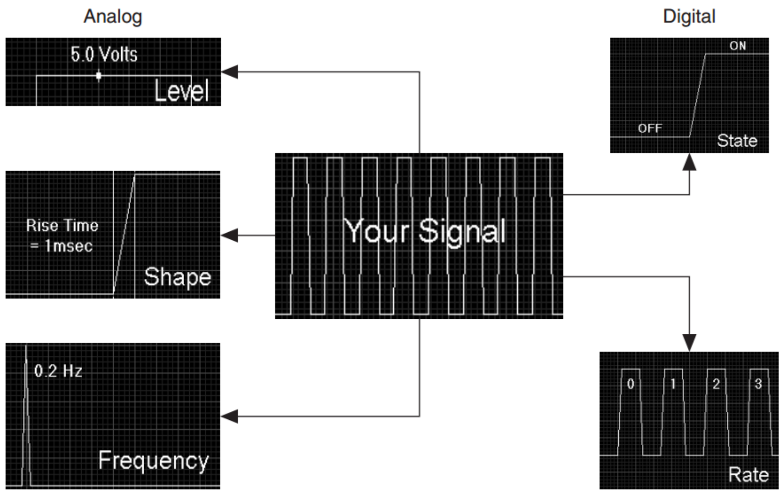


Figure 2.11: Different signal modes

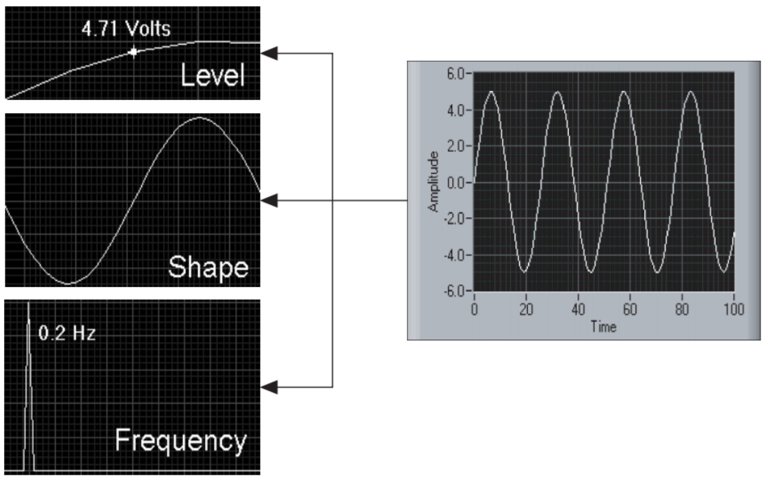


Figure 2.12: Types of analog signals

Analog Signal

Unlike digital signals, an analog signal can be at any voltage level with respect to time. Because an analog signal can be at any state at any time, the physical aspects to measure differ from those of a digital signal.

Analog Signal information

It is possible to measure the level, shape, and frequency of an analog signal, as shown in Figure 2.12.

- **Level** - Measuring the level of an analog signal is similar to measuring the state of a digital signal. The difference is that an analog signal can be at any voltage level, but a digital signal is either 0 V or 5 V.

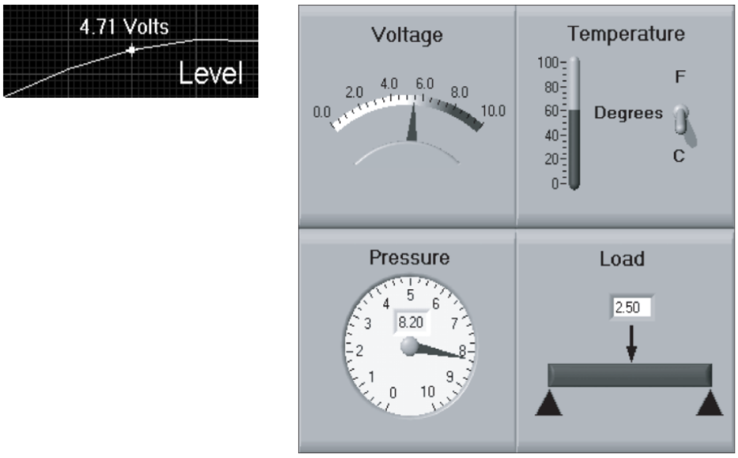


Figure 2.13: Analog signal level

- **Shape** - Measuring the shape of the signal is often important because analog signals can be at any state with respect to time. For example, a sine wave has a different shape than a sawtooth wave. Measuring the shape of a signal can lead to analysis of other aspects of the signal, such as peak values, slope, or integration.

- **Frequency** - Measuring the frequency of an analog signal is similar to measuring the rate of a digital signal. However, it is not possible to directly measure the frequency of an analog signal. It is needed to perform software analysis on the signal to extract the frequency information, usually with a Fourier Transform. The level of most signals does not change much with respect to time. However, it is usually needed to measure the signal with a high level of accuracy. Therefore, a DAQ device with a high resolution is needed, but not a high sample rate. Using a variety of transducers, it is possible to measure the voltage of a power supply, the temperature of a mixing tank, the pressure inside a hose, or the load on a piece of machinery, as shown in Figure 2.13.

When the shape of a signal is measured, it is needed to know the relationship of that signal with respect to time. Some signals change rapidly with respect to time. Most applications in which the shape of the signal is measured also need a high level of accuracy. Therefore, it is needed a DAQ device with a high resolution and a high sample rate.[11]

Examples of measuring shape are abundant in the medical, electronic, and automotive industries, and they range from measuring a heartbeat, to measure a video

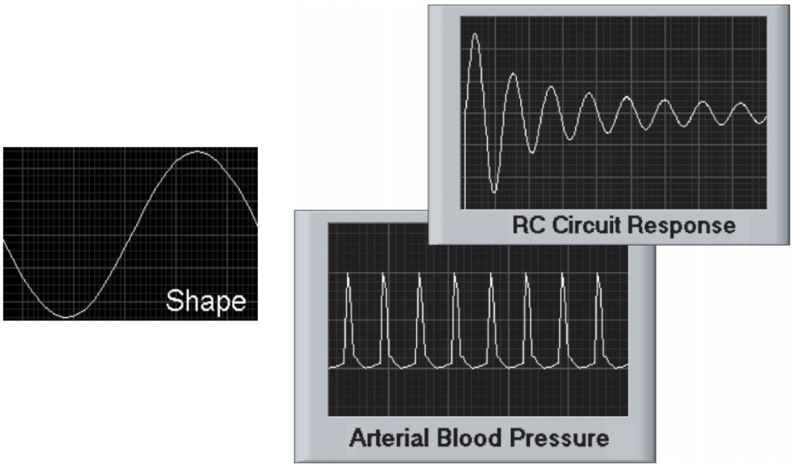


Figure 2.14: Analog signal shape

signal, to measure the vibration of a spring. After the signal is acquired, it is possible to analyze it to extract the specific information needed about the shape. For example, when blood pressure is measured, the peak value is important. However, when analysing a resistor-capacitor (RC) circuit response, the way the amplitude varies over time is more important, as shown in Figure 2.14.

When the frequency of a signal is measured, it is needed to know the relationship of that signal with respect to time. Many signals change rapidly with respect to time. Most applications in which the frequency is measured also need a high level of accuracy. Therefore, it is needed a DAQ device with a high resolution and a high sample rate. Once the signal with respect to time (time plot) is acquired, software analysis is used to convert the time plot signal into the frequency plot. LabVIEW provides the necessary software analysis, as shown in Figure 2.15.

Digital Signal

A digital signal has only two possible states: ON (logic high) or OFF (logic low). A digital signal is often referred to as a Transistor-to-Transistor Logic (TTL) signal. The specifications for a TTL signal define a voltage level between 0 and 0.8 V as logic low and a voltage level between 2 and 5 V as logic high. Most digital devices accept a TTL-compatible signal.

Digital Signal Information

It is only possible to measure two aspects of a digital signal: state and rate.

- **State** - A digital signal only has two possible states: ON or OFF. One of the

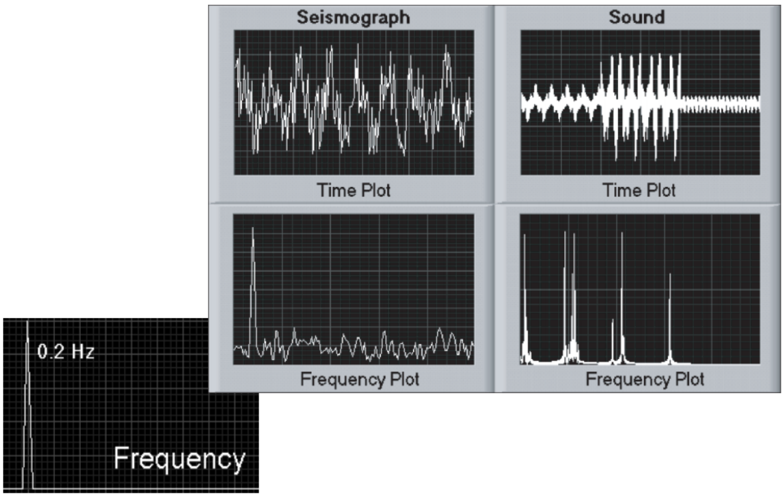


Figure 2.15: Conversion of the time plot into frequency plot using LabVIEW

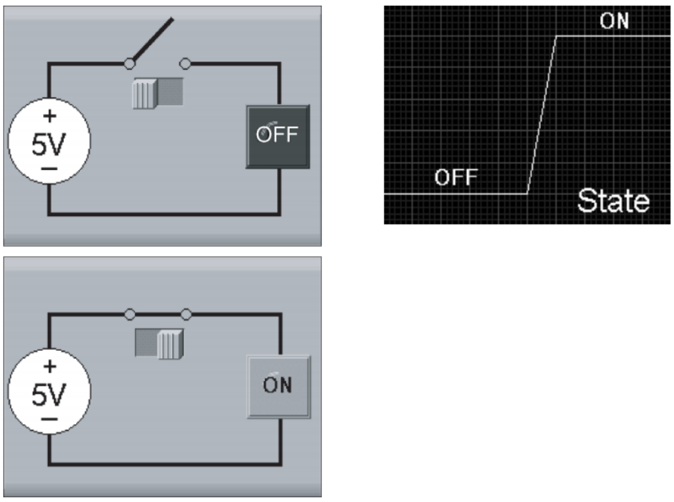


Figure 2.16: Digital Signal State

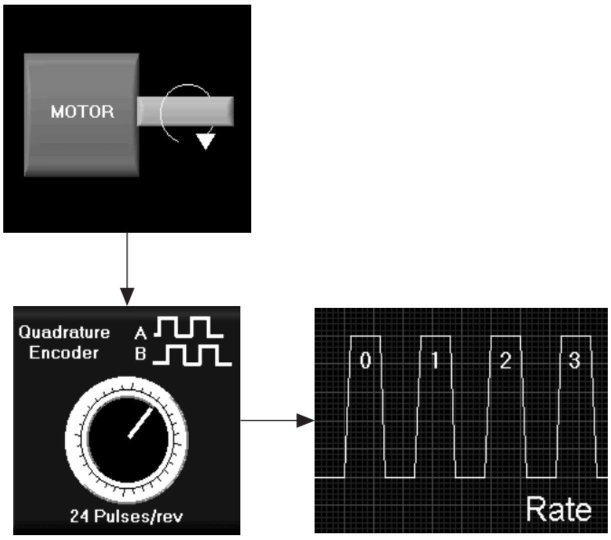


Figure 2.17: Digital signal Rate

aspects of a digital signal that can be measured is if the state is ON or OFF.

- **Rate** - A digital signal also changes state with respect to time. The other aspect of a digital signal possible to measure is the rate, or how the digital signal changes states over time.

The following example of measuring the state of a digital signal is taken from National Instruments Data Acquisitions and Signal Conditioning Course Manual (pages 1-8,1-9)[11].

> Assume you have a switch that you want to monitor. This switch turns a light on or off. In this example, when the switch is open, you measure 0 V (OFF). When the switch is closed, you measure 5 V (ON). By measuring the state of the digital signal, you can determine if the light is on or off. Now look at the following example for measuring the rate of a digital signal.
>
> Assume you have a motor, and you want to determine how fast the shaft of the motor is spinning. An encoder is a transducer that can convert the rotary motion of the motor shaft into a digital signal. When an encoder rotates, it produces two digital signals. Each digital signal is a series of alternating on or off states, called a pulse train. For each increment of rotation, you get a pulse. The increment of rotation depends on the encoder. For example, the DAQ Signal Accessory you use in this course has an encoder that gives 24 pulses per revolution. You can measure the rate of one of the

pulse trains to determine how fast the shaft is rotating. You can measure both pulse trains to determine not only how fast the shaft is rotating but also the direction in which it is rotating.

Capítulo 3: Concept of an automated adhesive dispensing system

This chapter presents the project for the creation of an automated drop dispensing system. The system must be able to move the wafer so that the droplets are properly positioned between the micro lenses. For this purpose, a system should be created for the fixation of the microdrop device, and this mounting system should be integrated into the positioning system of the wafer.

For the supervision of the task being performed, another system should be integrated, the camera system. The function of this is to generate images of the generation and dispensing of the drops as well as to show the alignment and positioning of drops on the wafer. For this, the camera system must be properly positioned respecting the specifications of the camera chosen for the project. This project is going to use two cameras, one to watch the formation of the droplets, and other to watch the dispensing process. All these systems must be integrated so that the device works properly.

A design in CAD was made to integrate the system physically. The physical integration system took into account the positioning needed between the drop dispensing system with the positioning system of the wafer, as well as the correct positioning for the camera system, so it could supervise the completion of the task.

For the system to be integrated logically it was used the software LabVIEW. The logic integration of the system aimed synchronization between the firing of drops and the movement of the XY Stage. The droplet dispensing was performed using the external trigger of the Microdrop system and also using the DAQmx package for data acquisition and generation. The signals were created on LabVIEW and sent to the Microdrop System. The next sections will explain in detail each part of the automated drop dispensing system.

3.1: Physical integration

The physical integration of the system was done using a holder that keeps the different components fo the system properly aligned and positioned. Two versions of holders were made for the system.

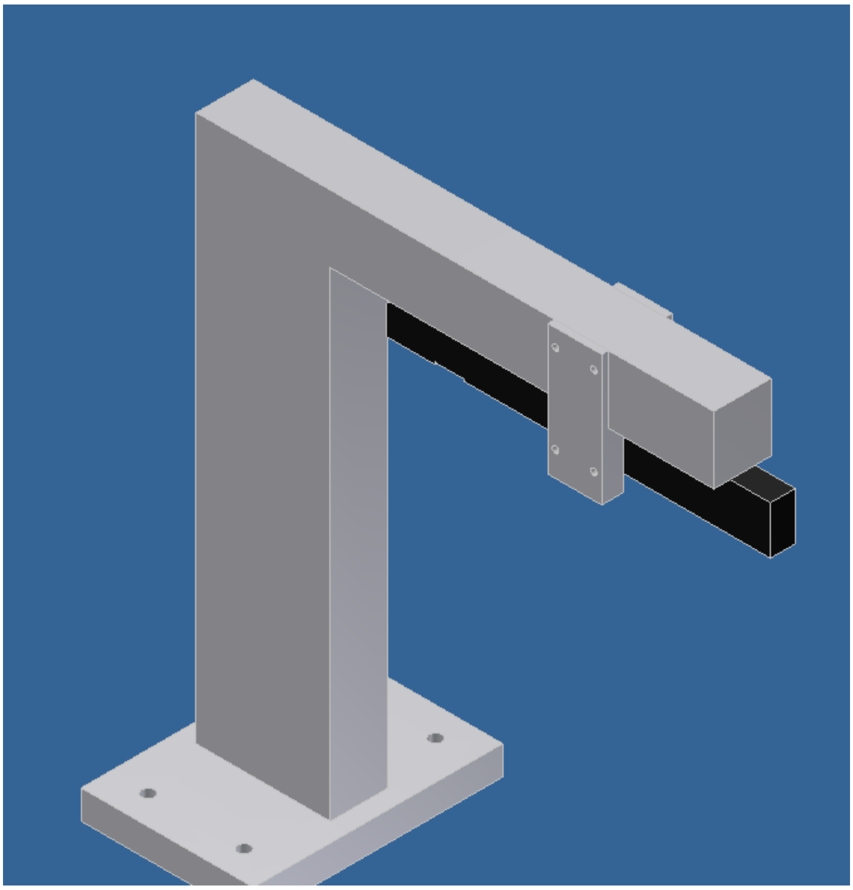


Figure 3.1: First version of the device

The first version (Figure 3.1) was created only for the testing of the dispensing strategies. In this first version, it was not taken into account the camera system and neither the fixation of the positioning system. The objective of this first version was only to fix the microdrop device for testing purposes.

The second version (Figure 3.2) of the holder system is the final device. In this version, it was considered the correct positioning of the XY Stage, as well as fixation and alignment of the camera for supervision and details such as wiring and aesthetic finishes.

The design of the two versions was done using the software Autodesk Inventor 2010.

As can be seen in the figures, the second version is more elaborate and with a better finish and more detail. The final version features an eject function, this function makes the front lid of the device open and facilitates the placement or removal of the wafer, bringing the XY Stage forward out of the device.

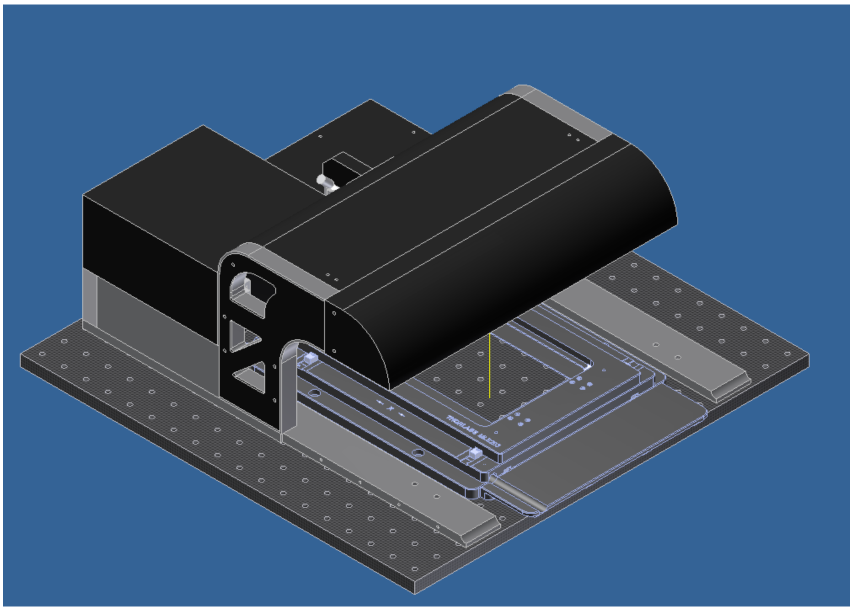


Figure 3.2: Second and final version of the device

3.1.1: Microdrop System

For positioning the microdrop device, certain characteristics and certain requirements were taken into account. The device should be centered in the system and must be positioned over the XY stage so that it can be utilized as much space in the stage and thus the wafer.

After the creation of the first model for the microdrop system fixing, there were some things that should be respected for the final version of the system. An important characteristic is the distance between the microdrop system nozzle tip and the wafer, which should be the minimum possible. Figure 3.3 shows the distance between the nozzle and the XY Stage where the wafer is going to be placed in the system. As the droplets are very small (volumes of 20 to 380 pl)[12], any disruption that happens while it travels the distance between the nozzle and the wafer can change the final positioning of the drop. Hence, another important characteristic comes into consideration, that is that the final system must be closed to prevent any outside disturbance that may interfere in the task

Another characteristic observed is that, while the microdrop system nozzle should be kept close to the XY table, it is also needed to take into account the position of the liquid reservoir. The solution to this problem was solved with the correct positioning of the XY Stage, which will be presented in the next section.

Figures 3.4 and 3.5 show the relative positioning between the microdrop system

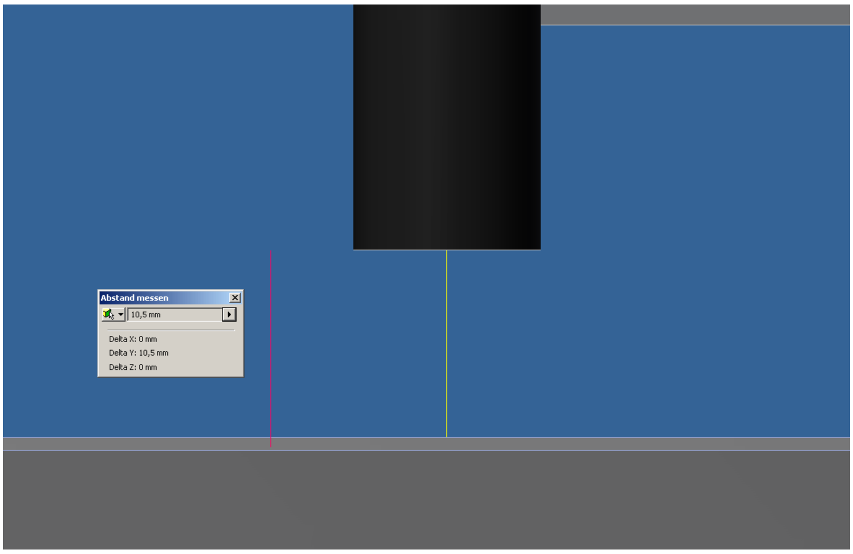


Figure 3.3: Distance between nozzle and XY Stage

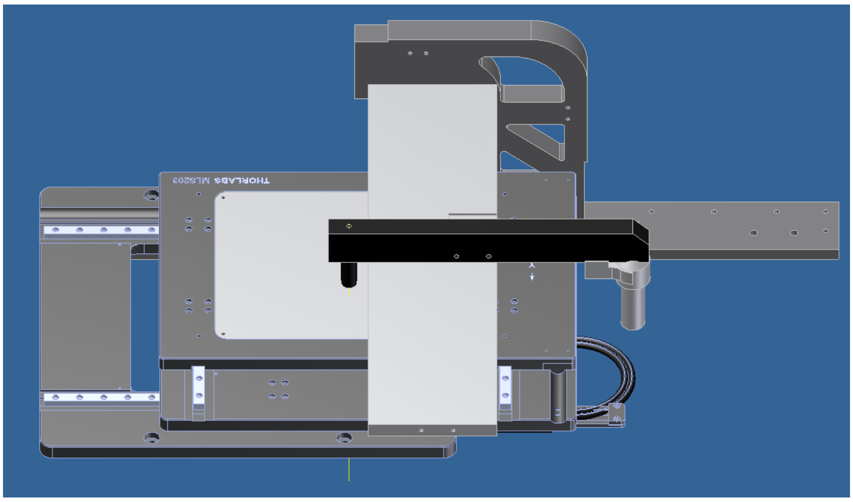


Figure 3.4: Positioning of the microdrop system and XY Stage

nozzle and the XY stage. In the picture you can also see the liquid reservoir of the micridrop system. The stage should be positioned in a way that enables a smaller distance between nozzle and wafer, but should also avoid collisions between the stage and the liquid reservoir while the stage is moving. In both Figures 3.4 and 3.5, the XY stage is positioned at the end of line of its X-axis. This is the closest from the liquid reservoir possible.

3.1.2: XY stage

The first thing that must be taken into account when positioning the XY stage is the positioning of the axes X and Y. The stage used in the project has a larger range in

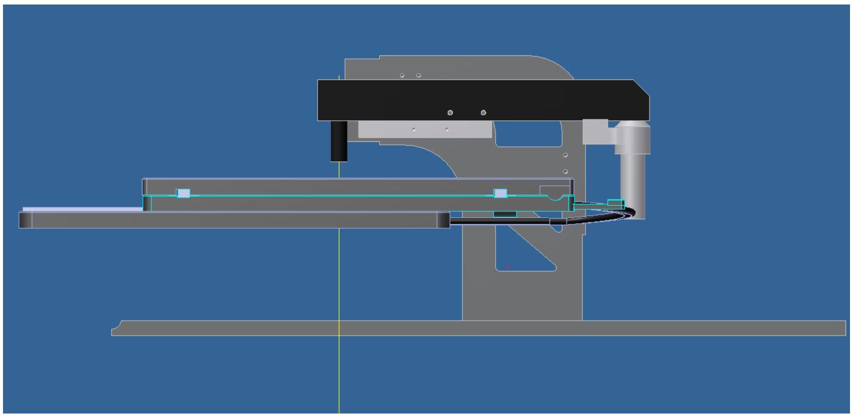


Figure 3.5: Side view of the positioning of the microdrop system and XY Stage

the X axis than on the Y axis (X axis: 110 mm, Y axis: 75 mm). As the two dimensions are large enough to cover the entire area occupied by the wafer, this characteristic was not decisive at first.

The difference between the range of the movement of the two axes was taken into account when determining the handling of the wafer in the system. As can be seen in the figures of the final system during the process of dispensing of adhesive, the wafer is positioned under the nozzle of the microdrop system. When the process ends, it is desirable that the wafer is positioned in a place that facilitates its handling (loading and unloading). To do this, the longest axis of the stage (X-axis) was positioned in such a way that the wafer can be positioned outside the working area and thus facilitate its handling. Figure 3.6 shows the positioning axes and Figures 3.7 and 3.8 show the eject-function. The first shows the Stage in the working position during the dispensing process and the second one, shows the stage at the eject-function position, with the Stage outside the workspace, to facilitate handling of the wafer.

Another factor taken into account was also the height of the Stage. To fix the Stage on the breadboard and also to fine-tune the distance between the nozzle and the XY Stage an adapter that sits between the XY stage and the breadboard was created. Figure 3.9 shows the piece mounted on the system.

3.1.3: Camera System

As stated in chapter 2, the project has two cameras with different tasks. The first camera is designed to observe the formation of the droplets in the microdrop system. The second observes the process of pouring the drops on the wafer.

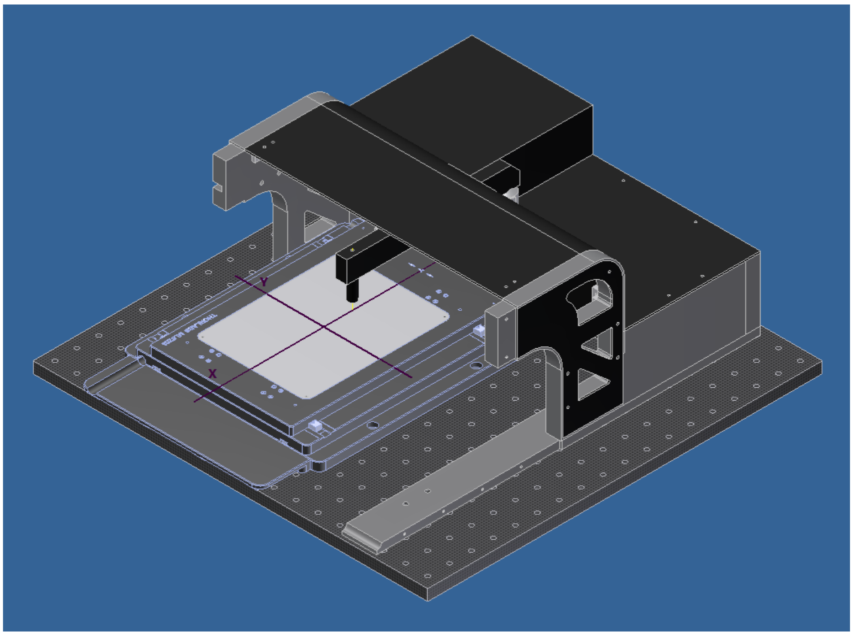


Figure 3.6: Position of the axes of the XY Stage

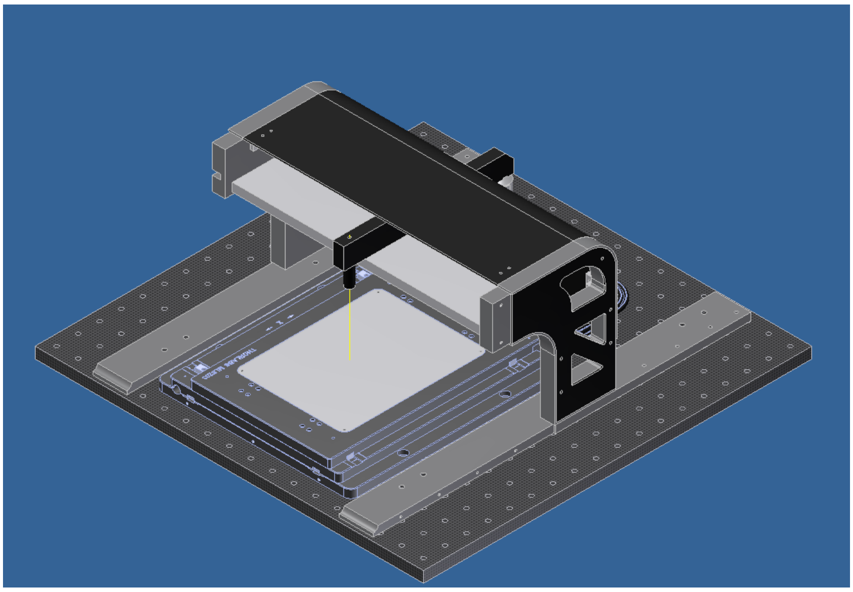


Figure 3.7: XY stage in dispensing mode

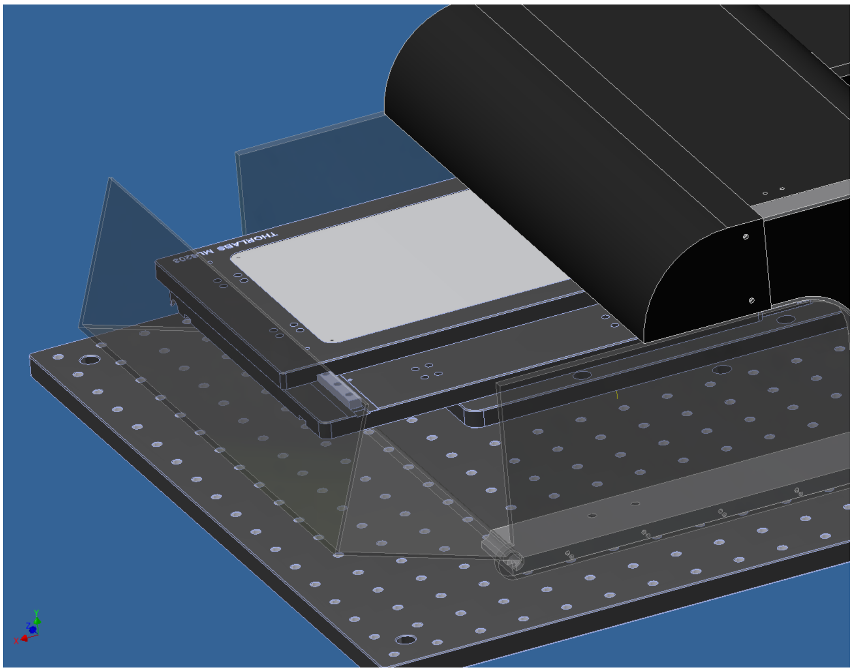


Figure 3.8: XY stage in eject mode

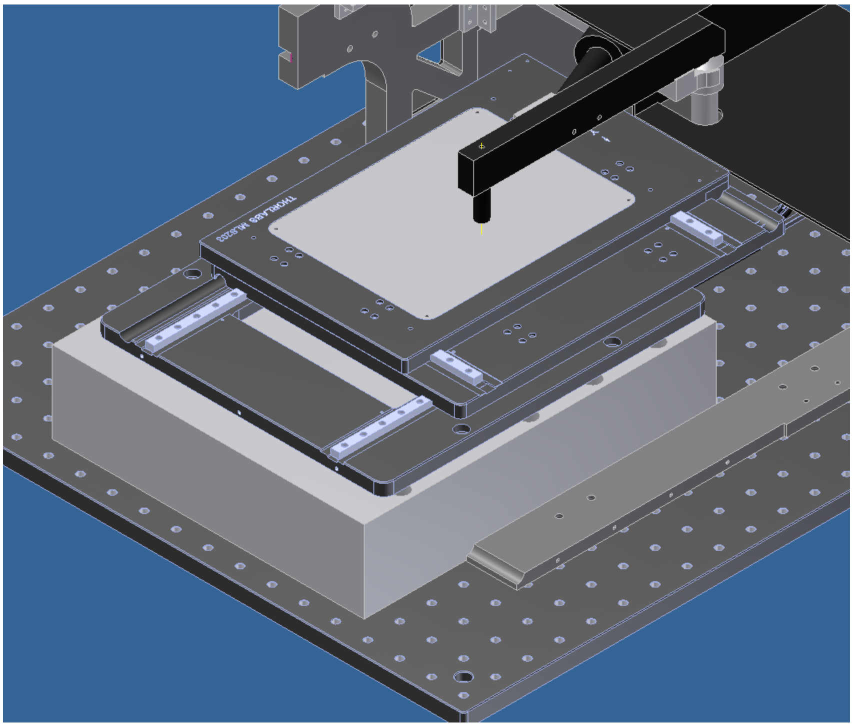


Figure 3.9: Fixation of the XY Stage

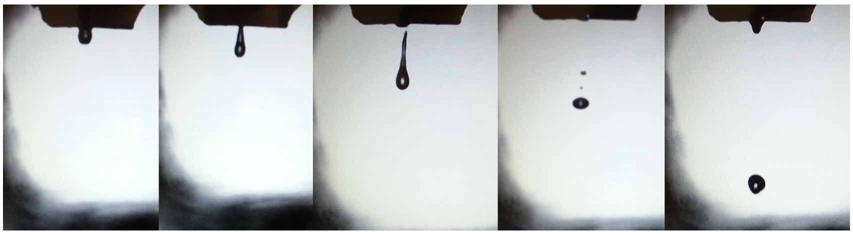


Figure 3.10: Droplet formation

Camera to observe the formation of the droplets

This first camera has a strobe, synchronized with the frequency of the drops dispensing. It creates an effect that causes the acquired image to be a drop frozen into position. A delay can be inserted between the dispensing frequency and the strobe frequency to observe different stages of the drop formation. Figure 3.10 illustrates the different stages of the drop formation observed by the camera.

For the positioning of the camera it was taken into account the focal length, the distance between camera and nozzle, the distance between camera and strobe and also the distance between the camera and wafer.

First, several lenses for the camera were tested to choose the one that suits the system. While a closer and more clear drop was desirable, the minimum distance between the camera and the wafer should be met, because of the necessity of the camera to be aligned with the nozzle tip and the need for a minimum distance between nozzle and wafer. An objective focal distance greater than the area of movement of the wafer beneath the nozzle tip was needed so that there is no collision between the camera lens and the wafer during the dispensing process. Figure 3.11 shows the positioning of the camera in the system design.

The position between camera and strobe is rather simple. The strobe shall be aligned with the camera so that the drop can be observed. As the dimensions of the strobe are not a problem, the alignment is done directly.

Camera to observe the dispensing process

This camera is used to observe the dispensing process of the drops on the wafer. Its job is to show the drops being dispensed onto the wafer and it does not need a quality and precision as good as the first camera. For the project several cameras were tested and reached the conclusion that a camera simple as a commercial webcam could be used.

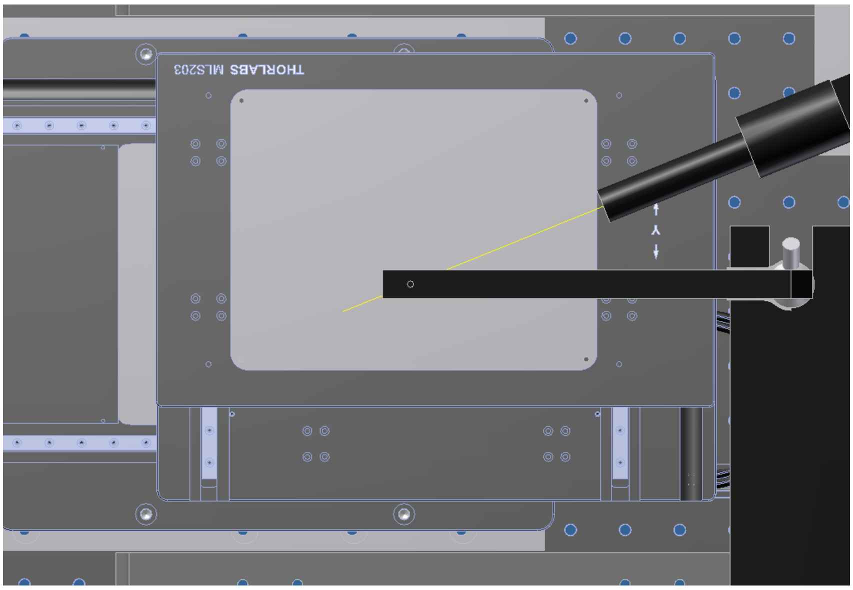


Figure 3.11: Angle between camera and tip of the nozzle

Figure 3.12: Dispensing process in short angle

For positioning this camera, it was considered the angle of inclination for the observation of the droplets on the wafer and another important factor that was taken into account was the illumination.

As the drops of adhesive used in the process are transparent, this camera should accompany an illumination system that can make these droplets become visible to the observer. Several tests were conducted for positioning the camera and illuminating the drops to decide which configuration can be used in the system.

Figures 3.12, 3.13 and 3.14 show three different positions for the camera. In the three positions the illumination system lies perpendicular to the wafer.

Figure 3.12 shows the first positioning for the tests. In this situation there is a smaller angle between the camera and the microdrop system. In this positioning of the camera, it is possible to have a better notion of the relative positioning of drops and

Figure 3.13: Dispensing process in wide angle

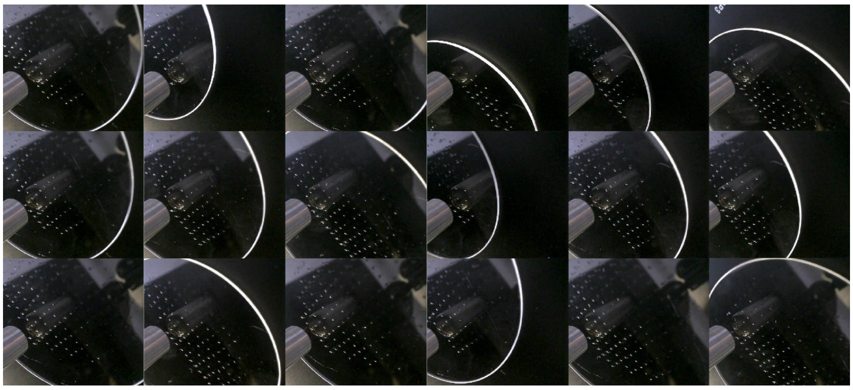


Figure 3.14: Dispensing process in mid angle

their alignment. As the angle between the camera and the illumination is less than in other positions, the drops are not as visible as compared to positions of greater angle.

In this second situation, a greater angle between camera and illumination is used. It is shown in Figure 3.13 the drops are more visible than in the positioning of the figure 3.12. But as the angle between camera and the wafer is large, the positioning and alignment of the droplets is less visible.

Figure 3.14 shows the last test of camera positioning. This position has an angle intermediate between the previous two. It is the best angle for the camera because it shows a good image of the droplet placement and alignment and also has a good visibility of the droplets.

3.2: Logical Integration

For the logical integration of the system, the LabVIEW software and data acquisition package DAQmx was used. The LabVIEW software made possible to control the XY Stage for positioning the wafer using the PC. The trigger signals were also created on LabVIEW. These signal will be sent to the microdrop system using the NI-DAQmx.

3.2.1: XY stage control using LabVIEW

The software LabVIEW enables the control of the XY stage using ActiveX [1] and has various functions for it. The functions used on the algorithms for this project will be presented below

HWSerialNum

Returns MG Return Code

Details

This property specifies the serial number of the hardware unit to be associated with an ActiveX control instance. The serial number must be set in the HWSerialNum property, before an ActiveX control can communicate with the hardware unit. This can be done at design time or at run time.

Every APT control unit is factory programmed with a unique 8-digit serial number. This serial number is key to operation of the APT Server software and is used by the Server to enumerate and communicate independently with multiple hardware units connected on the same USB bus.

For example, if two or more stepper hardware units are connected to the PC, different instances of the stepper ActiveX Control can be included in a client application. If each of these Control instances is programmed with a unique hardware serial number, then they will communicate with their associated hardware units. In this way, multiple graphical control panels communicating with multiple hardware units can easily be incorporated into a custom client application.

After a serial number has been allocated, an ActiveX control instance must be activated at run time by calling the StartCtrl method.

StartCtrl

Returns MG Return Code

[1] ActiveX is the general name for a set of Microsoft Technologies that allows to reuse the code and link individual programs together to suit the computing needs. Based on COM (Component Object Model) technologies, ActiveX is an extension of a previous technology called OLE (Object Linking and Embedding). Each program does not need to regenerate components, but rather, reuse components to give the power to combine applications together. LabVIEW offers support for ActiveX automation as a server as well as support for ActiveX Containers, and ActiveX Events.[14]

Details

This method is used in conjunction with the HWSerialNum property, to activate an ActiveX control instance at runtime. After the HWSerialNum property has been set to the required serial number (at design time or run time), this method can be called at run time to initiate the hardware enumeration sequence and activate the control.

EnableHWChannel

Parameters

lChanID - the channel identifier

Returns MG Return Code

Details

This method enables the channel(s) specified by the lChanID parameter. After a channel is enabled, it is good practice to home the motor, thereby restoring positional integrity.

MoveHome

Parameters

lChanID - the channel identifier

bWait - specifies the way in which the MoveHome method returns

Returns MG Return Code

Details

This method initiates the homing sequence on the channel specified by the lChanID parameter. Each axis on the associated stage has settings for the parameters Zero Offset and Minimum Position. The first value is the distance between the negative limit switch and the end of travel. The second value is the minimum absolute position that can be set for the stage axis. Typically, when MoveHome is called, the stage axis moves to its negative limit and then moves forward by a set distance (zero offset). The absolute position count is then reset to zero to provide the reference point for all subsequent absolute moves. If position is lost on a stage axis, the MoveHome method should be called to re-establish the zero (home) position.

If the bWait parameter is set to 'False', the method returns as soon as the homing sequence has been initiated. If bWait is set to 'True', MoveHome returns only after the motors have finished homing. In either mode, a HomeComplete event is fired once the homing sequence has been completed.

SteVelParams

Parameters

lChanID - the channel identifier

fMinVel - the minimum velocity at which to start and end a move

fAccn - the rate at which the velocity climbs from minimum to maximum, and slows from maximum to minimum

fMaxVel - the maximum velocity at which to perform a move

Returns MG Return Code

Details

This method is applicable to moves initiated from software by calling the MoveRelative, MoveAbs or MoveVelocity commands and allows the trapezoidal velocity profile parameters to be set for all moves.

The applicable channel is specified by the lChanID parameter.

The fMinVel parameter value is locked at zero and cannot be adjusted.

MoveAbsolutEX

Parameters

lChanID - the channel identifier

dAbsPosCh1 - the absolute position associated with channel 1

dAbsPosCh2 - the absolute position associated with channel 2

bWait - specifies the way in which the MoveAbsoluteEx method returns

Returns MG Return Code

Details

This method initiates a motor move on the channel specified by the lChanID parameter.

The absolute position to move is specified by the dAbsPosCh1 and dAbsPosCh2 parameters.

If the bWait parameter is set to 'False', the method returns as soon as the move has been initiated. If bWait is set to 'True', MoveAbsoluteEx returns only after the motors have completed their moves. In either mode, a MoveComplete event is fired once the motor moves have been completed.

GetPosition

Parameters

lChanID - the channel identifier **pfPosition** - the current position of the associated channel

Returns MG Return Code

Details

This method obtains the present position for the channel(s) specified by the lChanID parameter, and returns a value in the pfPosition parameter.

The position of the stage associated with the specified channel is determined by its displacement from the 'Home' position.

StopProfiled

Parameters

lChanID - the channel identifier

Returns MG Return Code

Details

This method is called to stop motor moves on the channel specified by the lChanID parameter.

Moves are stopped in a profiled manner using the velocity profile parameters set using the SetVelParams method.

This method can be called to stop prematurely, absolute or relative moves.

Move RelativeEX

Parameters

lChanID - the channel identifier **dRelDistCh1** - the relative distance associated with channel 1 **dRelDistCh2** - the relative distance associated with channel 2 **bWait** - specifies the way in which the MoveRelativeEx method returns

Returns MG Return Code

Details

This method initiates a motor move on the channel specified by the lChanID parameter, which takes values specified by the HWCHANNEL enumeration.

The distance to move, relative to the present position, is specified by the dRelDistCh1 and dRelDistCh2 parameters.

If the bWait parameter is set to 'False', the method returns as soon as the move has been initiated. If bWait is set to 'True', MoveRelativeEx returns only after the motors have completed their moves. In either mode, a MoveComplete event is fired once the motor moves have been completed.

StopCtrl

Returns MG Return Code

Details

This method is called to deactivate the operation of an ActiveX control instance.

When this method is called, communication to the associated hardware unit is stopped. It is efficient programming practice to call StopCtrl on any ActiveX control instances that are no longer required to be active.

The NI-DAQmx package was used to generate the external trigger signals for the microdrop system. It was necessary to create in LabVIEW the signal suitable for the dispensing process. After creating the signal, it was treated still in LABView and then sent to the Microdrop Controlling system via the data acquisition card.

Figure 3.15 shows the wizard for signal generation of DAQmx package. With it, it is possible choose the shape of the signal, as well as frequency range and duration.

Figure 3.16 is a piece of code generated by DAQmx wizard for signal generation.

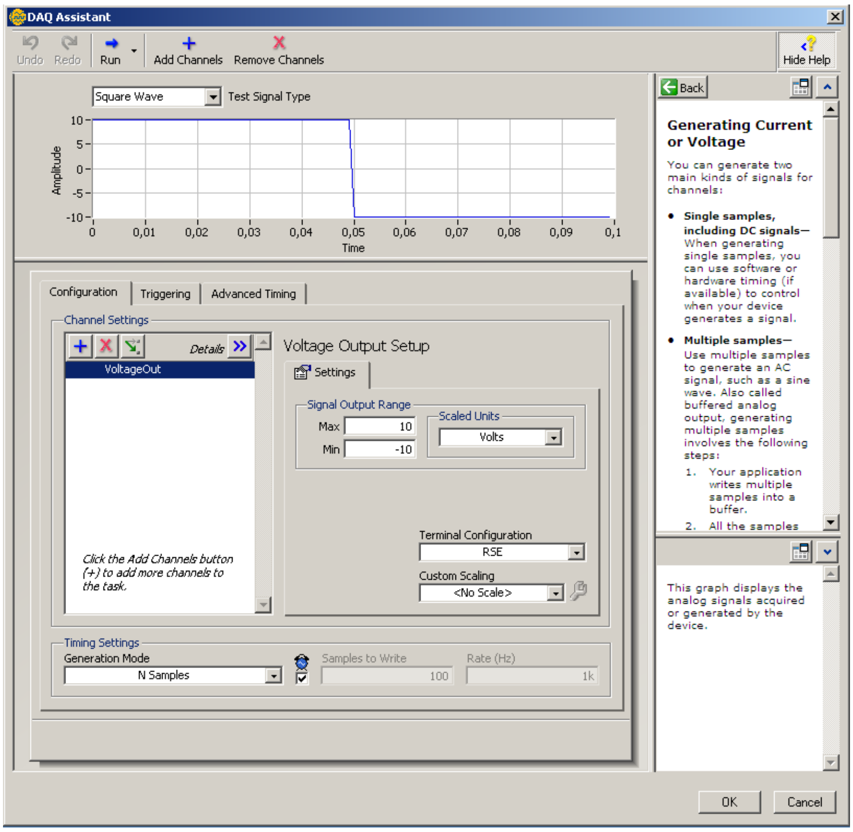


Figure 3.15: Wizard for signal generation

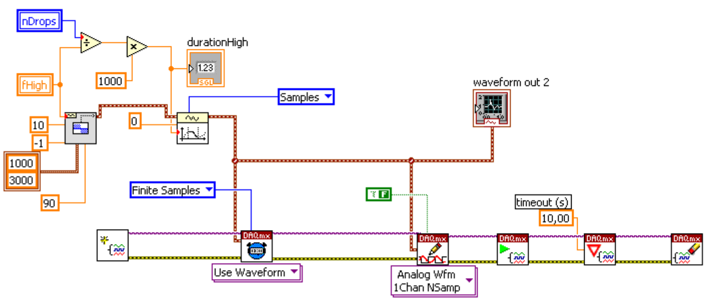


Figure 3.16: Code generated by the signal generator

Capítulo 4: Automated adhesive dispensing strategies

In this chapter we discuss the strategies of the adhesive droplets dispensing. Two strategies were created. The first dispense the droplets of adhesive with the wafer positioned and stopped in the exact spot where the drop is supposed to be. In the second strategy, the droplets of adhesive are dispensed with the wafer moving, one line at a time. The lines and the path that must be followed to dispense the adhesive on both strategies are illustrated in Figure 4.1.

The first strategy was created to generate a more precise positioning of the droplets and the second one to perform the task in a shorter time.

The red lines in figure 4.1 shows the portions in which the system moves dispensing the droplets, and the blue dashed lines show the positioning movement, without dispensing droplets. The small lenses are the circles, and adhesive should not be dispensed on the lenses. During the part in which the nozzle passes over the lenses, a smaller number of droplets must be dispensed, which are positioned in the spaces between each lens.

Further details of the two strategies will be discussed in the following sub-chapters.

4.1: Dispensing while Stage is Stopped

In this first strategy, the droplets of adhesive are dispensed only when the wafer is properly positioned and stopped under the nozzle. After dispensing a drop, the wafer is moved to the position where the next drop of adhesive is supposed to be placed.

The algorithm uses the X axis of the XY Stage to move over the adhesive lines and the Y axis to go to the next line of adhesive.

As the motion of the motor occurs in steps, the function used is MoveRelativeEX (section 3.2.1.9). The step is the distance between the droplets. While the dispensing process occurs on lines that do not pass through the lens, the distance between the droplets is simple $(2.51mm)$, when it occurs in lines that pass through the lenses, the distance is double $(5.02mm)$.

The algorithm strategy is divided into four parts:

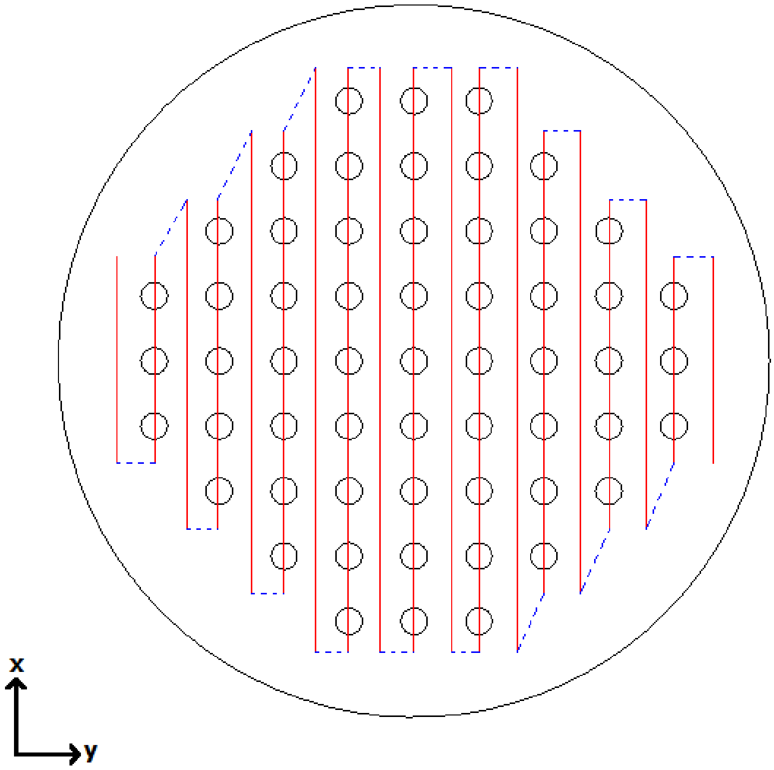


Figure 4.1: Path for the dispensing process

- Home, engine calibration and initial positioning
- Dispensing of droplets in a line
- Lateral movement of the XY Stage (to start a new line of droplets)
- Adjustment of the variables (direction of movement of the XY Stage, number of droplets)

The first step is necessary every time you start the control of the XY stage. It serves to calibrate and determine the zero point of the Stage (the two axes at halfway position). After engine startup, the Stage is moved to the starting point of the strategy of the droplets dispensing. Thereafter, it shoots a droplet (with the Stage stopped) and moves one step, which is the exact distance between two droplets. After reaching the end of the current line, the Stage takes a step to the side (to start a new line) and in the next step, the internal variables of the algorithm are adjusted, like the number of droplets in the next line and direction of movement of the Stage (contrary to the previous line). After moving through all the path shown in Figure 4.1 the strategy ends.

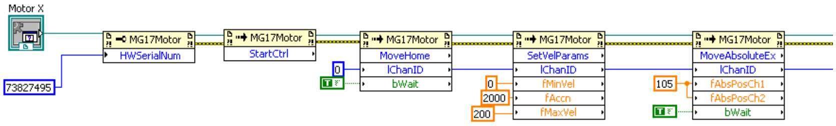


Figure 4.2: Motor X initiation and calibration

After the last step, the algorithm returns to the second step until the task is finished. In this strategy, the XY Stage moves at full speed in both directions.

The speed of movement of the XY Stage does not affect the positioning or alignment of the droplets since the shooting is done only with the XY Stage properly positioned and stopped.

4.1.1: Creating the LabVIEW algorithm

Home, engine calibration and initial positioning

Figures 4.2 and 4.3 shows the first step of the algorithm. In this step, the two engines are started. In this first strategy, the same steps are used for both engines.

First, the function HWSerialNum (3.2.1.1) is used with the parameter containing the serial number of the motor controller, followed with the initialization function of the engine StartCtrl (3.2.1.2).

After these first steps, the engine is zeroed with MoveHome function (3.2.1.4). The input parameters of this function are the channel numbers of the engine (remembering that the hardware used in the design has two channels, namely two motors) and also a boolean variable **bWait** that when positive, forces the algorithm to wait for the engine to calibrate before returning a value and move to the next function. It is an important step for synchronization of the motors during the process.

With the engine positioned halfway, the parameters are adjusted to their speed using the function SetVelParams (3.2.1.5). The parameters adjusted are speed, acceleration and maximum and minimum velocities. The minimum speed is always zero, because before moving the engine will always be stopped, so this parameter does not have much importance. The maximum speed and acceleration have a greater importance because they make a big difference during the performance of the algorithm. As in this strategy the droplets are dispensed only with the wafer properly positioned under the nozzle, it was chosen the highest values for these two parameters in order to perform the process in the shortest possible time.

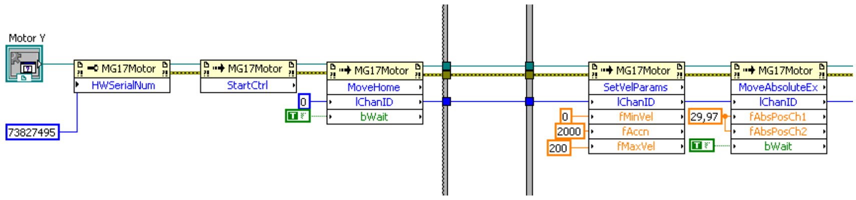


Figure 4.3: Motor Y initiation and calibration

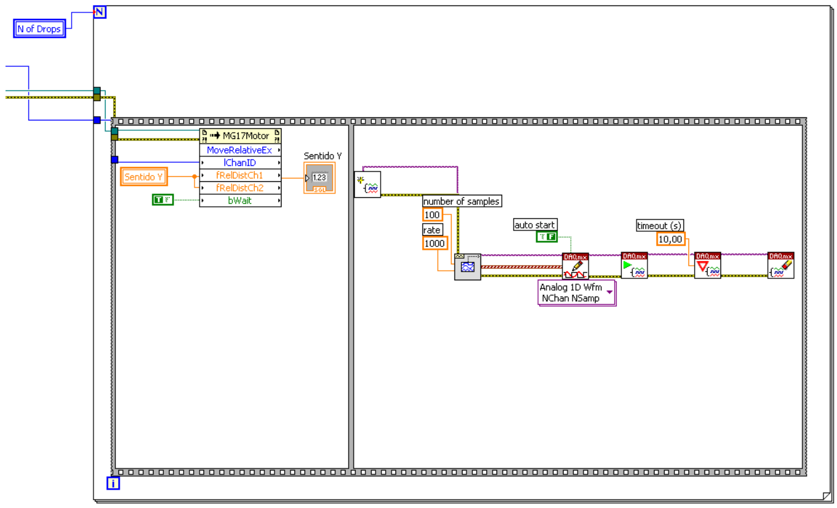


Figure 4.4: Piece of code of the dispensing process

The last step of this first part of the algorithm is the positioning of the wafer to begin the dispensing process. The function MoveAbsoluteEX (3.2.1.6) receives the parameters of relative position (in mm) and again, the parameter **bWait** explained above.

<u>Dispensing of droplets in a line</u>

In this part of the algorithm, only the Y axis motor moves. All this is part is inside a *FOR* loop and the given parameter **N of Drops** is the number of droplets of that is dispensed on the current line, ie, the number of triggers that will be sent to microdrop system.

Inside the **FOR** loop two steps are performed. First the engine takes the first step for positioning the wafer. The function MoveRelativeEX (3.2.1.9) receives as a parameter the variable *Sentido Y* that is the step size ($2,51mm$ for the lines without lens and $5,02mm$ for the lines with lens) and also informs the direction of the step according to the sign of the value passed (in this strategy, the values are $2,51mm$ to lines without lenses and $-5,02$ for lines with lens). After the wafer is positioned correctly (hence the importance of the parameter **bWait**) a trigger signal is generated and sent to the microdrop system. The signal generated in this algorithm is generic, it

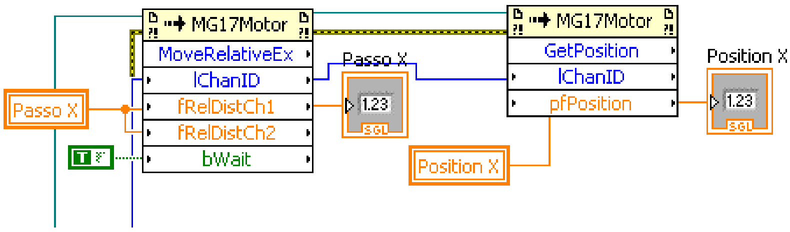


Figure 4.5: Piece of code of the lateral step

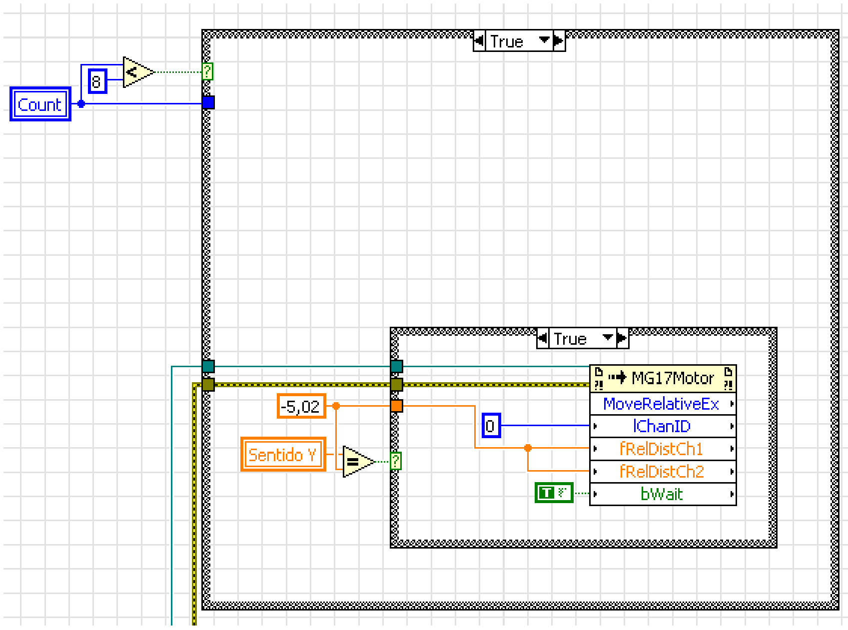


Figure 4.6: Adjustment of the variables of the process

only serves to synchronize the dispensing process with the movement of the XY Stage. No matter your frequency or the number of samples. The parameters for the correct drop generation are set in the microdrop hardware.

Lateral movement of the XY Stage

This part of the algorithm happens whenever one line of droplets is finished. The X axis engine is used in this part. After the completion of the dispensing process in a line, the wafer is positioned correctly for the beginning of the next line. First the function MoveRelativeEX (3.2.1.9) gives the step for positioning the wafer on a new line of droplets. Once positioned, its position is stored with the function GetPosition (3.2.1.7).

Adjustment of the variables

In this step all the variables of the algorithm are adjusted and updated.

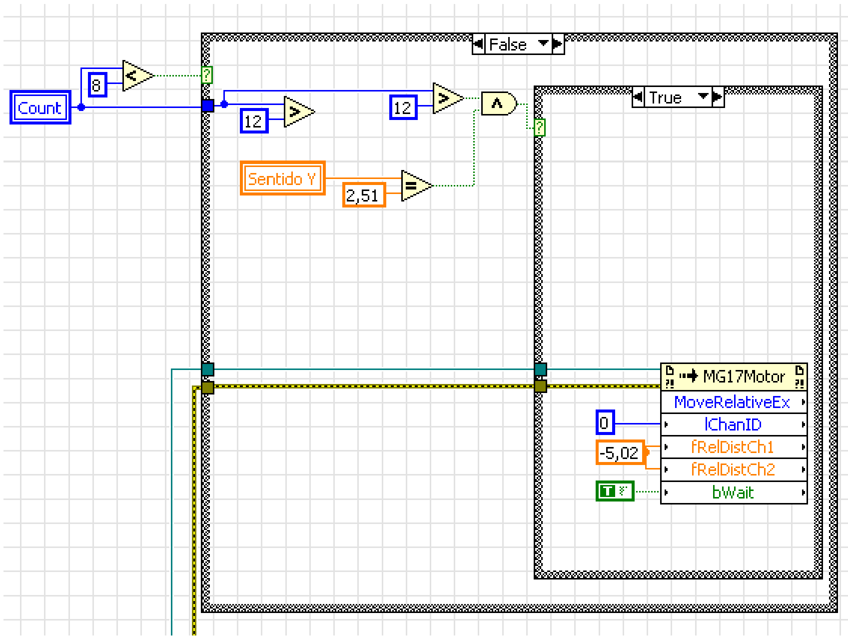


Figure 4.7: Adjustment of the variables of the process

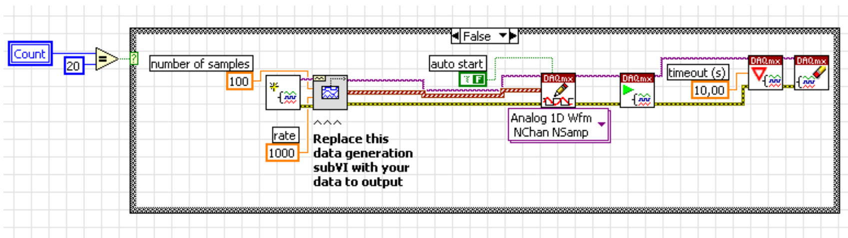


Figure 4.8: Drop dispensing to begin a new line of droplets

Figures 4.6 and 4.7 show the adjustment in the positioning of the wafer. Between the lines where the number of droplets varies (inclined blue dashed lines in figure 4.1) besides the step to the next line, there should also be a shift in the direction of the current line to be followed. That is where this adjustment is made.

The variable *Count* is the current line number of the dispensing process. After this step, the variable *Count* is incremented. Meaning that a new line will be started. As seen in the dispensing stage (4.1.1.2), before dispensing the first drop in the line, a step is given to adjust the position. Therefore, at this stage illustrated in figure 4.8 a droplet is added to the wafer, which will be the first of the new line of droplets. The condition loop only prevents that a drop is added after the last line is filled.

Figure 4.9 shows the last stage of adjustments. Here, the variable *Sentido Y* is adjusted to switch between the steps values that are the distances between the droplets.

The same figure also shows the adjustment of the *N of Drops* variable, that gets

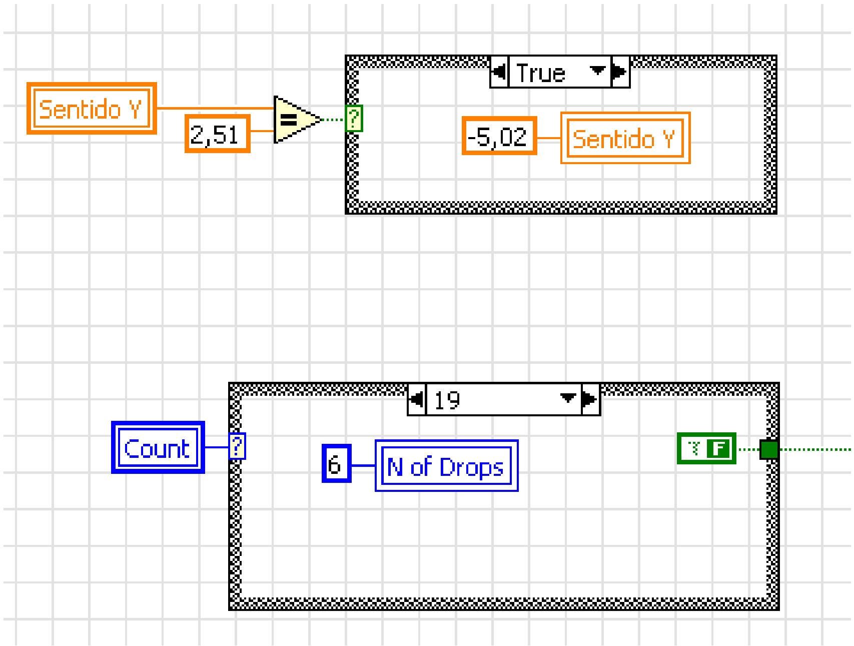


Figure 4.9: Final adjustments of the algorithm

its values according to the variable *Count*.

A boolean variable shown in this figure serves to signal the end of the process. It turns *True* only after the last line of adhesive is filled.

4.2: Dispensing while the stage is moving

In this strategy, the droplets are dispensed with the XY Stage in movement. The XY Stage starts the movement and then the nozzle starts dispensing the droplets. This strategy needs a good synchronization between the XY Stage movement and the dispensing of the droplets. To simplify the strategy, the dispensing of droplets of adhesive was performed only when the table was moving in one way. When dispensing in both ways, it was observed a misalignment between the lines. It happens because when the stage is moving, any delay to start the dispensing process can cause a misalignment of the droplets on the wafer. These delays are caused by the communication between the computer and the microdrop system when sending the trigger signal. It depends on the speed of the communication and also the processing speed of the computer. These delays tends to be constant, so it is easier to adjust the positioning of the line of droplets when dispensing with the stage moving just one way because there is no misalignment between the lines. This strategy as the previous one, is also divided into four parts:

- Home, engine calibration and initial positioning
- Initiation of XY Stage movement in a direction and dispensing of the droplets.
- Lateral movement of the XY Stage (to start a new line of droplets).
- Variables adjustment.

As in the previous strategy, the first step is necessary whenever you start to control the motors of the XY Stage.

The difference between the strategies is in the second step. Here, the table begins to move in one direction and simultaneously the nozzle dispenses the droplets. Synchronization is very important in this step, since the speed of the table has to be precise so the firing time between shooting of droplets is adjusted and the droplets are separated by the exact distance. In the third step, the table moves laterally and back to the initial position in the X axis to start another line moving in the same direction as the previous line.

As in the last strategy, the last step serves to adjust the internal variables of the algorithm (number of droplets and the time between firing of droplets)

4.2.1: Creating the LabVIEW algorithm

<u>Home, engine calibration and initial positioning</u>

The first step of this strategy is almost identical to the previous strategy explained in subsection 4.1.1.1. What changes in this step is that some other adjustments are needed, they are illustrated in Figure 4.10.

As in this strategy the speed of movement of the Y axis is adjustable, some variables must be calculated from the speed chosen by the user. The variables *fLow* and *fHigh* indicate the frequency of the trigger signal to be sent to the microdrop system. There are two of them because there are lines with lenses and without lenses and the number of droplets is different in the two. These values must be integers to facilitate the creation and processing of the signal that is sent as a trigger, so there is a rounding of the value selected by the user. The actual speed is also calculated and saved in the variable *Vel Y*.

The variables *delayHigh* and *delayLow* are used to adjust the dispensing of the droplets at different frequencies.

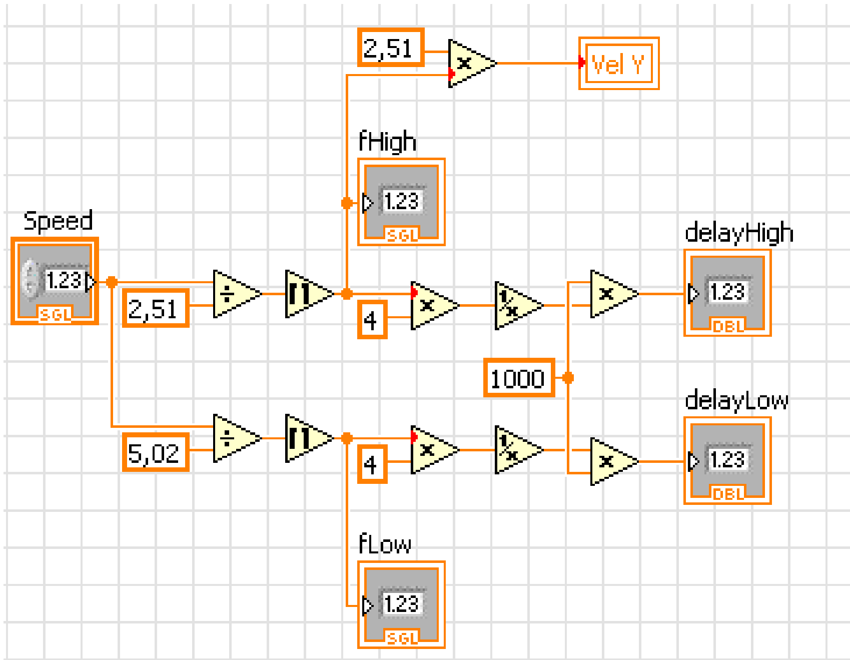


Figure 4.10: Variables initiation

The initial position of the Y axis is indicated by the variable *StartY*.

<u>Initiation of XY Stage movement in a direction and dispensing of the droplets</u>

The figure 4.11 shows part of the algorithm in which the movement of the XY Stage starts. The movement for dispensing adhesive occurs only in the axis Y. The movement of the XY Stage occurs with the function MoveAbsoluteEX (3.2.1.6). As the position parameter the maximum value possible for this axis of the stage is given. Note that for the parameter **bWait** value is now *False*. This is because continuation of the algorithm, namely the dispensing of droplets, must occur while the movement is made.

Figure 4.12 shows the part of the algorithm that generates the signal and send it to the microdrop system. Here, the signal generated is different than in the previous algorithm. In this algorithm, a square wave is generated in LabVIEW with the desirable characteristics. The most important information passed is the wave frequency, calculated in the first step of this algorithm.

After the wave is generated, the signal must be treated. As the number of droplets is variable, the wave must be trimmed, to send the correct signal as the trigger. The number of descents on the signal represents the number of droplets.

Figure 4.13 shows two signals. On top, the wave created and below, the same signal trimmed. The trimming occurs choosing the signal duration.

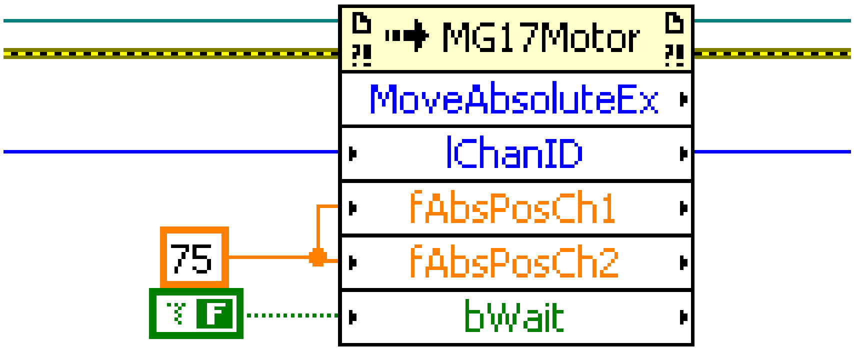


Figure 4.11: Initiation of the XY Stage movement to dispense droplets while moving

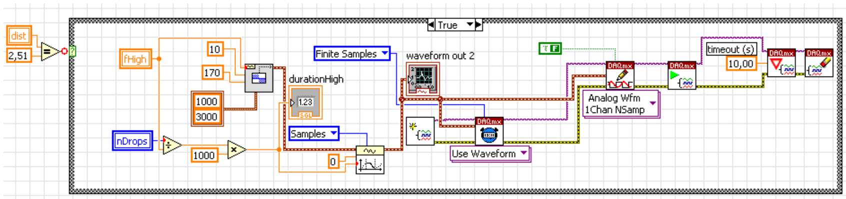


Figure 4.12: Generation and sending of the trigger signal

Lateral movement of the XY Stage

As in the previous algorithm, this step is given with lateral MoveRelativeEX function (3.2.1.9).

Variables adjustement

The first step in adjusting and updating the variables is the distance that must exist between two droplets. As previously stated, there are lines with and without lenses, and the distance between the droplets on these lines is different. It can be seen in Figure 4.14 a part of the algorithm responsible for this updating.

In this same step, the waiting time between the start of movement of the motor and the start of the droplets dispensing is adjusted. As can be seen in Figure 4.15, the first decline (which is the trigger for pouring drop) of the two waves are not being sent at the same moment. The wave with less frequency takes longer to begin its first descent. Therefore, the difference in time between the first descent of the waves is discounted using the variables *delayHigh* and *delayLow*.

Another variable set is the variable *StartY*. It indicates the start position of Y-axis in each line. Here the variable *nDrops* is also set and it is the number of droplets of

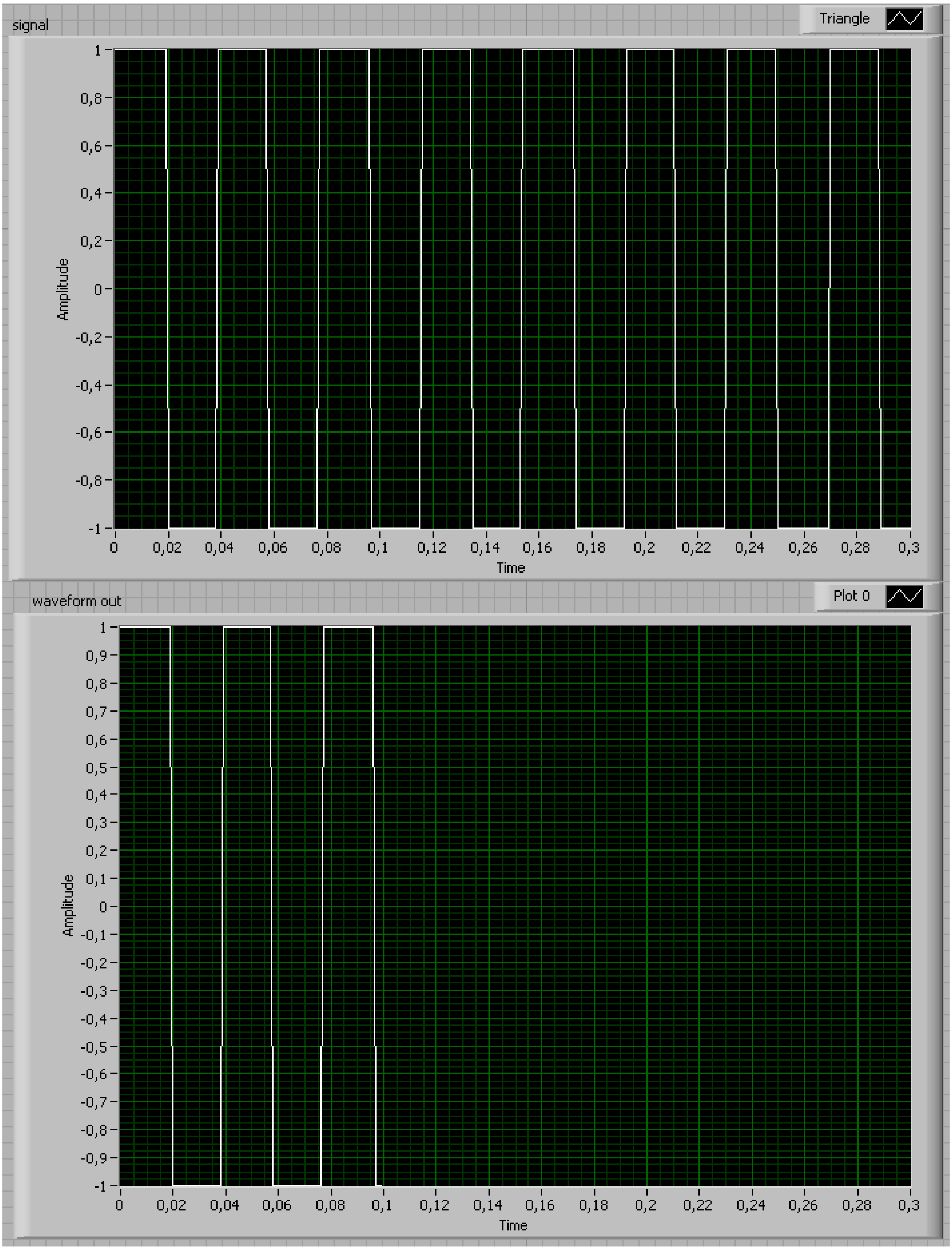


Figure 4.13: Signal generated and trimmed for the trigger

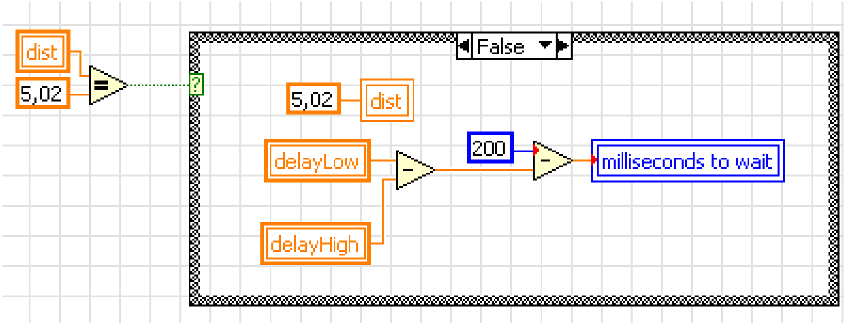


Figure 4.14: Adjustment for synchronization

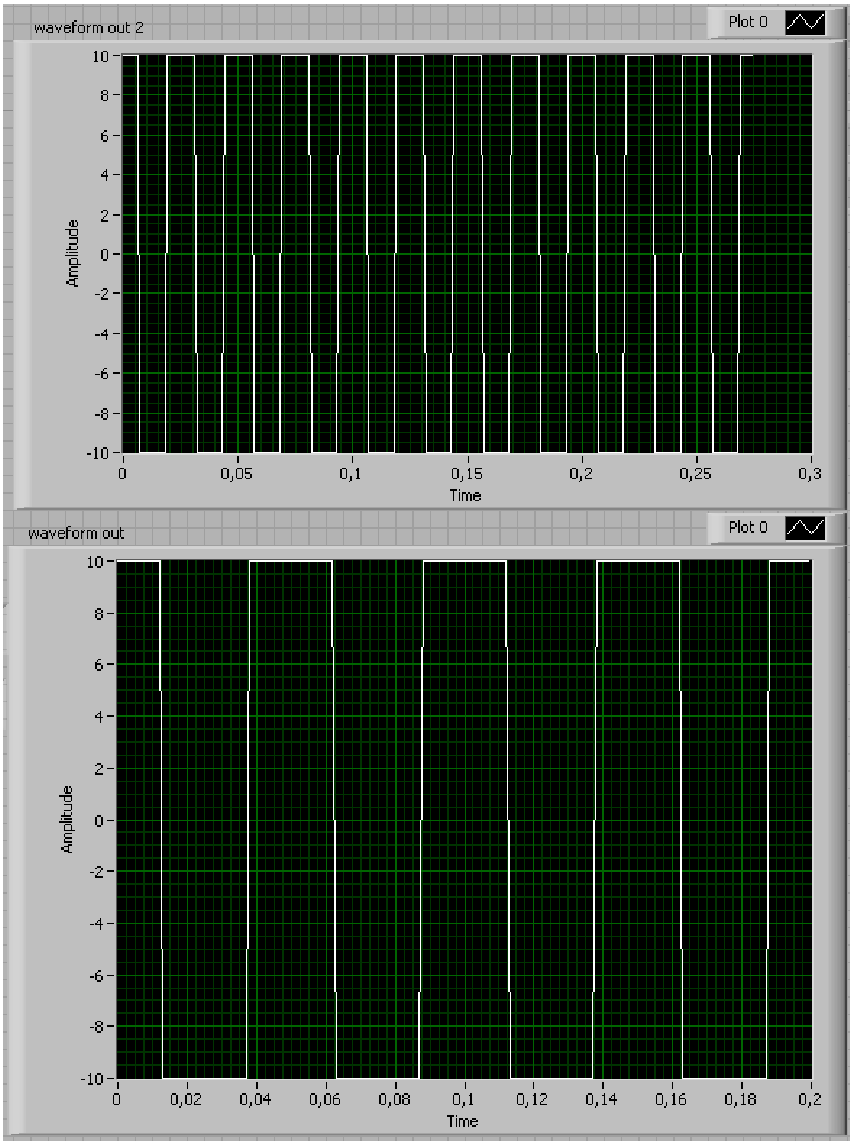


Figure 4.15: Difference between waves

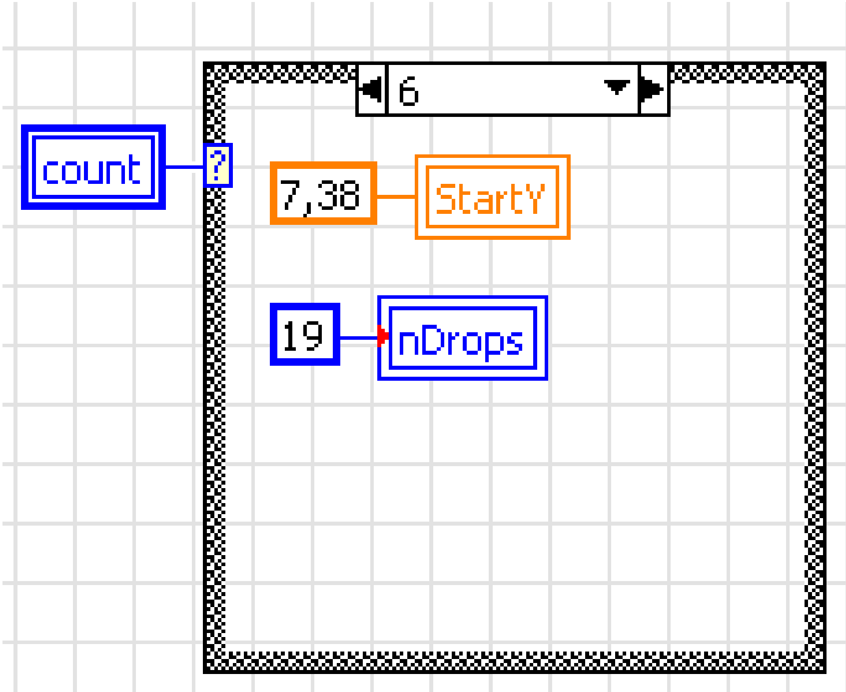


Figure 4.16: Adjustment of the variable for the starting position of the Y axis

each line. These two variables are adjusted according to the value of the variable *count* that indicates the current line number. After dispensing adhesive in the last line, a stop signal is done and the algorithm ends. Before starting a new line, the variable *count* is incremented.

4.3: Results

The dispensing process is a challenging process because it needs a perfect synchronization between the drop dispensing and the movement of the XY Stage. These two tasks are controlled by the algorithm in LabVIEW. It is important that the movement and positioning of the axes of the XY Stage are as perfect as possible to obtain a perfect positioning and alignment of droplets on the wafer.

Another factor that influences the positioning of droplets is the proper operation of the microdrop dispensing unit. The system must be in working order because any deviation of the drop commits its operation. Any dirt lodged in the system nozzle can cause a deviation of the drop.

While the drop makes its way between the tip nozzle and wafer there are factors that influence the final positioning of the droplet on the wafer.

The Adhesive-Dispensing-Unit system design was done so that the system can run in perfect synchronization and also that the factors that affect the final placement of the drop in the wafer is eliminated or, at worst, minimized.

The XY stage used has a closed loop control that rejects errors with an accuracy of 0.1 μm. The axes of the XY stage have positioning errors smaller than 100 nm.

To minimize errors of droplet placement caused by outside disturbances during the dispensing process, the system was designed so that the nozzle is as close as possible to the wafer and also that during the dispensing process, the system is closed to the outside, preventing any disturbances that may influence the final placement of the droplets.

Another factor that influences the positioning and alignment of the droplets is the algorithm used. As stated in the previous chapter, two algorithms were created for this project. The goal was to compare these two algorithms and reach a conclusion about which one would be used in the final version of the system considering their advantages and disadvantages.

In the following subsections, the results of each algorithm will be presented and discussed. The next section will show a comparison between each strategy and a conclusion on which algorithm showed better performance considering all the needs of the project.

4.3.1: First strategy: dispensing while XY stage is stopped

This first strategy does the dispensing of the droplets with the XY stage stopped. Since there is no relative movement between the nozzle and the wafer while the droplet is dispensed, the alignment accuracy of the droplets in this algorithm is very high.

If on one hand the dispensing of the droplets with the wafer stopped influences positively the positioning and alignment of the droplets, on the other hand this process takes a longer time to be completed. The average time that this strategy takes to complete the task is $1m25s$. The average duration of each stop for drop dispensing is $110ms$. This time can become higher the greater the number of micro optical components contained in the wafer. For the wafer used to run the tests, there were 208 droplets that needed to be placed on the wafer. So that is about $22,5s$ spent without movement on the algorithm. Besides the stopped time, acceleration time and deceleration of the XY stage also adds to the total time of the process. Considering that this is a production process, any time spent unnecessarily during the cycle can result in

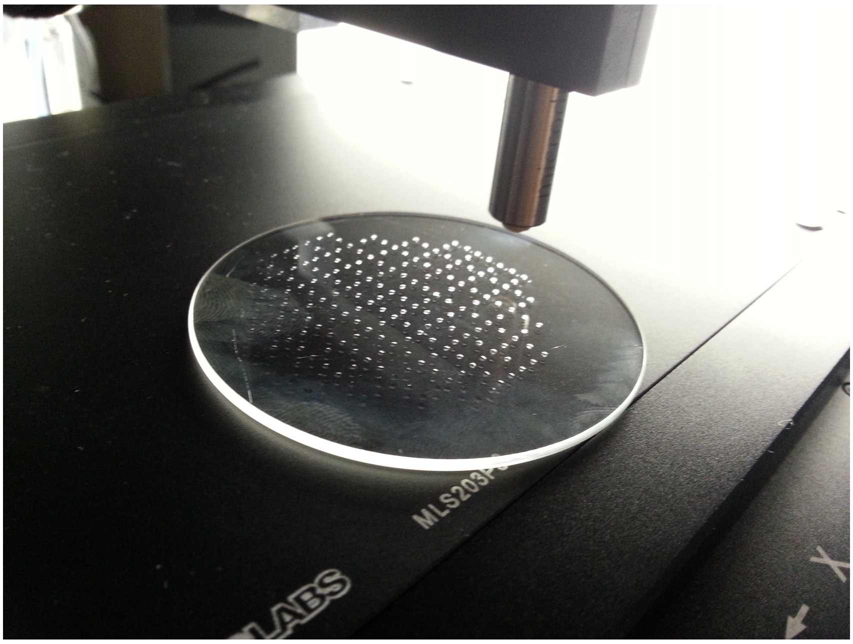


Figure 4.17: Result of the Stop and Dispense strategy

unnecessary costs to the production as a whole.

4.3.2: Second strategy: dispensing while XY stage is moving

This second strategy is the dispensing of droplets with Stage XY moving. As now the table is in motion relative to the nozzle, the process becomes more susceptible to an alignment or positioning error. In this strategy, the final alignment of the droplets on the wafer is less acurate than the alignment of the first strategy. More than in the previous strategy, here the proper functioning of all elements of the integrated system as well as its perfect synchronization is highly required for the task success.

Although this strategy has a degree of precision not as high compared with the first one, the time required to perform the task decreases significantly. In this strategy there is no stop to dispense the droplets. The droplets are dispensed on the wafer in lines and not individually.

The average time needed to perform the task is $44s$ if the task is performed at the maximum speed allowed by the algorithm which is $198mm/s$. In this strategy, the objective was to accomplish the task in the shortest possible time, thereby avoiding any wastage of time with unnecessary adjustments during the process or stops to dispense the droplets.

One difficulty emerged during the tests of this second strategy was related to the

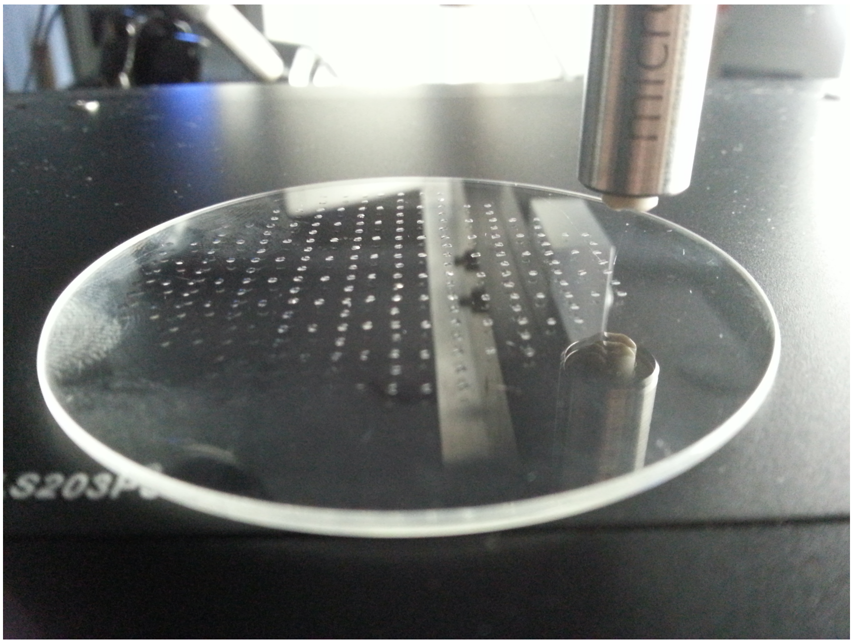


Figure 4.18: Result of the Stop and Dispense strategy

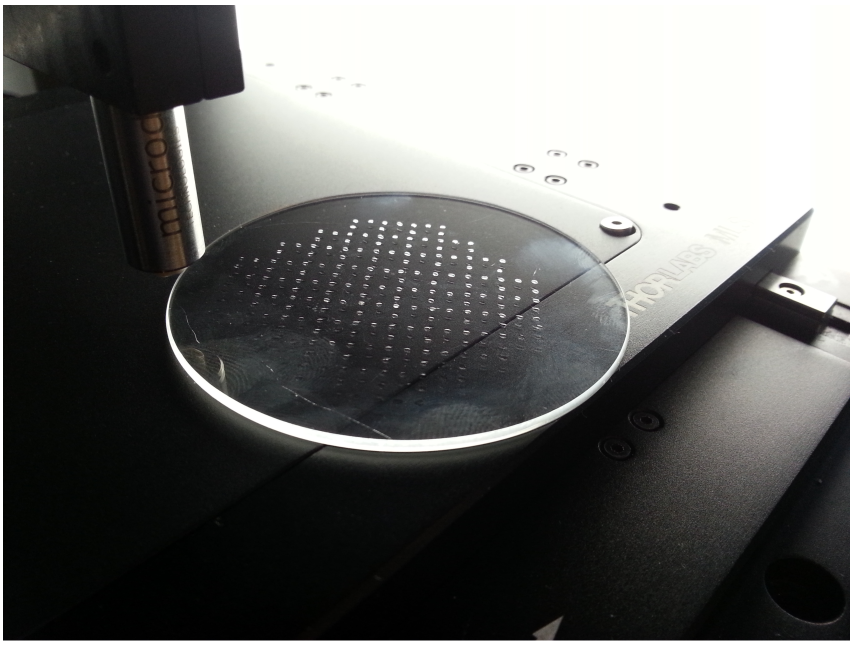


Figure 4.19: Result of the Stop and Dispense strategy

Figure 4.20: Result of the Move and Dispense strategy

operation of the drop dispensing system. The system showed instability in the operation. The biggest problem was the generation of droplets. In some tests the nozzle did not dispensed the droplets properly, creating a diversion in the final positioning of the drop.

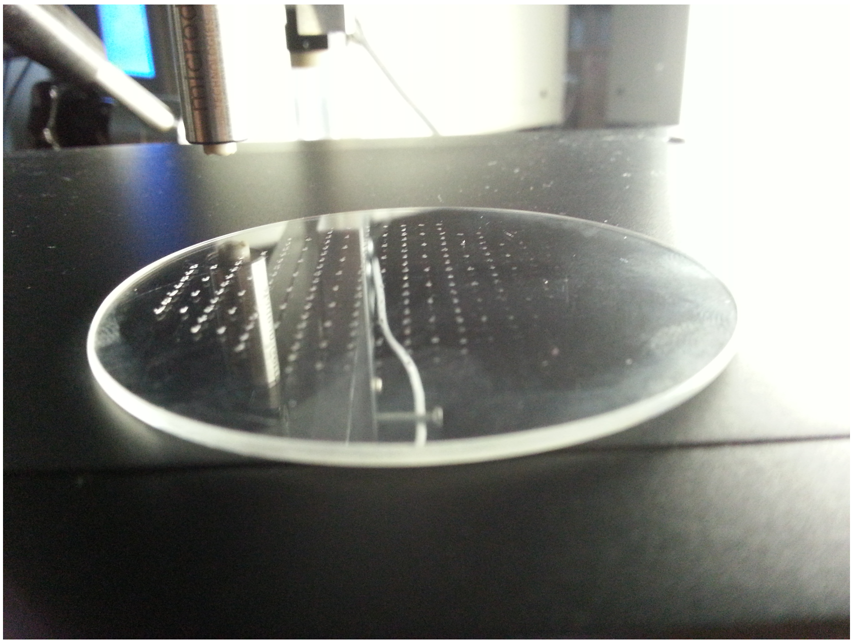


Figure 4.21: Result of the Move and Dispense strategy

Figure 4.22: Result of the Move and Dispense strategy

Strategy	Advantages	Disadvantages
First Strategy: dispensing of droplets with the XY Stage Stopped	High precision of alignment and positioning of droplets	Time spent stopping and accelerating XY Stage to dispense droplets
Second Strategy: dispensing of droplets with the XY Stage in movement	Drops dispensed per line, and not individually. Reduced time to complete the task	Not very high precision alignment and positioning of droplets. High dependence on the proper functioning of the other tools of the system

Table 4.1: Comparisson between both strategies

4.4: Comparison of the Strategies

With the results of the two strategies of droplets dispensing presented in the previous chapter, a comparison should be made to decide between the advantages and disadvantages of each strategy and finally come to a decision on which strategy should be used in the final system.

The process of positioning of the droplets on the wafer will be followed later by a process of aligning wafers. Because it is a sensitive Optical micro systems, any imperfection in the alignment of the wafers can cause the optical system to behave undesirable. These imperfections in the alignment process have an influence on the function of the optical system.

Figure 4.25 illustrates this for a typical optical system, consisting of three elements: the optical function of the perfectly aligned system is shown in the upper right corner of Figure 1, containing some spherical aberration. If the middle lens of the system is now decentered by only $5\mu m$ in the y-direction, the optical function is greatly influenced, showing strong coma effects. Those distortions find their numerical expression in the significantly increased RMS-value (+12 percent) and PV-value (+ 40 percent) of the aberrated wavefront, depicted in the down right corner.

However, the precision and optical function of a micro-optical system is not only dependent on the accuracy of the alignment, but also on the capability to cement the aligned wafer to one another with high accuracy and within a well determined position.

The challenging conditions of the application process are a result of its impor-

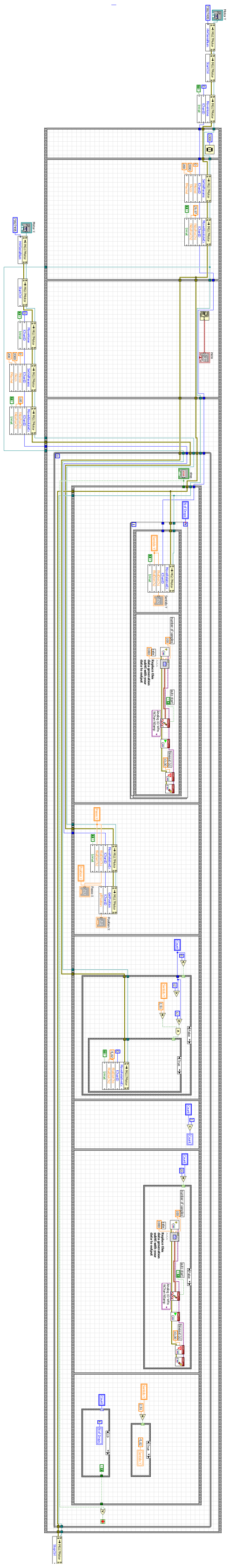


Figure 4.23: First strategy algorithm in LabVIEW

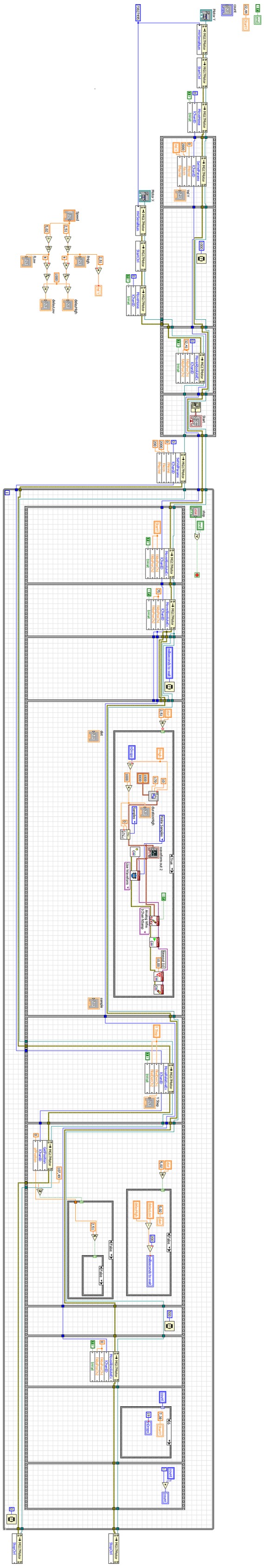


Figure 4.24: Second strategy algorithm in LabVIEW

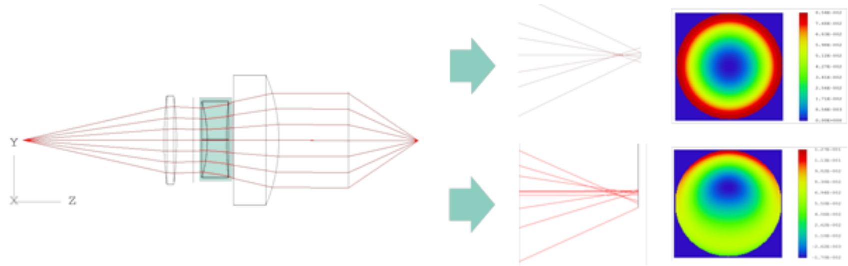


Figure 4.25: Influence of the decentration of $5\mu m$ on the optical function

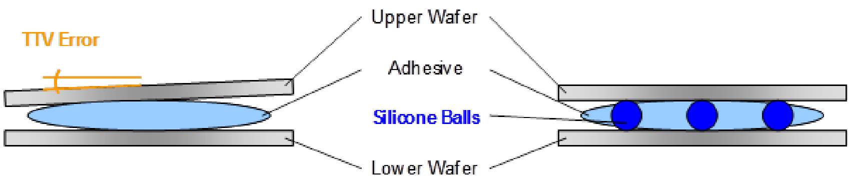


Figure 4.26: TTV avoiding function of specialized adhesives

tance for carrying the achieved alignment accuracy into the final micro-optical system. Because of that, the applied adhesive must be comprehensive enough to provide a stable cementing patch, with an adequately broadness for dicing the separate elements. However, great amounts of adhesive introduce the danger of compromising the apertures of the optical elements by inflowing adhesive as well as greater errors within its total thickness variation (TTV see Figure 4.26).

The accuracy of positioning of the droplets may compromise the operation of micro optical end if large quantities are applied and afterwards during the alignment and bonding, the adhesive leak into the space occupied by the lenses on the wafer. As stated before, this can introduce errors in optical function of the optical elements. The amount of adhesive should also be constant in all the droplets, so that there is no variation in the thickness of the end element (Figure 4.26). As a large amount of adhesive applied may cause the leaking of the adhesive into the lenses spaces on the wafer, a poorly adjusted process of applying adhesive can also produce the same effect. The droplets of adhesive must contain sufficient volume to bond the wafers and also must be spaced sufficiently from the lens so the inflow does not occur.

Analyzing the results obtained with the two strategies, the difference in the positioning and alignment of the droplets is not a factor to dismiss the second strategy, which has the lowest accuracy. Considering this, the other characteristic analyzed is the time spent to complete the task. In relation to the duration of the process, the second strategy has considerable advantages over the first one.

Capítulo 5: Conclusion

Throughout the process of the creation and testing of the strategies for applying adhesive on the wafer, the LabVIEW software showed to be extremely suiting for the task. The ease of integration to control the XY stage and also the option to create a signal and send it to the microdrop system were very important to the project's progress.

The XY stage used has a perfect operation and the functions to control their movements in LabVIEW are simple. The positioning accuracy of its axes is high and proved sufficient to perform the required task.

The microdrop system showed functional issues since the beginning of the project. The manufacturer was contacted and some adjustments were made, but at the end it did not showed an acceptable operation, and somehow it undertook the project progress.

The software Autodesk Inventor 2010 was used to the design the adhesive application device. Despite the version used being in german, it did not showed great difficulty of use. Knowledge acquired during the undergraduate degree in Control Engineering and Automation were crucial to use the tool. The design of the device was performed without problems, but the final version could not be mounted during the internship period because the parts for the assembly were not ready.

In general, the project involved several knowledge seen during the graduation course. The use of programming techniques to create the algorithms of the adhesive dispensing process, the knowledge of CAD software and technical drawing for the design of the pieces of the adhesive dispensing device were crucial to the project's progress.

The internship period was very important for both academic and professional development.

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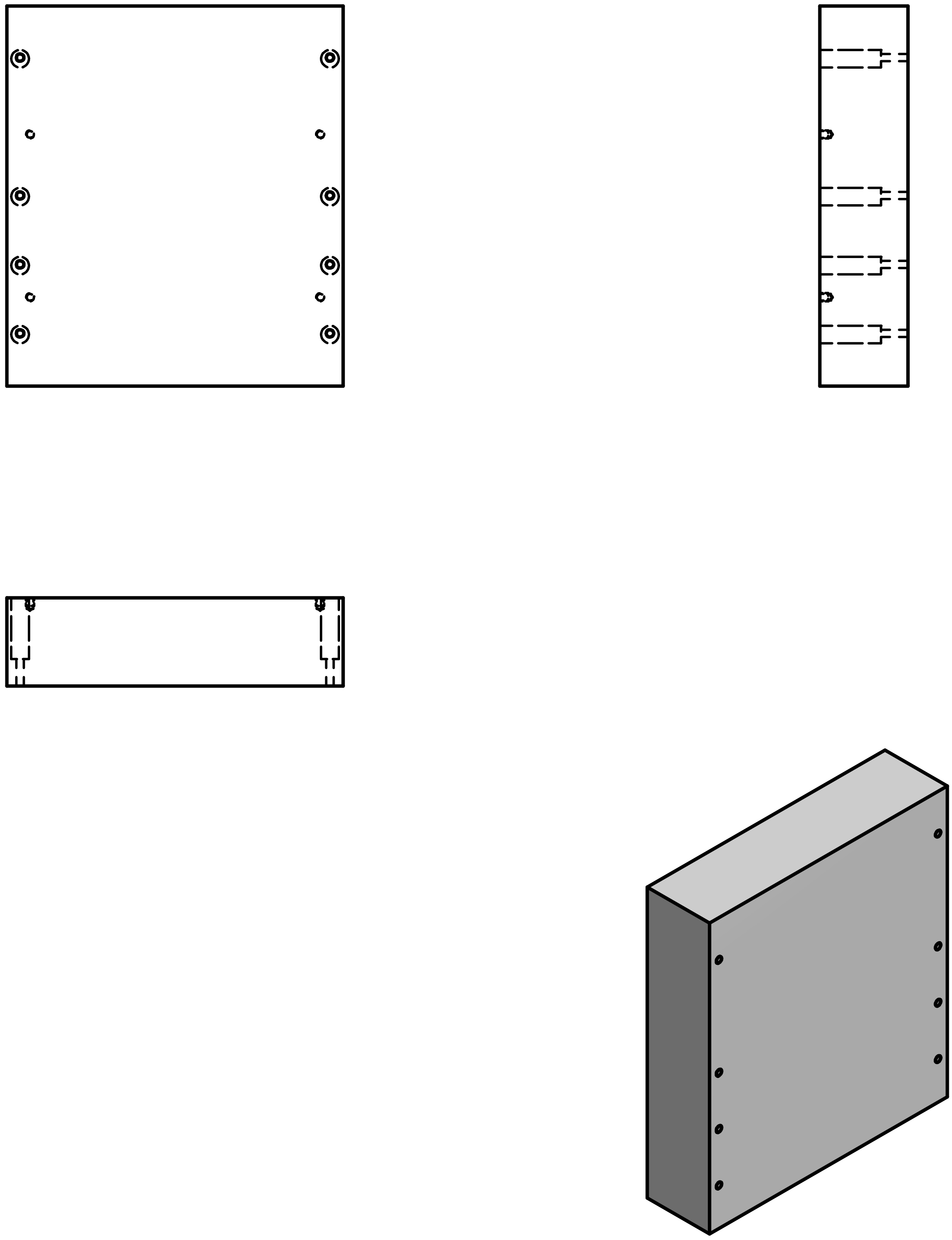
Appendix A : Drawings

The next pages are going to show the drawins of all the parts of the device that was designed in Autodesk Inventor 2010.



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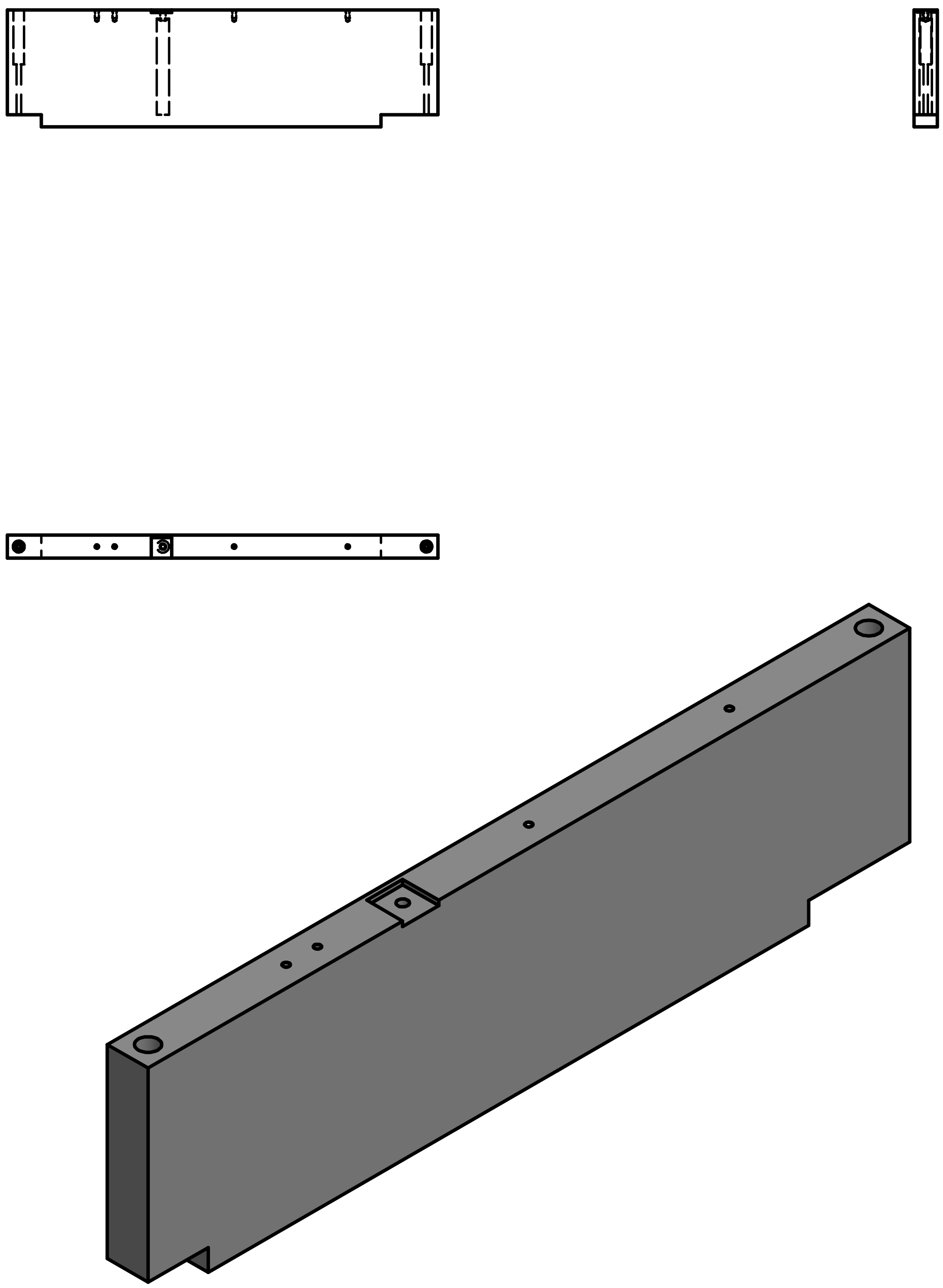

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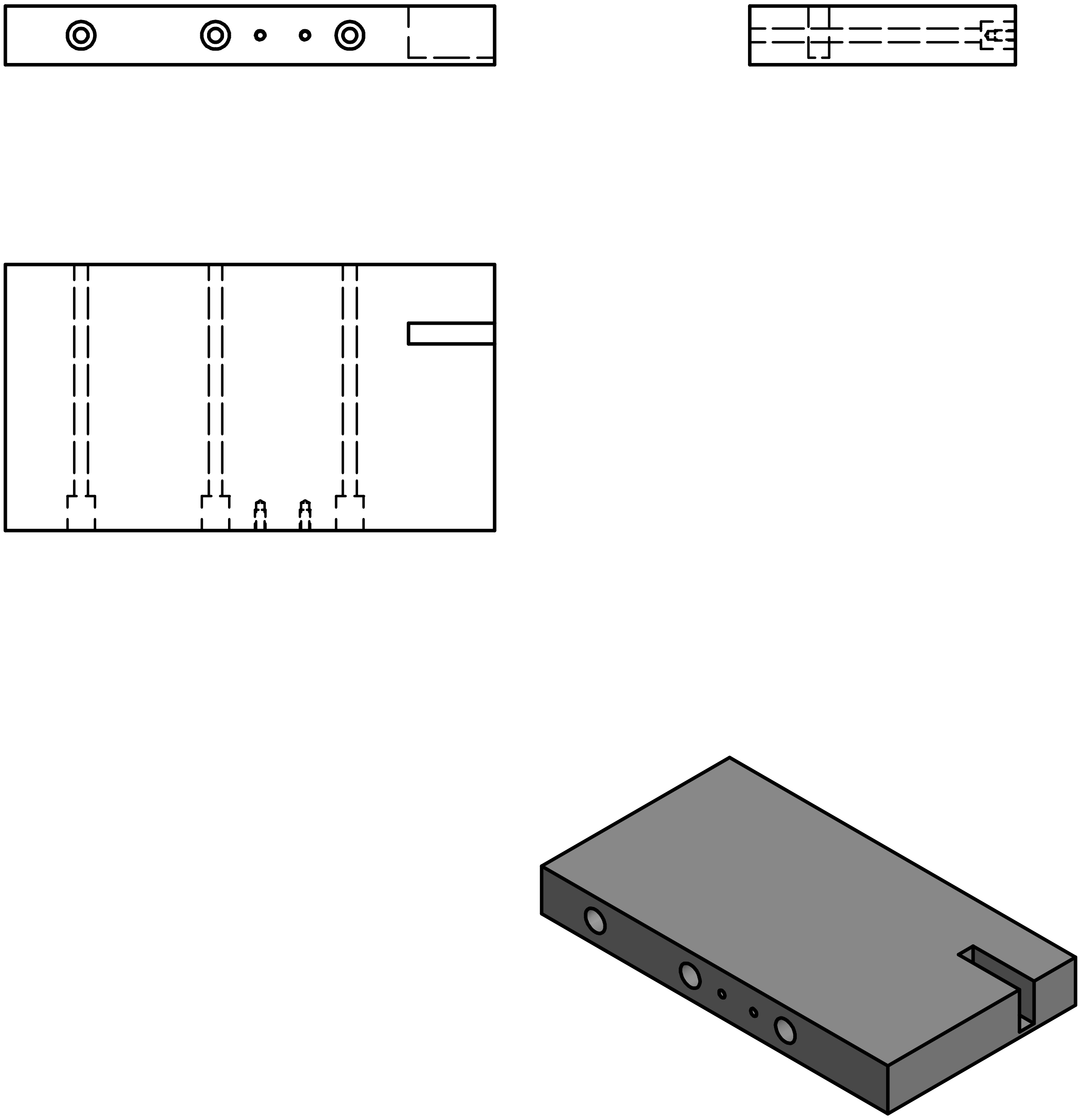

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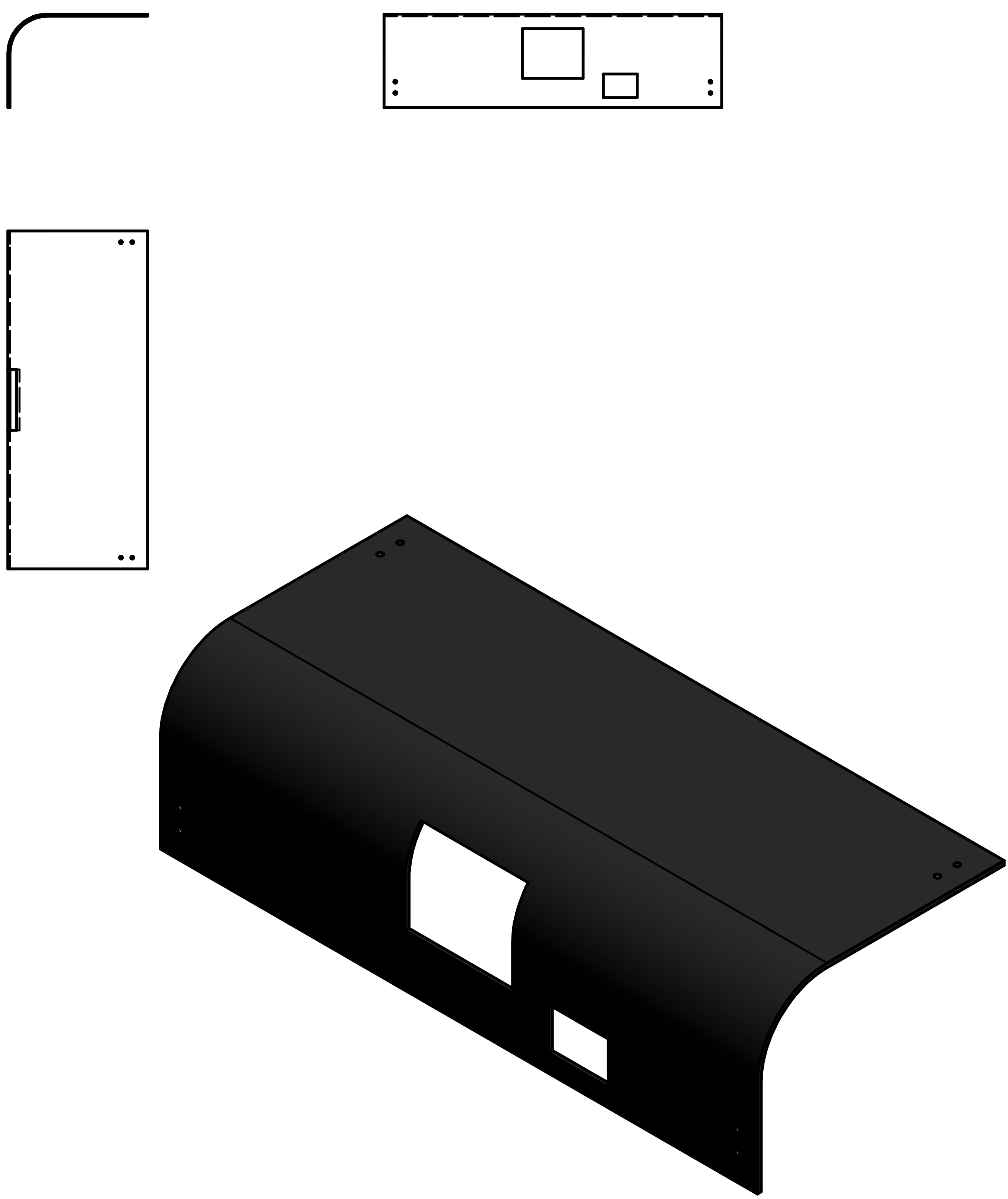

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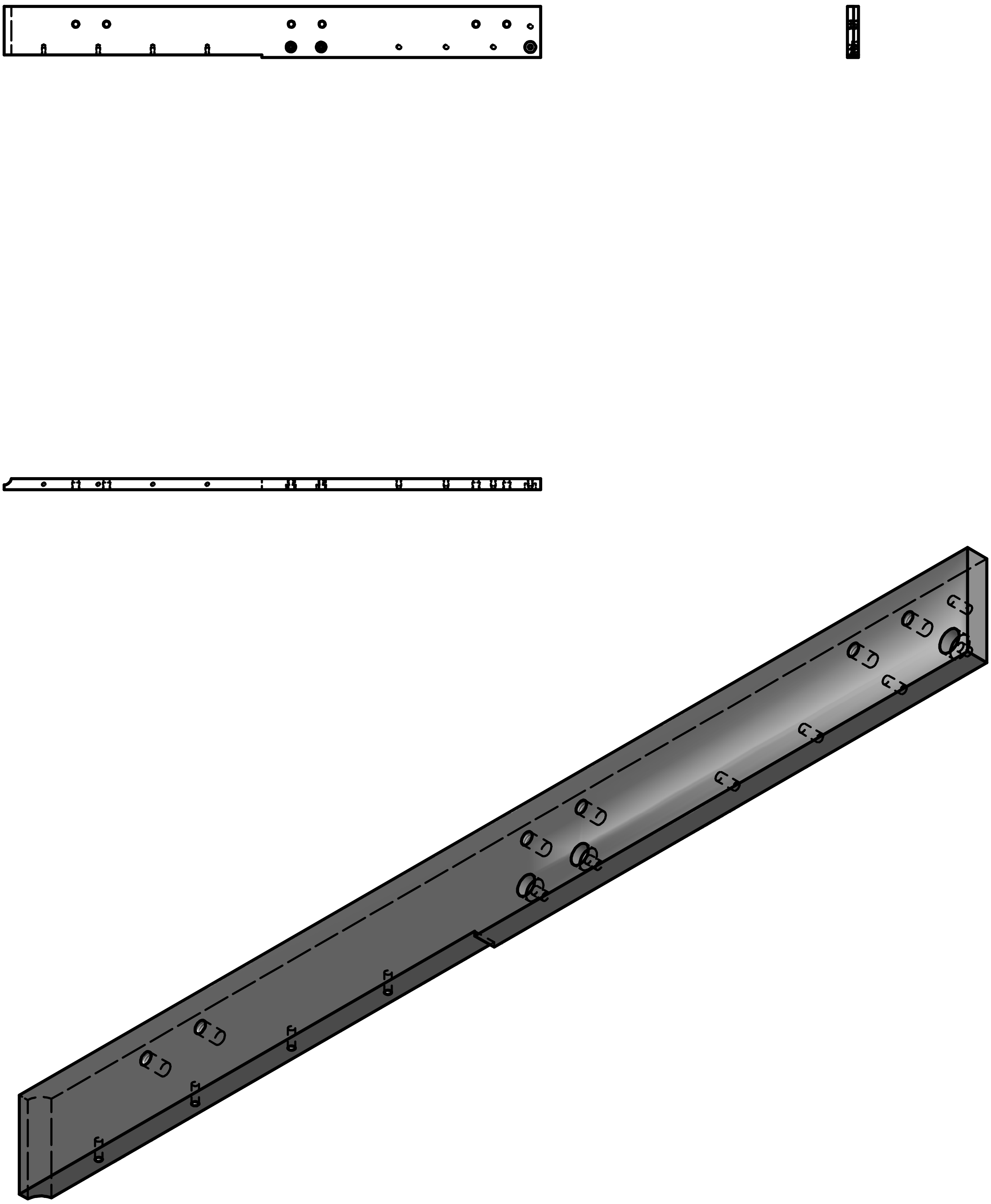

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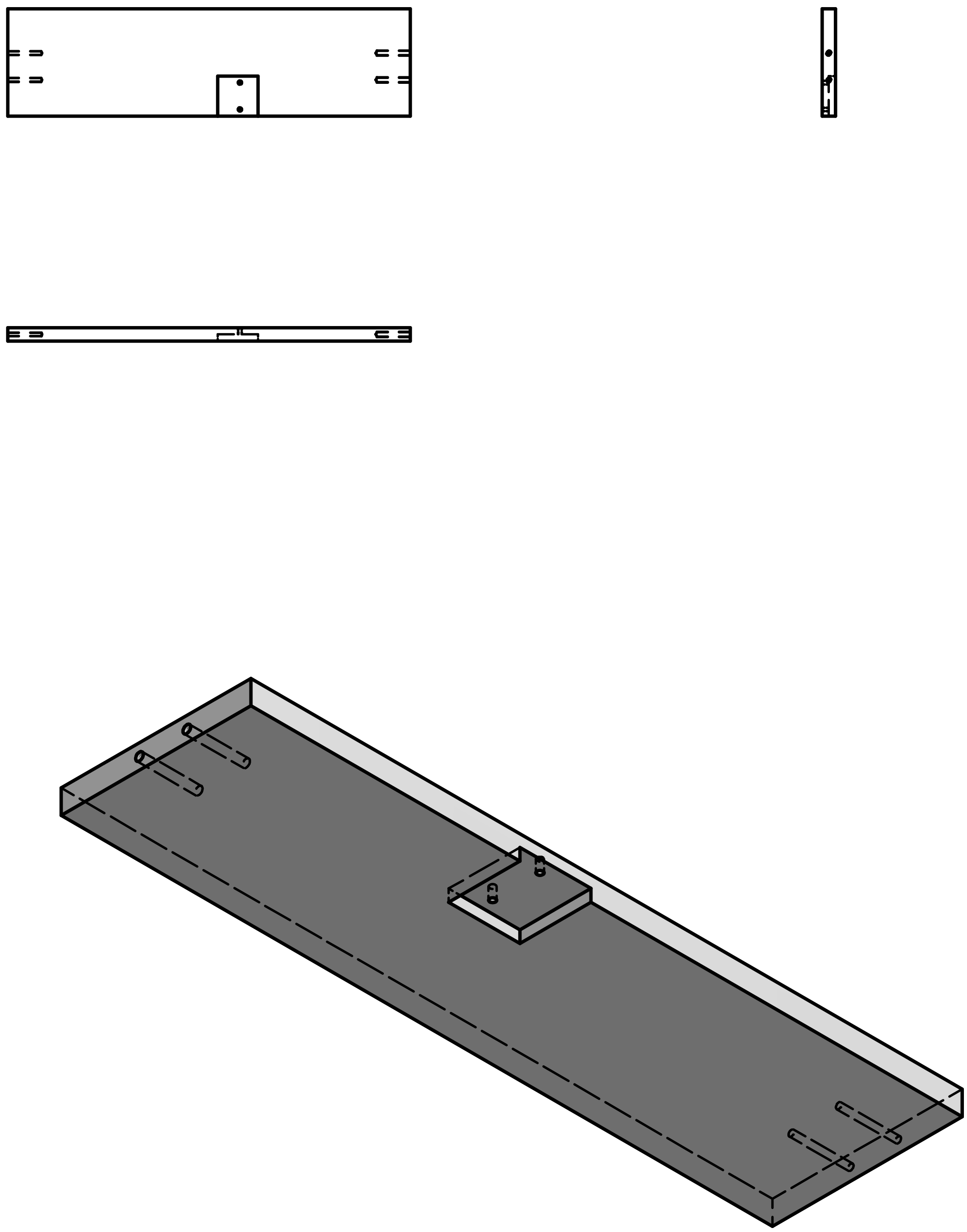

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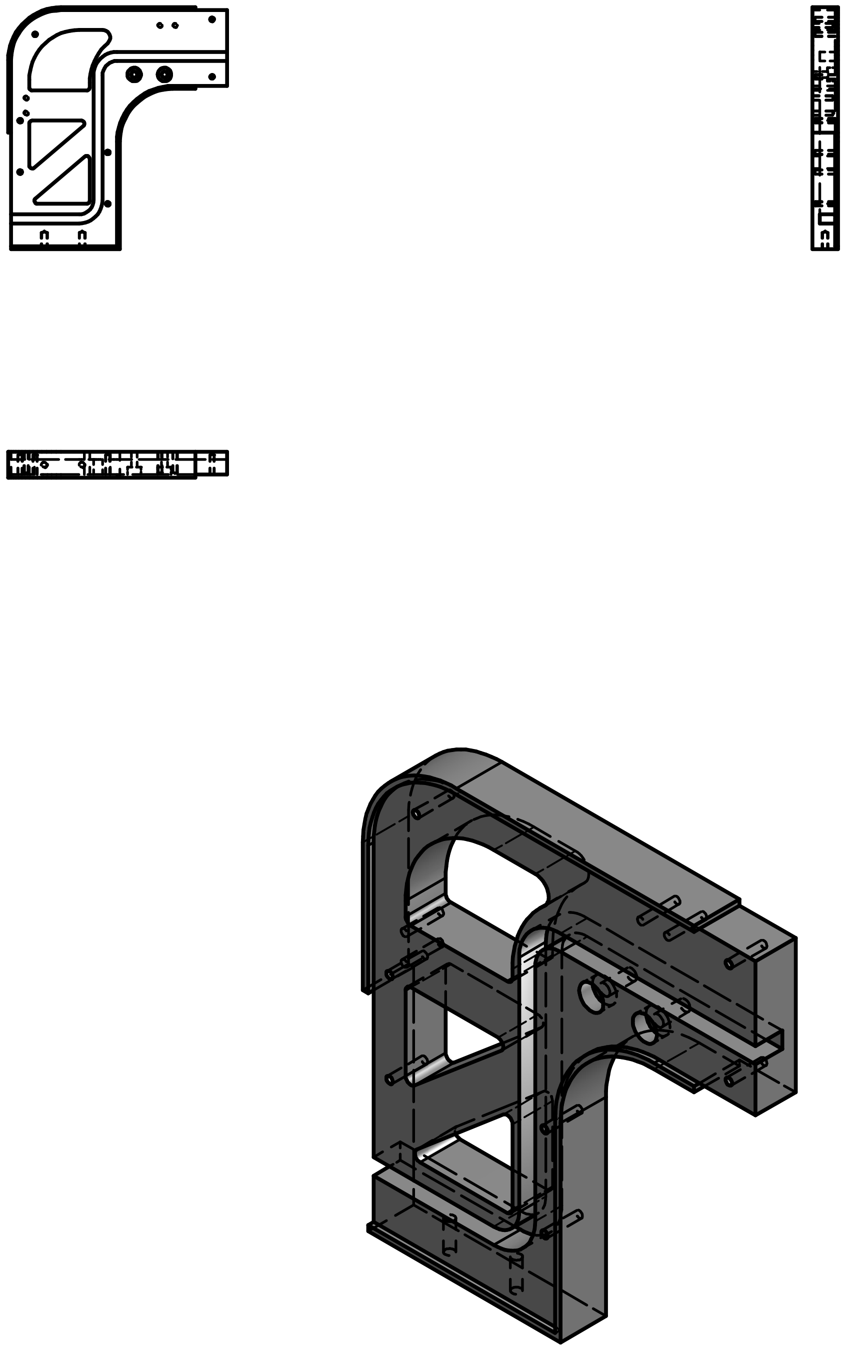

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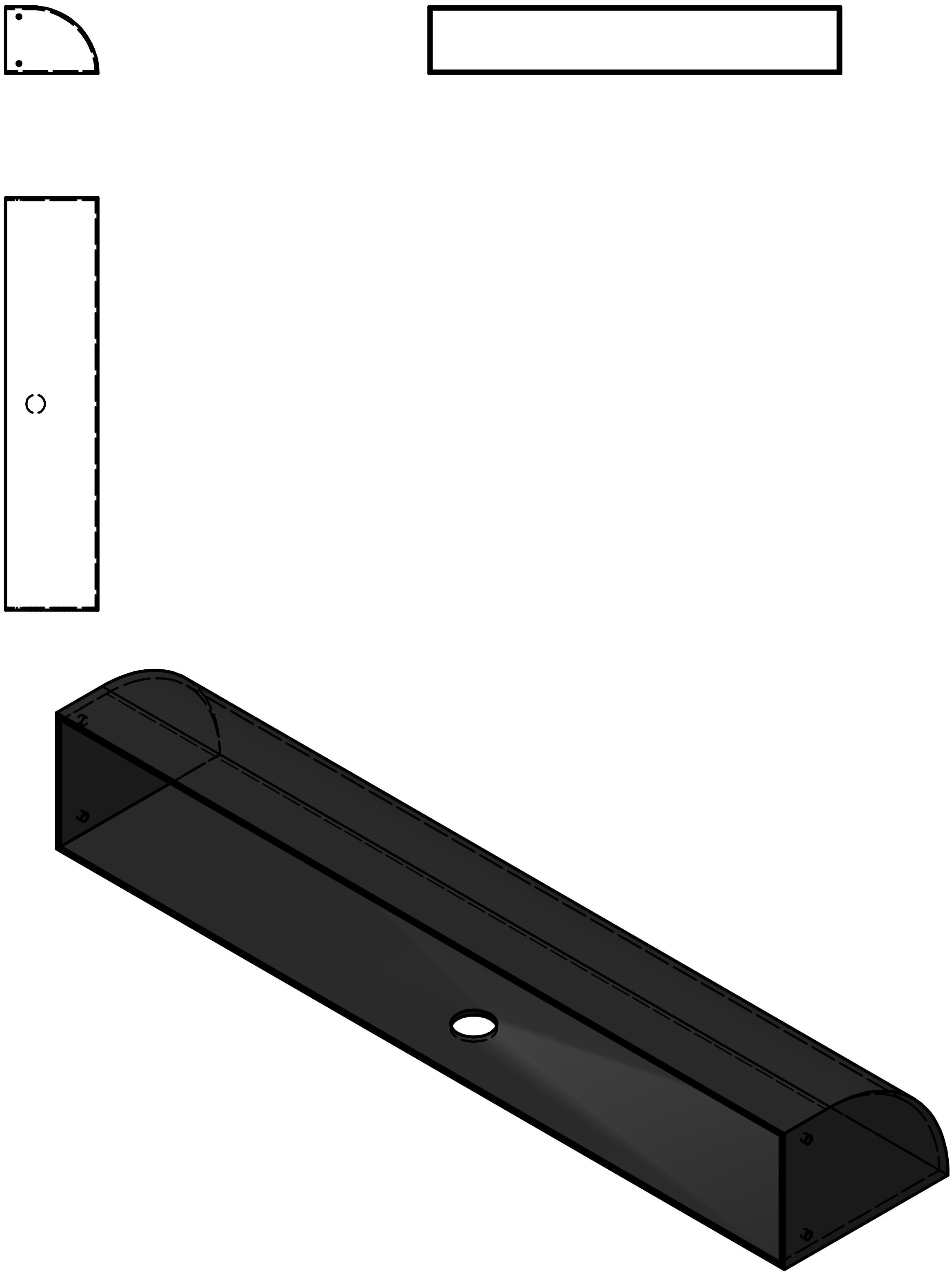

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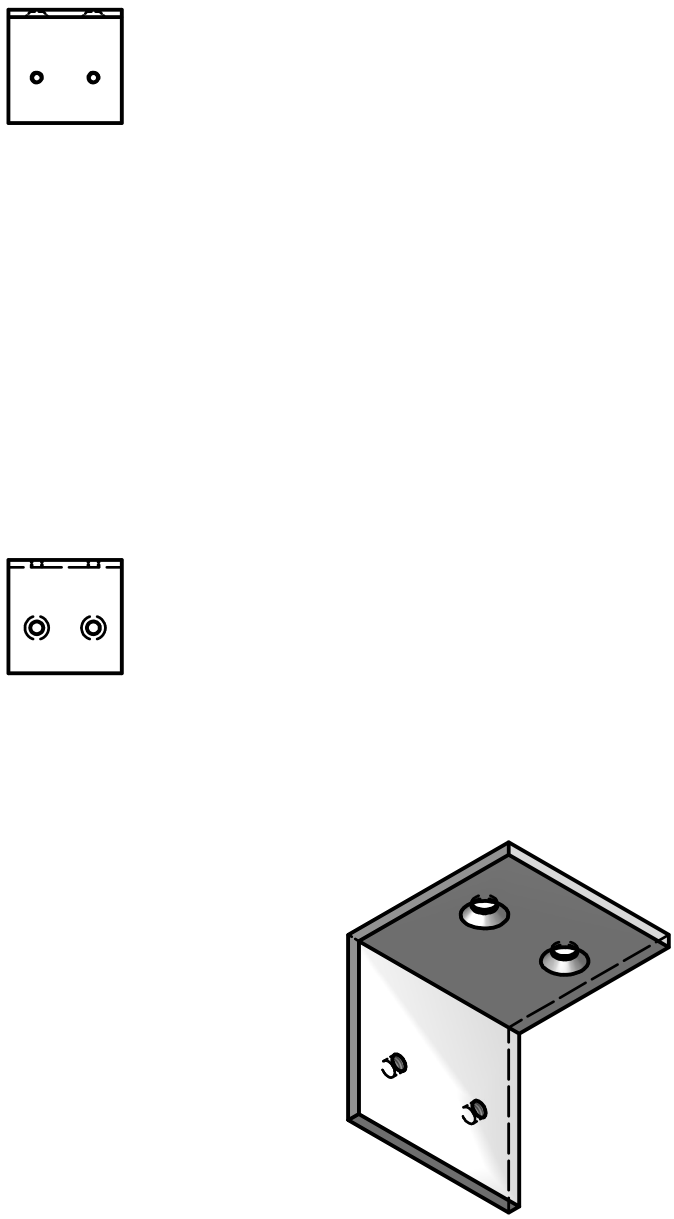

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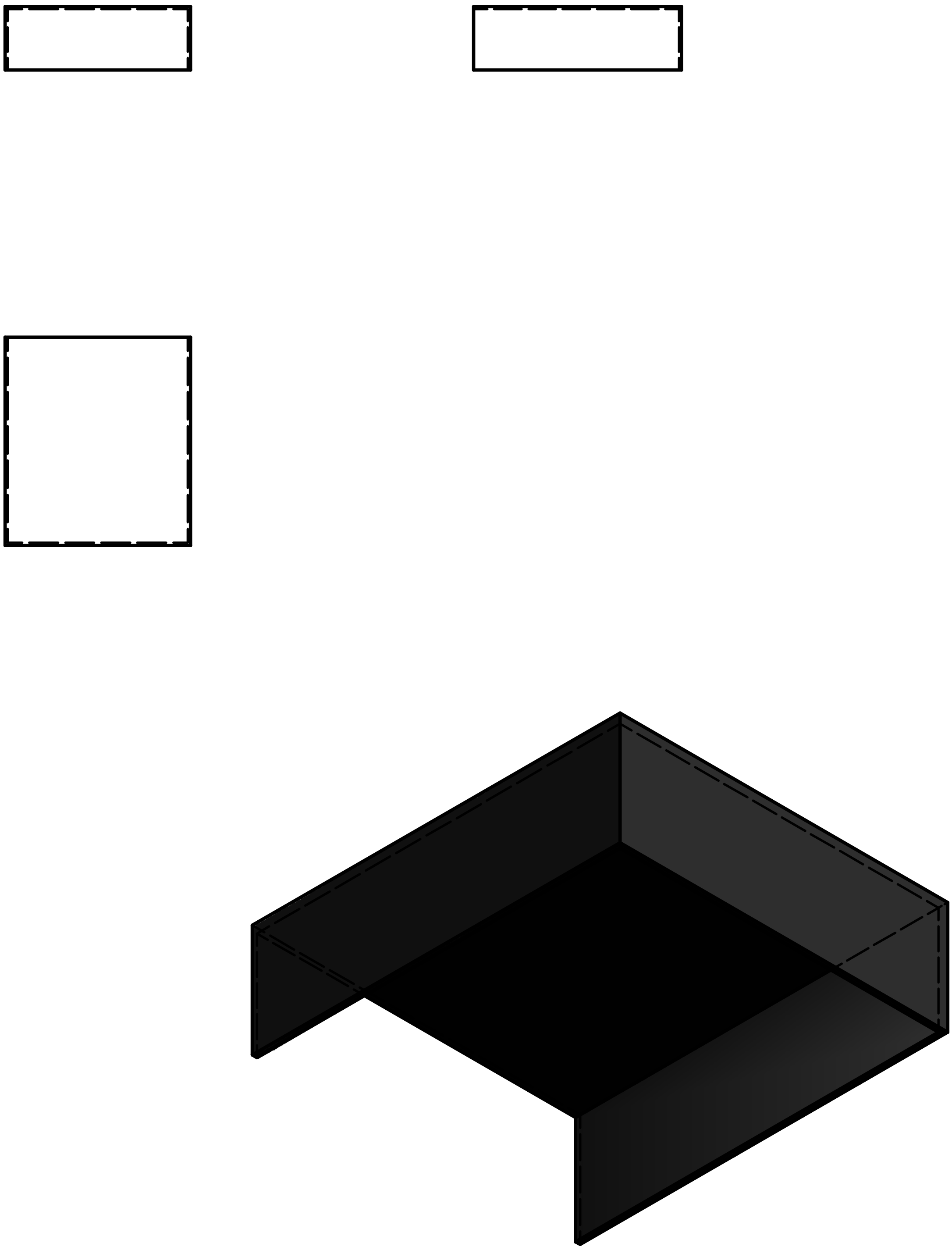

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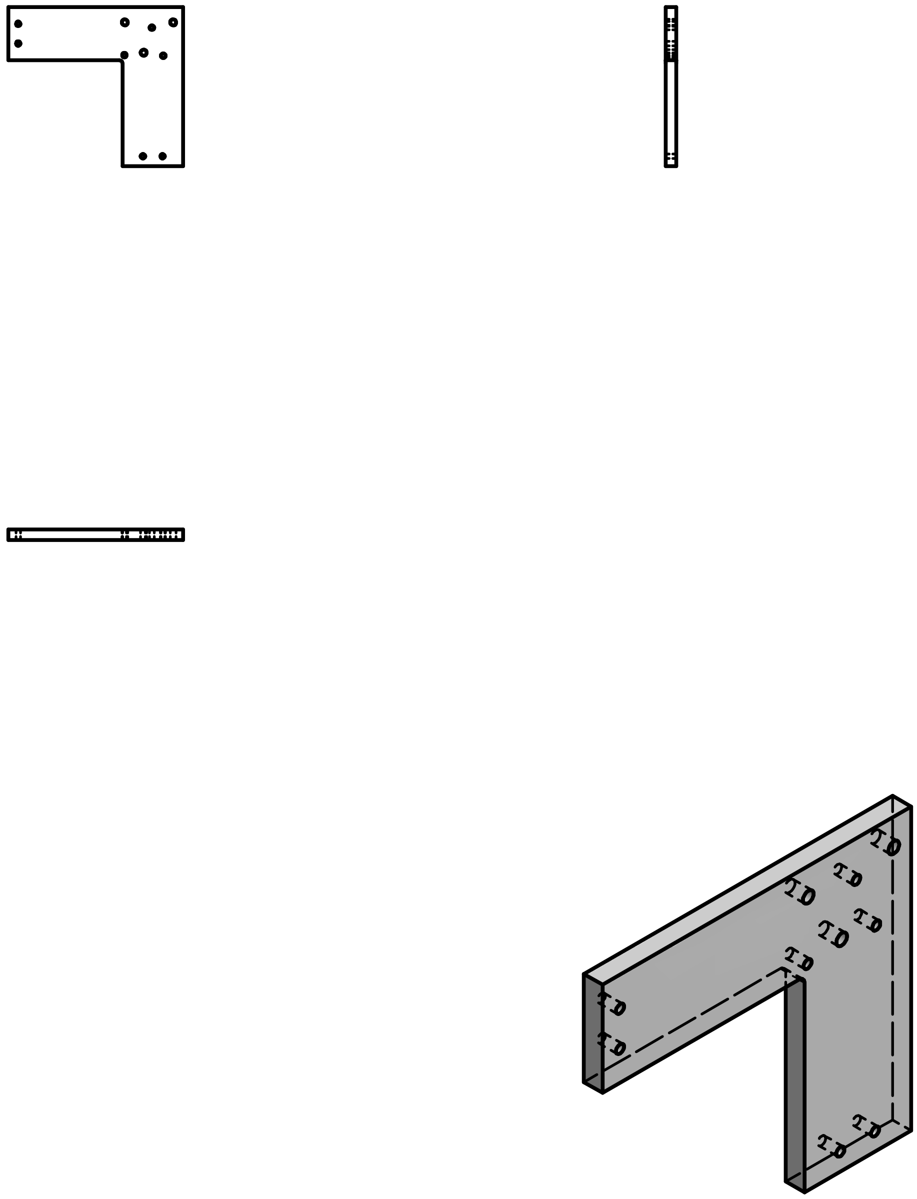

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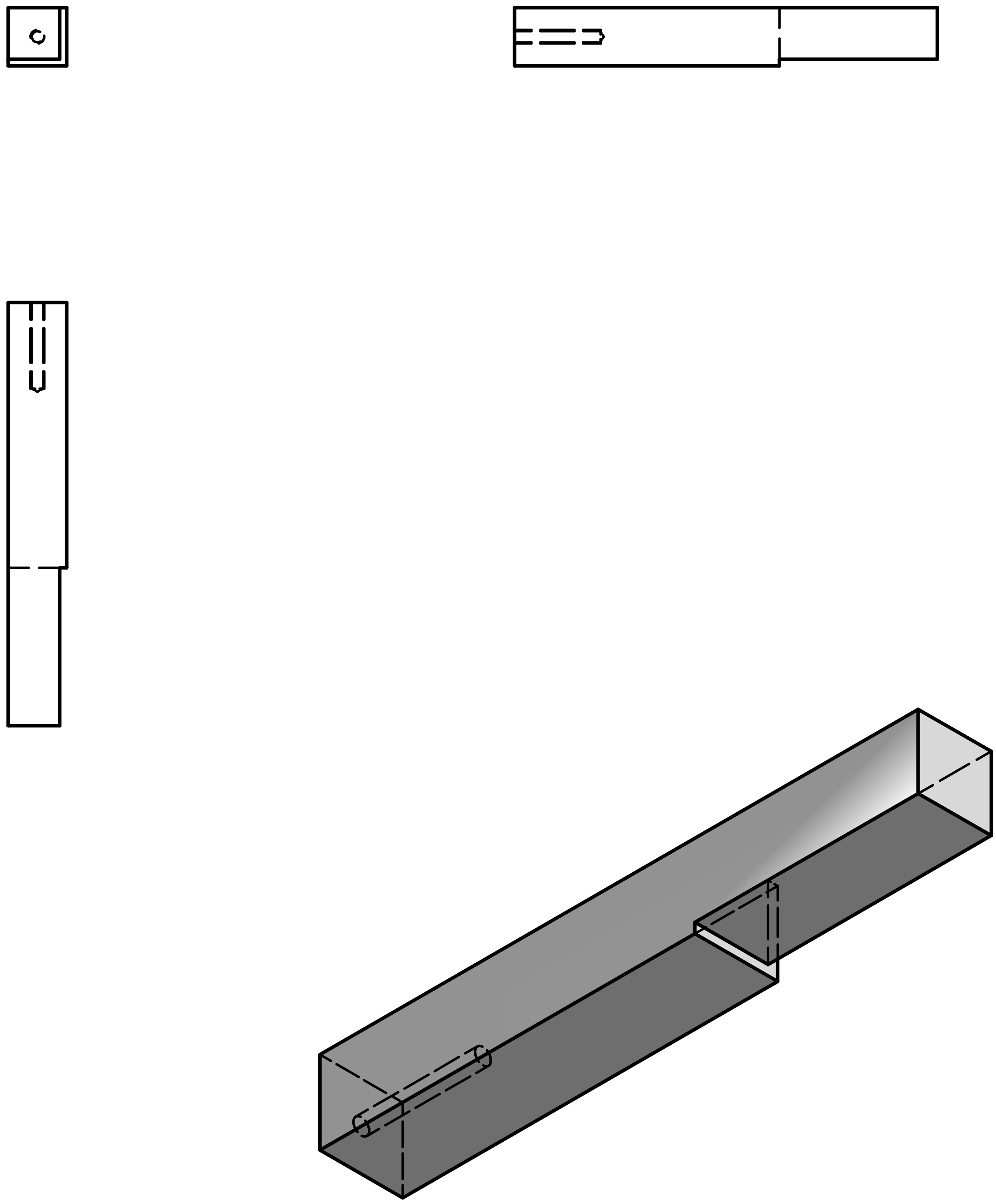

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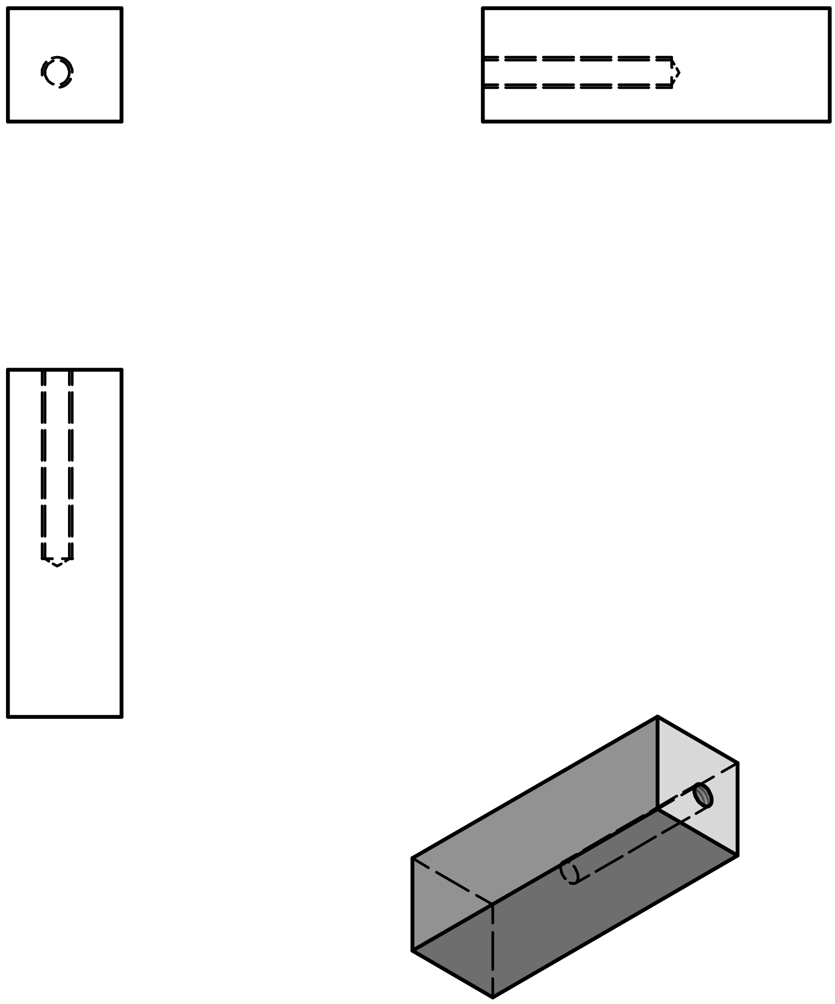

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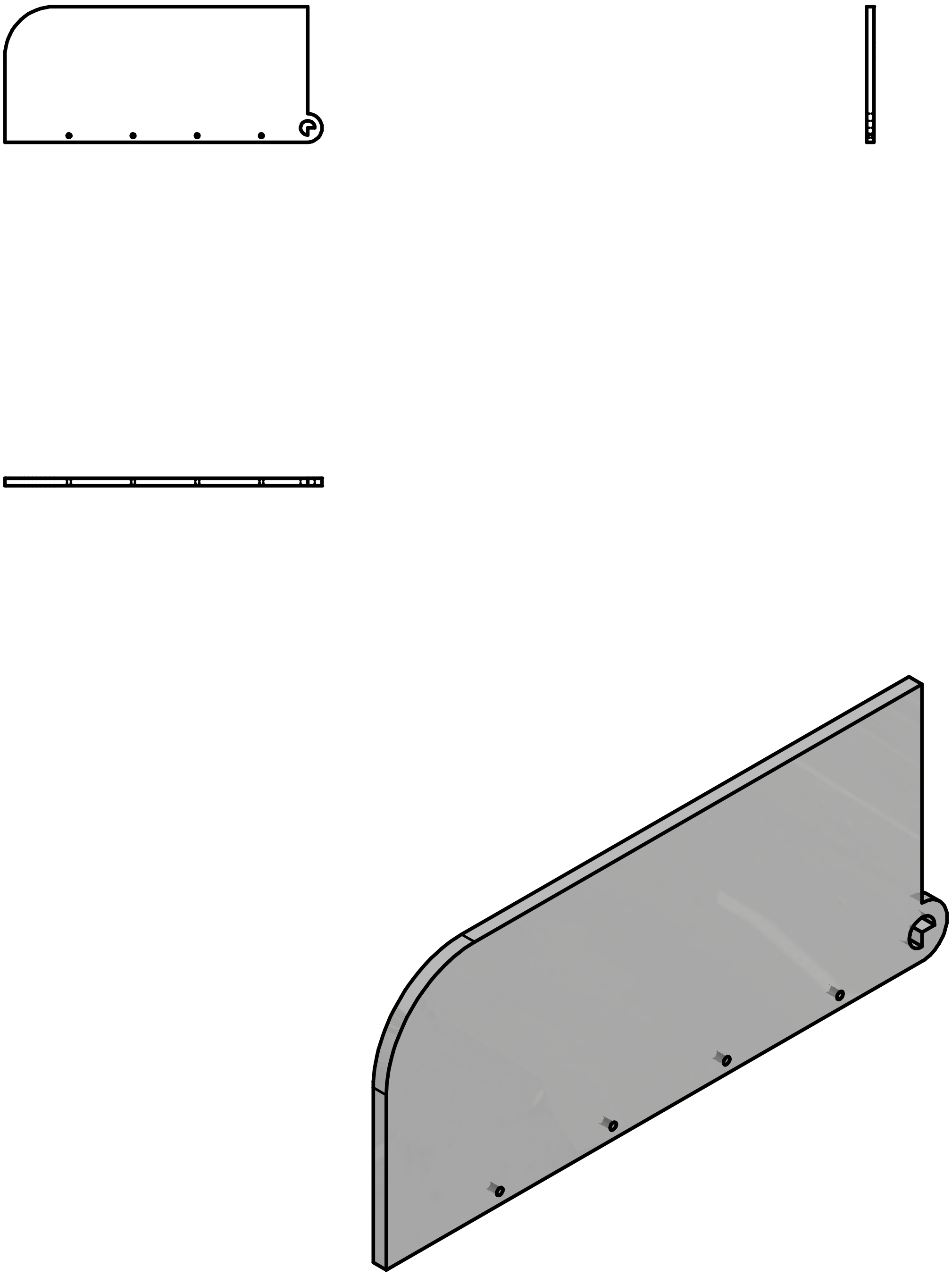

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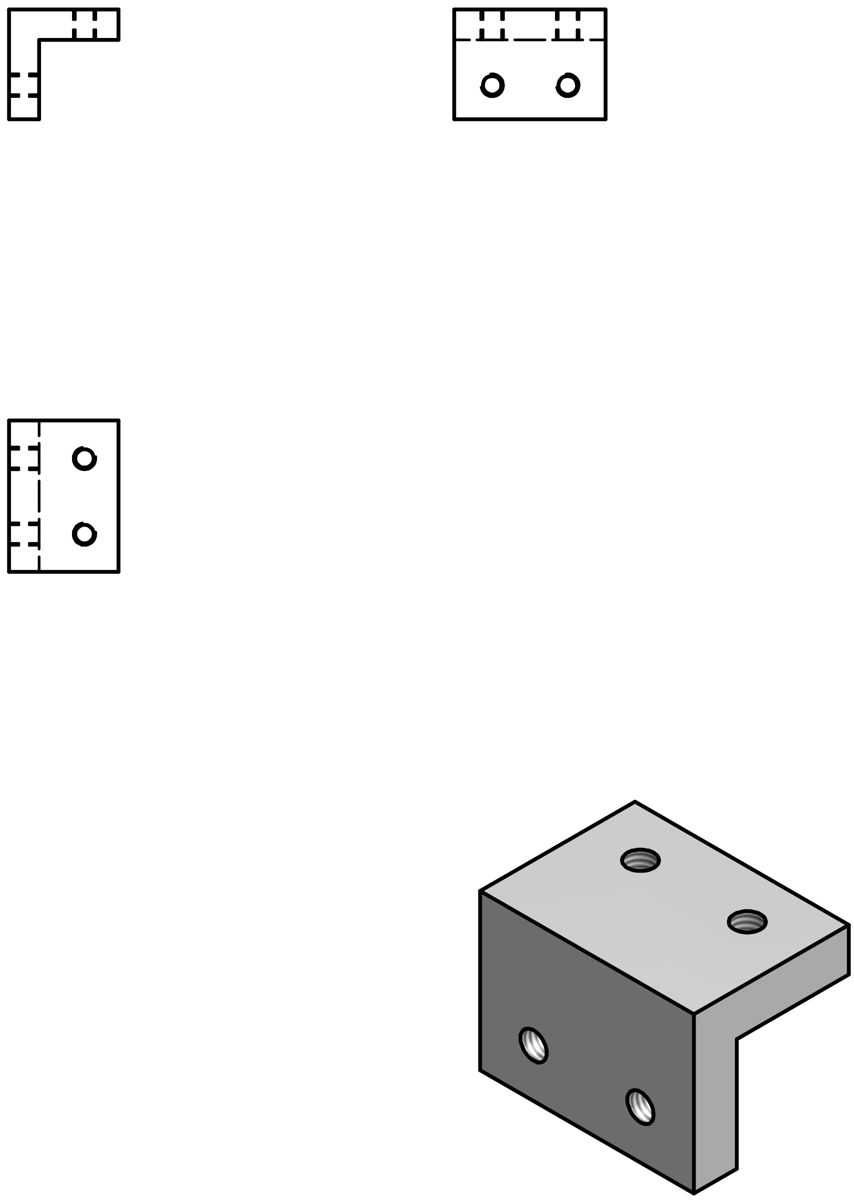

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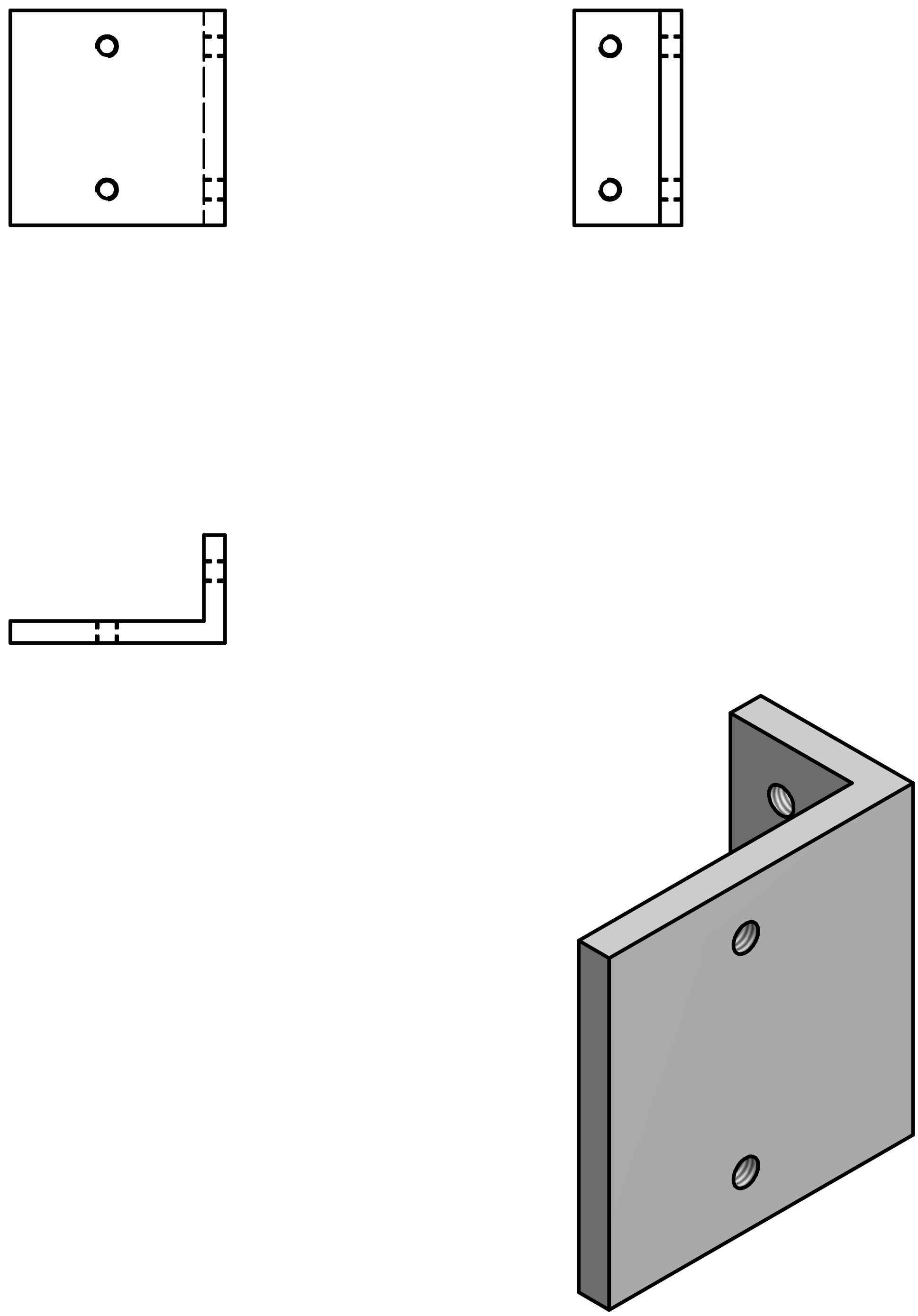

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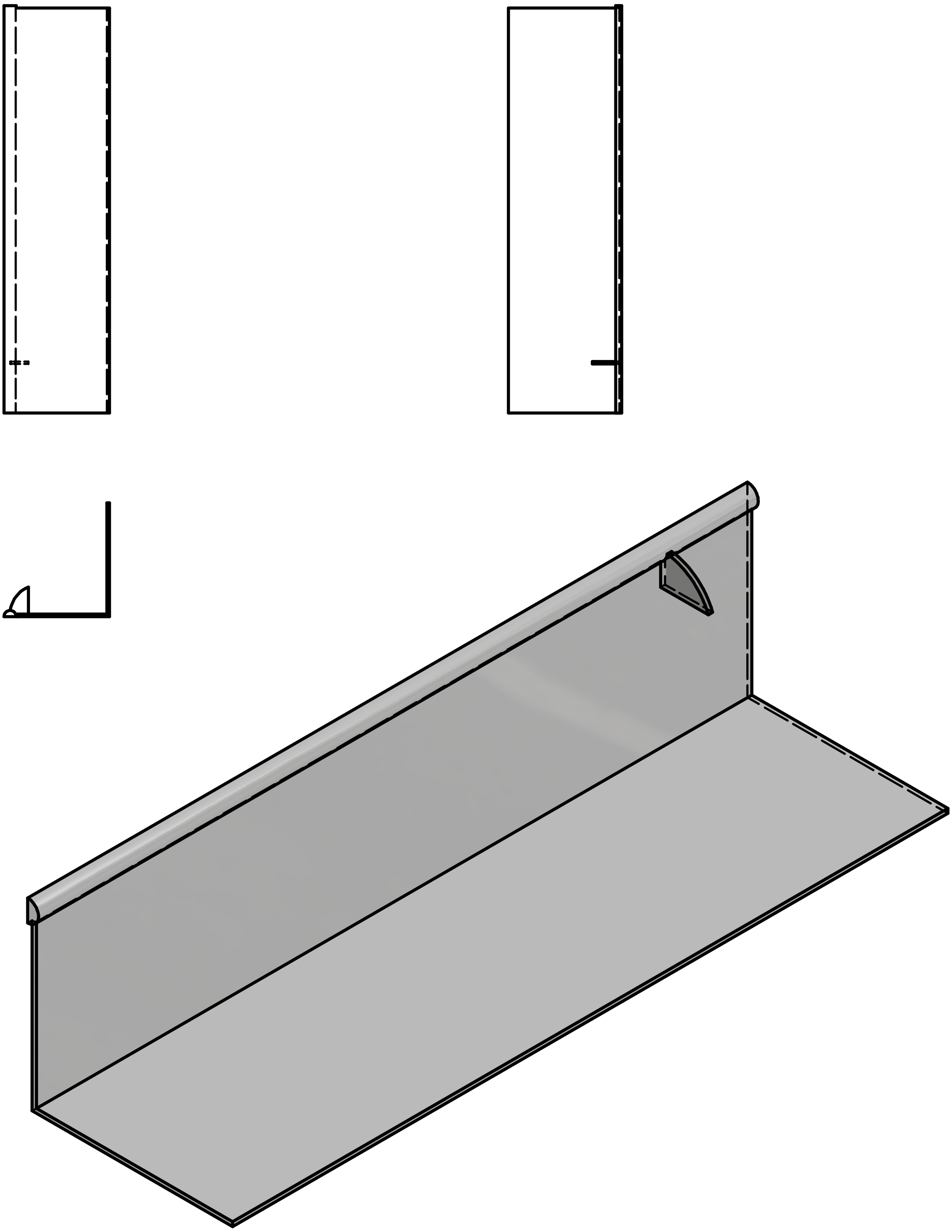

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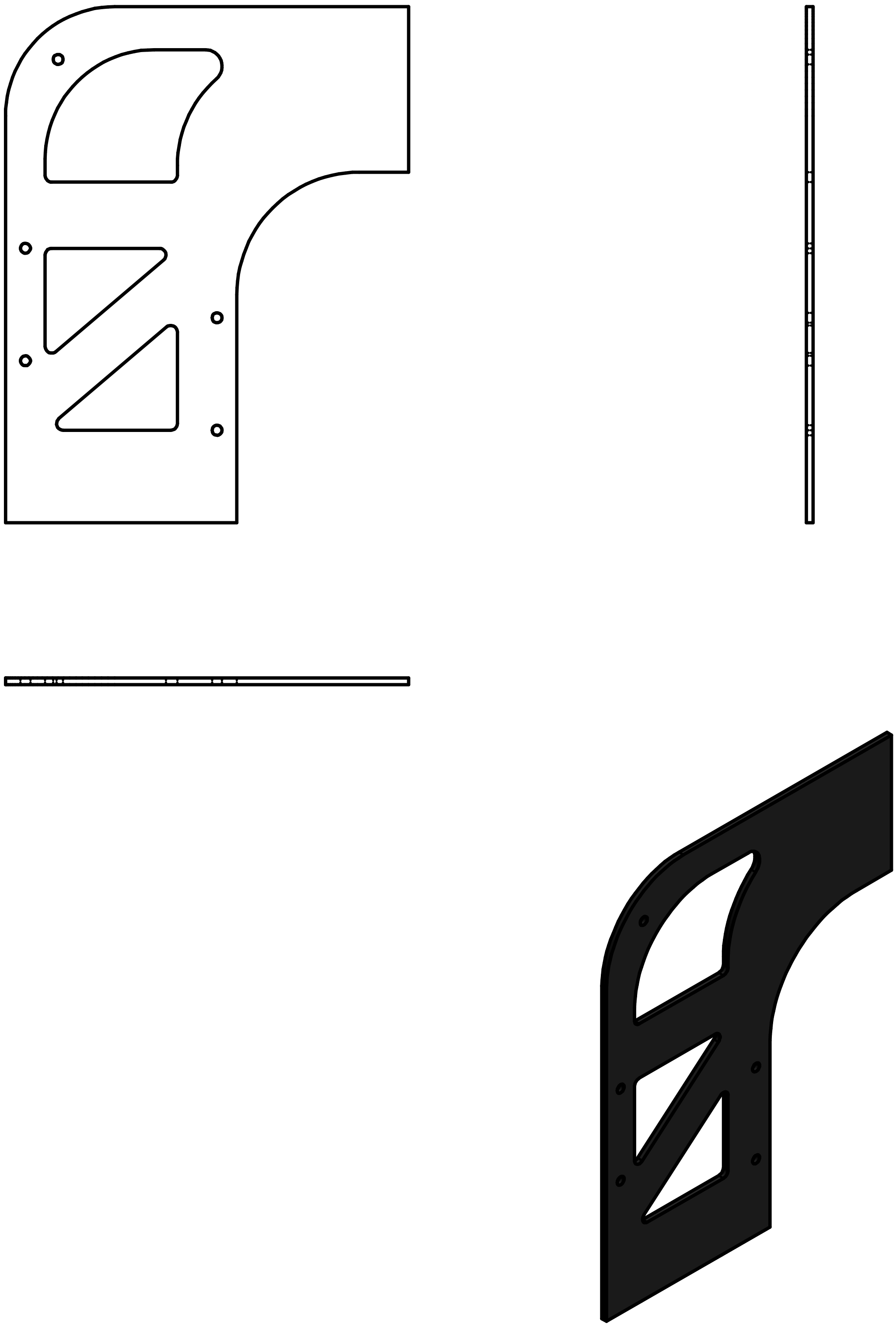

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