KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Murali Obula

QUALITY ANALYSIS OF MICROSTRUCTURE REPLICATED BY MECHANICAL HOT IMPRINT METHOD USING PULSE AND RANDOM EXCITATION

Master's Degree Final Project

Supervisor
Prof. Dr. Arvydas Palevičius
Faculty of Mechanical Engineering
and Design,
KTU, Lithuania.

KAUNAS, 2017

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"Quality Analysis of Microstructure Replicated by Mechanical Hot Imprint Method using Pulse and Random Excitation"

Master's Degree Final Project

MECHANICAL ENGINERRING (621H30001)

Supervisor

(signature) Prof. Dr. Arvydas Palevičius

(date)

Reviewer

(signature) Lect. Dr. Rokas Sakalys

(date)

Project made by

(signature) Murali Obula

(date)

KAUNAS, 2017

KAUNAS UNIVERSITY OF TECHNOLOGY

Mechanical Engineering and Design

(Faculty)

Murali Obula

(Student's name, surname)

Mechanical Engineering, 621H30001

(Title of study programme, code)

"Quality Analysis of Microstructure Replicated by Mechanical Hot Imprint Method using Pulse and Random Excitation"

Final project

DECLARATION OF ACADEMIC INTEGRITY

20 17

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Kaunas

I confirm that the final project of mine, **Murali Obula**, on the subject, **Quality Analysis of Microstructure Replicated by Mechanical Hot Imprint Method using Pulse and Random Excitation** is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources; all direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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Head of Mechanical Engineering Department

____
(Signature, date)

Vytautas Grigas
____
(Name, Surname)

Head of Study Programmes in the Field of Mechanical Engineering

____
(Signature, date)

Kęstutis Pilkauskas
____
(Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT

STUDY PROGRAMME MECHANICAL ENGINERING - 621H30001

Approved by the Dean's Order No. V25-11-20 of December 8th, 2016 y

Assigned to the student **Murali Obula**
____
(Name, Surname)

1. Title of the Project

Quality analysis of microstructure replicated by mechanical hot imprint method using pulse and random excitation

2. Aim of the project

To Analysis Quality of microstructure replicated by mechanical hot imprint method using pulse and random excitation

3. Tasks of the project

1) Literature review of polymers and diffraction gratings manufacturing methods.
2) Analysis of Mechanical hot imprint process.
3) To replicate periodic microstructure according to temperature and pressure with vibroactive pad using pulse and arbitrary excitation
4) To find the maximum diffraction efficiency using laser beam.
5) To show the Quality of microstructure and defects per area on polymer using optical microscope.

4. Specific Requirements

Conducting the final experimental project thesis according to KTU regulations and requirements.

5. This task assignment is an integral part of the final project.

6. Project submission deadline: 2016 December 20^{th}.

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Task Assignment received ____________________________ ______________________

(Name, Surname of the Student) *(Signature, date)*

Supervisor ____________________________ ______________________

(Position, Name, Surname) *(Signature, date)*

MURALI OBULA. **"Quality Analysis of Microstructure Replicated by Mechanical Hot Imprint Method Using Pulse and Random Excitation".** Master's Final Project / supervisor Prof. Dr. Arvydas Palevičius; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study field and area: Technological science, Mechanical engineering

Keywords: Periodic Microstructure; Optical Microscope; Diffraction Efficiency; Vibroactive Pad; Pulse and Arbitrary Wave Frequency; Hot Imprint;

Kaunas, 2017. 49 p.

SUMMARY

Sensors are widely used in bio-sensing of processes, such as analysis of concentration of micro particles in biological environment. Diffraction grating is one of the main optical components of a sensor and It helps in splitting the light into several beams. Diffraction grating is produced by mechanical hot imprint method. In this research study quality of microstructures, created by pulse wave and arbitrary excitation are analysed and compared.

Two types of tests are performed to measure the diffraction efficiency and defects in replicated microstructure, in order to analyse the quality of microstructure. Diffraction efficiency is measured from the data obtained from experimental setup. Defects in replicated microstructure is measured using an optical microscope with CCD camera. vibro-active pad, whose fundament is piezoelectric element, is used to generate high frequency longitudinal vibrations. At the same temperature, pressure and time modes, two types of microstructures are created by Pulse and Arbitrary wave excitations. Laser and photodiode BPW-34 are used to Analysed the diffraction measurements. Dependency of Diffraction efficiency on Diffraction maxima is defined using red and green lasers at different temperatures 148℃, 152℃ and pressures ranging from 1 to 5 Bar. In the end of the paper replicated microstructure are experimentally analysed using already discussed using Diffraction efficiency and Optical microscope parameter. Furthermore, this method does not require expensive or complex developments of the experimental setup and could be applied in most equipments of thermal imprint.

MURALI OBULA, Mikrostruktūrų antrinamų karštu spaudimo būdu naudojant impulsinį ir atsitiktinį žadinimą kokybės analizė, Mechanikos inžinerija / Vadovas Prof. Dr. Arvydas Palevičius; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir plotas: technologijos mokslai, mechanikos inžinerija

Raktiniai žodžiai: Periodinė mikrostruktūros; Optinis mikroskopas; Difrakcijos efektyvumas; Vibroactive bloknotas; Pulsas ir Savavališkas bangų; Karšto Atspaudas;

Kaunas, 2017. 49 p.

SANTRAUKA

Jutikliai yra plačiai naudojami biologiniuose jutimo procesuose, pavyzdžiui mikro dalelių koncentracijos biologinėje aplinkos analizėje. Difrakcinė gardelė yra vienas iš pagrindinių jutiklio optinių komponentų, ji išskaido šviesą į keletą pluoštų. Difrakcinė gardelė yra gaminama terminio spaudimo metodu. Šiame darbe yra analizuojama ir lyginama mikrostruktūros kokybė, kuri pagaminta naudojant pulsinį ir atsitiktinį žadinimą proceso metu.

Dviejų tipų bandymai atliekami matuojant difrakcijos efektyvumą ir defektus atkartotose mikrostruktūrose, siekiant išanalizuoti mikrostruktūros kokybę. Difrakcinis efektyvumas yra matuojamas pagal duomenis, gautus naudojant eksperimentinę įrangą. Defektai yra matuojami naudojant optinį mikroskopą su CCD kamera. Vibropadas, kurio pagrindas yra pjezoelektrinis elementas, yra naudojamas generuoti aukšto dažnio išilginius virpesius. Esant tai pačiai temperatūrai, slėgiui ir laiko režimams, yra pagamintos dviejų tipų mikrostruktūros naudojant pulsinį ir atsitiktinį žadinimą. Lazeris ir fotodiodas BPV-34 yra naudojami difrakcijos efektyvumo matavimams. Optinio įspaudo techniniai parametrai ir termiškai atkartotos mikrostruktūros kokybė yra nustatomi naudojant raudonos ir žalios šviesos lazerius, esant skirtingoms temperatūroms 148 ℃, 152 ℃ bei slėgiams nuo 1 iki 5 bar. Darbo pabaigoje atkartota mikrostruktūra yra eksperimentiškai analizuojama atsižvelgiant į naudotą pulsinį ar atsitiktinį žadinimą. Be to šis metodas nereikalauja brangios ar sudėtingos įrangos ir gali būti taikomas daugeliui terminio spaudimo įrenginių.

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INTRODUCTION

Polymer microfabrication strategies have become more and more vital as affordable alternatives to the semiconducting material or glass-based MEMS technologies. chemical compound hot embossing and injection moulding square measure replication strategies applicable to micro replication of a diversity of materials and microstructures. The replication of chips consists of microchannel for microfluidic device, micro optical elements, micro reactors and capillary electrophoresis. In materials chemical compound microstructure of stable and duplicate with structural and optical properties meeting different biocompatibility and need detection. the method involves few variable parameters and leads to high structural accuracy fitted to good vary of microfabrication application.

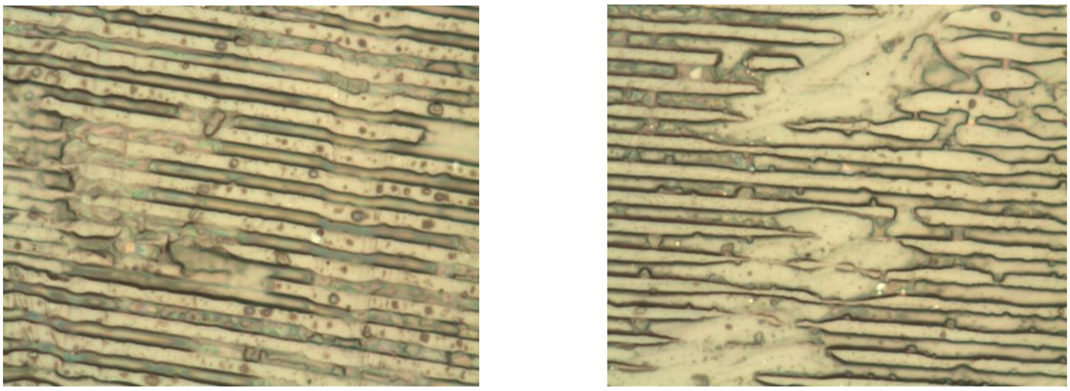
Typically, potential of hot imprint technology like low price, straightforward execution and talent to get enhance the talent resolutions area unit the explanation to analysis, establish and apply such as producing capabilities. The mechanical hot imprint following major steps based on fundamental principle; initial of the all compound substrate is heated on top of its glass transition temperature. Then a mould or master is ironed against the polycarbonate. At the end of process, the system is cooled below glass transition temperature and also polycarbonate is demoulded from the tool.

Hot embossing may be a microstructure formation technique, used for acquisition microstructures on a substrate, victimisation preheated master mildew. It consists from following steps. initial of all chemical compound is being preheated till chemical compound glass transition temperature (Tg), this enables minimize the force, needed to deform the chemical compound. Then, the chemical compound is being imprinted with the required imprint with specific imprint force, at the temperature, below that it behaves fluid-like. Finally, the mildew is being withdrawn from the surface of chemical compound On the alternative hand there is necessity to review the possibility of formed microstructure potential defects, which could occur as a result of the results of fabric melting and cathartic of the structure from the mould. These defects embody material shrinkage, visible cracks, etc. one in each of the ways that within which to spice up the quality of replicas square measure typically usage of high-frequency vibrations inside the strategy of mechanical hot imprint. supersonic vibrations unit wide applied in industrial processes, significantly in fastening and affiliation of thermoplastic with low softening temperature.

1. LITERATURE REVIEW

1.1 PERIODIC MICROSTRUCTURE

Quality of Microstructure are important parameter in the Optical parameter. Especially in Diffraction Gratings Quality of Periodic structure consider as significant parameter. Replication method are used to manufacturing the Diffraction Gratings example using Injection moulding are Replicated the microstructure after replication there is some defects, shrinkages and due to Pressure Variation Quality of Microstructure Are Replicated as well.



(a) (b)

Figure 1.1 (a) defects of Periodic Microstructure (b) Due to high pressure melted materials

There are many methods for complex microstructure creation. Using computer generated hologram technique is one of them. Computer generated hologram creation is based on complex mathematical algorithms. The most important factor is the quality and low cost.

The quality of the replicas is the main problem of all replication technological processes. The requirements for mass manufacturing include resolution, overlay accuracy, and economy. The quality replicas were improved using high-frequency vibration in mechanical hot imprint process and it makes better diffractive efficiency of optical element. Improving the quality of replica by high-frequency vibrations makes possible to create the complex micro/Nano level optical elements (DOE) with better optical properties and higher resolution and enables to use them in bio-medical, micro optics, micro-fluidic devices, electronics, micro-electro-mechanical systems (MEMS), etc.

1.2 ELECTROACTIVE POLYMERS:

Electroactive polymers area unit one in every of the foremost promising technologies. Compared to inorganic materials the versatile polymers have numerous enticing properties, like being light-weight, cheap and straightforward to manufacture. Tremendous quantity of analysis and development has diode to Electroactive Polymers (EAP) which will additionally modification size or form once stirred by the proper external electrical activation mechanism, which means they'll convert power into energy. particularly within the actuators phase activity are often seen for specialised applications like medical devices and biomimetic-robotics. Here the options of electroactive polymers area unit accustomed change movement and generate force furthermore as electrically aerofoil properties. Haptics for client transportable bit screen devices and peripherals goes to be future huge application and doubtless the primary large-scale implementation of EAP actuators normally with an expected penetration of hr for tactile feedback in mobile phones for 2018. Today, EAPs area unit on the market that turn out giant strains and show nice potential for applications. as compared to solely tiny response within the early development years' electroactive polymers show important deformation within the vary of 2 to a few orders of magnitude.

1.2.1 POLYCARBONATE (PC):

Polycarbonates area unit long-chain linear polyesters of acid and dihydric phenols, like biphenyl A. Before beginning to list properties of polycarbonate, it's most likely knowing make a case for why the properties area unit the manner they're. First, the technical stuff. Take a glance at the on top of diagram. In it, you'll see 2 six-sided structures. These area units referred to as phenyl teams. you'll additionally see 2 teams known by the label CH3. These area unit methyl radical teams. The presence of the phenyl teams on the molecular chain and also the 2 methyl radical aspect teams contribute to molecular stiffness within the polycarbonate. This stiffness encompasses a giant result on the properties of polycarbonate. First, attraction between of the phenyl teams between totally different molecules contributes to a scarcity of quality of the individual molecules. This ends up in sensible thermal resistance however comparatively high consistence (i.e., low soften flow) throughout process. The inflexibility and also the lack of quality stop polycarbonate from developing a major crystalline structure. This lack of crystalline structure (the amorphous nature of the polymer) permits for light-weight transparency.

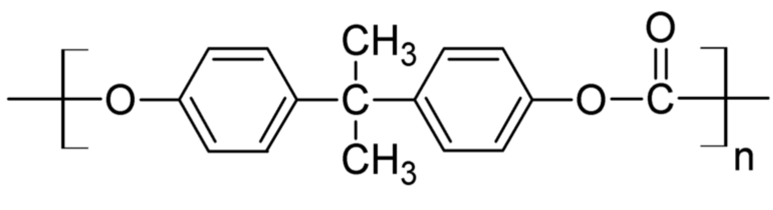


Figure 1.2 Polycarbonate formula [6]

Now for the clearer, less technical version of the properties. Polycarbonate is naturally transparent, with the ability to transmit light nearly that of glass. It has high strength, toughness, heat resistance, and excellent dimensional and colour stability. Flame retardants can be added to polycarbonate without significant loss of properties.

Thermal properties of polycarbonate

- Melting temperature (Tm) 267◦C
- Glass transition temperature (Tg) 150◦C
- Heat deflection temperature - 10 kN 145◦C
- Heat deflection temperature 0.45 MPa 140◦C
- Heat deflection temperature - 1.8 MPa 128–138◦C
- Upper working temperature 115–130◦C
- Lower working temperature −40◦C
- Linear thermal expansion coefficient 65–70×10−6/K
- Specific heat capacity 1.2–1.3 kJ/(kg·K)
- Thermal conductivity 23◦C 0.19–0.22 W/(m·K).

Mechanical properties of polycarbonate

- Young's modulus 2.0–2.4 GPa
- Tensile strength 55–75MPa
- Compressive strength >80 MPa
- Poisson's ratio 0.37
- Coefficient of friction 0.31

The general properties can be summarized as follows:

- excellent physical properties
- excellent toughness
- very good heat resistance
- fair chemical resistance
- transparent
- moderate to high price fair processing.

Application of polycarbonate:

It can be injection moulded, blow moulded, and extruded and is an ideal engineering plastic with good electrical insulating properties, finding applications in electric meter housings and covers, casket hardware, portable tool housings, safety helmets, computer parts, and vandal-proof windows and light globes. The price of polycarbonate restricts its use to mainly engineering applications.

Other engineering applications include the following:

- equipment housings
- exterior automotive components
- outdoor lighting fixtures
- nameplates and bezels
- non-automotive vehicle windows
- brackets and structural parts
- medical supply components
- plastic lenses for eyeglasses

1.2.2 POLYVINYL CHLORIDE (PVC):

Polyvinyl chloride, usually all are called as PVC. the more accurately yet strangely poly (vinyl chloride), is the world's third-most broadly delivered manufactured plastic polymer, after polyethylene and polypropylene.

PVC comes in two essential structures: inflexible (at times abridged as RPVC) and adaptable. The inflexible type of PVC is utilized as a part of development for pipe and in profile applications, for example, entryways and windows. It is additionally utilized for containers, other non-sustenance bundling, and cards, (for example, bank or enrolment cards). It can be made gentler and more adaptable by the expansion of plasticizers, the most generally utilized being phthalates. In this shape, it is additionally utilized as a part of pipes, electrical link protection, impersonation cowhide, signage, inflatable items, and numerous applications where it replaces elastic.

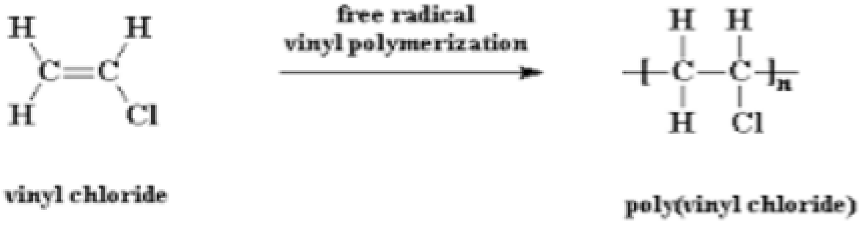


Figure 1.3 The polymerisation of vinyl chloride [6].

What is PVC utilized for?

The differing qualities of PVC applications challenges the creative ability. In regular daily existence, they are surrounding us. PVC is utilized for everything from development profiles to medicinal gadgets, from material films to Visas, and from youngsters' toys to funnels for water and gas. Couple of different materials are as flexible or ready to satisfy such requesting particulars. Along these lines, PVC encourages innovativeness and advancement, making new potential outcomes accessible consistently.

Why use PVC?

Just in light of the fact that PVC items make life more secure, bring solace and happiness, and ration characteristic assets and battle environmental change. Also, because of a brilliant cost-execution proportion, PVC permits individuals of all wage levels access to these essential advantages.

How does PVC add to a more secure world?

There are many reasons why PVC and wellbeing are indistinguishable. Because of magnificent specialized properties, PVC is the most utilized material forever sparing, expendable, restorative gadgets. For example, restorative tubing of PVC does not crimp or break and is anything but difficult to clean.

As a result of natural imperviousness to fire, wire and links sheathed with PVC counteract possibly lethal electrical mishaps.

Encourage, PVC is a solid material. At the point when utilized for auto parts, PVC in this way decreases the danger of wounds if there should arise an occurrence of mishaps.

How does PVC save regular assets and battle environmental change?

Since PVC is inherently a low-carbon material which expends less essential vitality than numerous different materials and is anything but difficult to reuse.

Likewise, most PVC items are durable and require at least support and repair. For example, the administration life of PVC water and sewage channelling is over 100 years. Furthermore, current autos last numerous years longer essentially on the grounds that PVC shields the underside from water and consumption.

Physical Properties:	Value:
Tensile Strength:	2.60 N/mm^2
Notched Impact Strength:	2.0 - 4.5 KJ/m^2
Thermal Coefficient of Expansion:	80 x 10^{-6} $W/(m^2K)$.
Max. Continued Use Temperature:	60 ^oC (140 ^oF)
Melting Point:	212 ^oC (413 ^oF)
Glass Transition Temperature:	81 ^oC (178 ^oF)
Density:	1.38 g/cm^3

Table 1.1 physical properties of PVC [6]

1.3 INJECTION MOULDING

Injection moulding may be a method within which a compound is heated to an extremely plastic state and made to flow beneath high into a mold cavity, wherever it solidifies. The wrought half, known as a molding, is then aloof from the cavity. the method produces distinct elements that square measure nearly always internet form. the assembly cycle time is often within the vary ten to thirty seconds, though cycles of 1 minute or longer aren't uncommon. Also, the mould could contain quite one cavity; so multiple moldings square measure created every cycle.

Complex and complicated shapes square measure potential with injection molding. The challenge in these cases is to style and fabricate a mould whose cavity is that the same pure mathematics because the half and that additionally permits for half removal. half size will vary from concerning fifty g (2 oz.) up to concerning twenty-five kilos (more than fifty lb), the higher limit portrayed by elements like icebox doors and automobile bumpers. The mould determines the half form and size and is that the special tooling in injection molding. for big advanced elements, the mould will price many thousands of bucks. for tiny elements, the mould are often engineered to contain multiple cavities, additionally creating the mould costly. Thus, injection molding is economical just for giant production quantities.

Injection molding is that the most generally used molding method for thermoplastics. Some thermosets and elastomers square measure injection wrought, with modifications in instrumentation and operational parameters to permit for cross-linking of those materials.

Established technologies like injection moulding, injection compression moulding and hot embossing area unit wide utilized in micro-scale replication. Hot embossing is changing into a promising producing method, that dead suits for manufacturing precise microstructures with high side ratios and low distortions. The injection mildewing method involves the injection of a soften chemical compound into a mold wherever the soften cools and solidifies to make a plastic half. This method includes a 3 phases: filling, packing and cooling. the merchandise is ejected from the mildew once the cavity becomes stable.

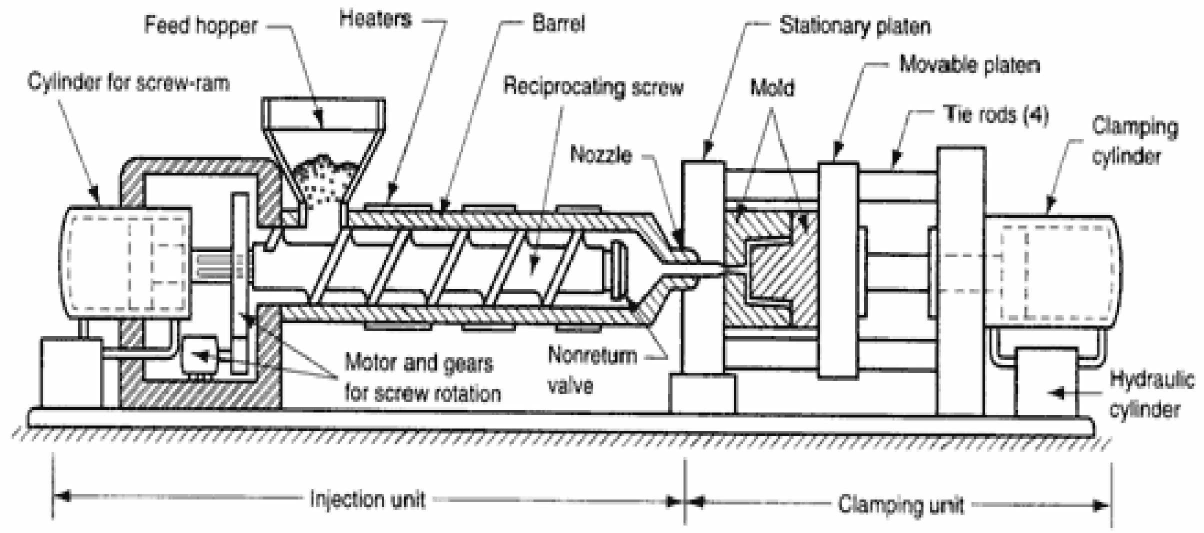


Figure 1.4 Schematic diagram of an injection moulding equipment [12].

Injection moulding could be a producing method for manufacturing plastic injection mold from each thermoplastic and thermoset plastic materials. Material is fed into a heated barrel, mixed, and made into a mould cavity by a reciprocal screw or a ram convenience, wherever the injection formed half cools and hardens to the configuration of the mould cavity. when a district is intended, typically by Associate in Nursing industrial designer or Associate in Nursing engineer, moulds area unit then factory-made by Associate in Nursing injection mold company, wherever it's appointed to a mould maker (or toolmaker). Injection mold area unit typically created exploitation either steel or metal, and precision-machined to make the options of the specified components. Injection moulding is wide used for producing a spread of components, from the tiniest part to entire body panels of cars. Injection moulding is that the commonest technique of production, with some unremarkably created injection formed things as well as laptop parts to out of doors article of furniture

Injection compression moulding may be a combination of injection moulding and hot embossing (Fig.1.4). initial of all, the compound is liquefied consistent with the quantity of the formed half and is then injected into a mildew that's not part opened. owing to the gap between the mildew halves the injection may be performed with comparatively lower pressure, these leads to a reduced shear rate and shear stress of the compound soften. once the injection halves shut. This compression stage is split into a velocity-controlled motion and, if the specified press force is earned, during a force-controlled holding of the ultimate clamp force over a certain cooling time.

1.4 ATOMIC FORCE MICROSCOPY

The atomic force microscope (AFS) is one kind of scanning probe microscope (SPM). Which is used to measure the properties, such as height, friction, magnetism, with a probe. To acquire an image, the SPM raster-scans the probe over a small area of the sample, measuring the local property simultaneously.

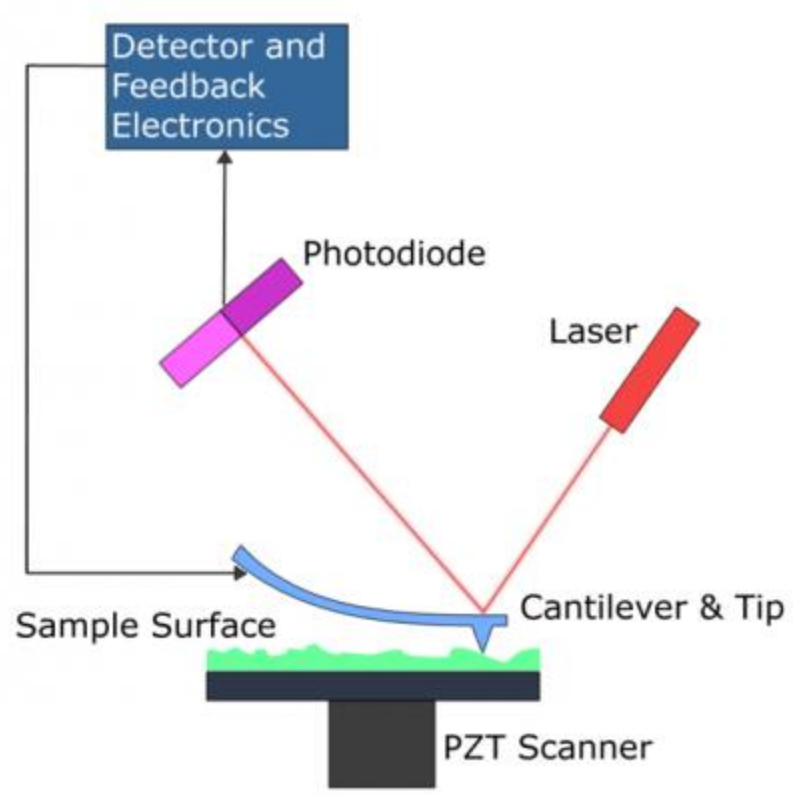
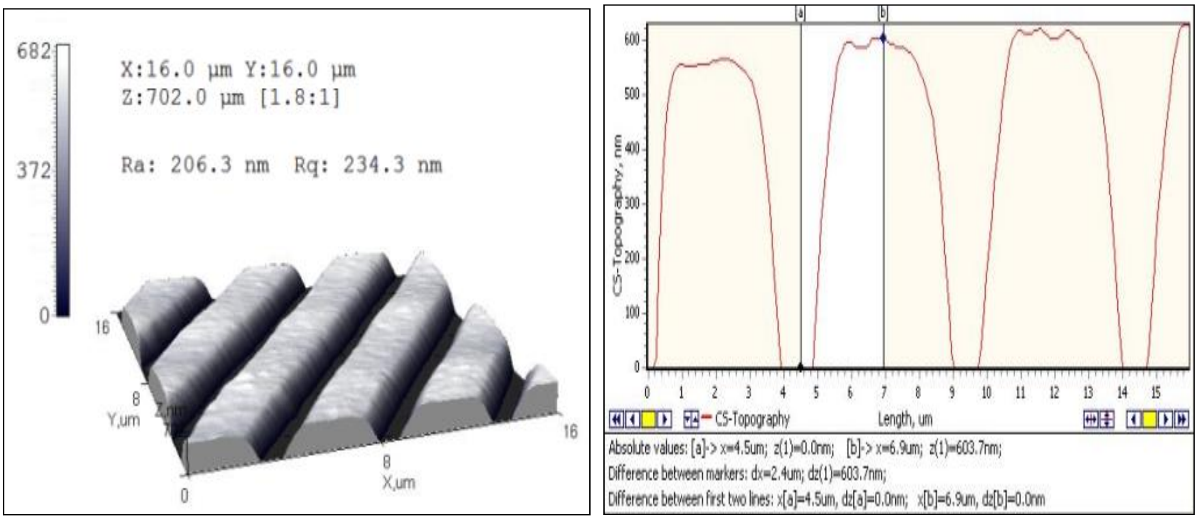


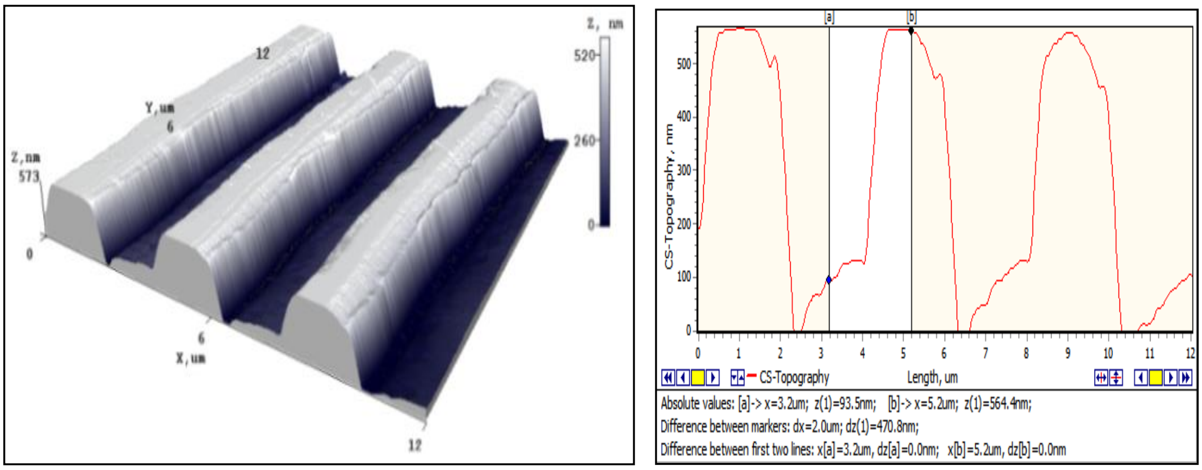
Figure 1.5 Atomic Force Microscope [16]

Atomic force microscope NANOTOP-206 is used to analytical evaluation of geometrical parameters of surface of replicated periodic microstructure was performed. Using this method investigation, the surface of the polycarbonate which show profile of surface parameters like maxima and average height etc.



(a) (b)

Figure 1.6 (a) 3D view of master periodic microstructure, (b) the profile view of original periodic macrostructure [21]



(a) (b)

Figure 1.7 (a) 3D view of replicated periodic microstructure, (b) the profile view of replication periodic macrostructure [21].

1.5 APPLICATION OF GRATINGS:

Optical interconnects

Because the quality and speed of integrated circuits and laptop systems increase, there's a trade-off between the length of a wire signal path and also the bandwidth supported by those ways. Optical interconnects don't exhibit this trade off and within the future can probably replace metal wiring for long interconnects. Researchers have conjointly shown that optical interconnects give blessings over electrical interconnects in terms of fan-out, energy conversion, latency, and electromagnetic interference immunity. many researchers have enforced diffractive grating couplers because the coupling part for optical interconnect systems. optical phenomenon gratings area unit fascinating as a result of they're a lot of compact than alternative coupling schemes.

Integrated Optical Devices

optical phenomenon gratings conjointly notice Associate in Nursing application in integrated optical devices. Integrated optical devices decide to accomplish an equivalent task as bulk optics, but on a compact and integrated scale. Some samples of diffractive integrated optical devices area unit beam expanders, polarization dependant devices, and holoFigureic filters for beam intensity profile reshaping. alternative integrated optical devices with applications to laptop systems area unit optical read/write heads, grating coupled surface emitting lasers, optical sensors, and printer heads.

Fiber Optical Communications

Another space during which optical phenomenon gratings have found application is in fiber optical communications. Optical communications over fiber optic links have potentially massive bandwidths and skill low loss for long distances. One advance within the information measure of optical communications is wavelength division multiplexing. Wavelength division multiplexing and dense wavelength division multiplexing need devices that area unit sensitive to wavelength for interacting with slender wavelength communication channels. optical phenomenon gratings have the potential to play a vital role during this arena. Some optical device devices that have been incontestable by researcher's area unit Bragg gratings for wavelength division multiplexing and optical filters.

Gratings for Industrial Applications:

Gratings manufacturing procedures to create diffraction gratings that are utilized as a part of an assortment of modern applications. These built up procedures are improved to guarantee high volume creation limit and the normal level of modern part quality, at focused costs.

Our gratings are copies which offer predictable optical execution that is regularly fundamental for mechanical applications, where similar item is made for a long time. It likewise permits more adaptability to coordinate the scope of expected natural conditions (temperature, moistness and so on.). In spite of the fact that we have a standard scope of gratings we can likewise redo these to offer diverse sizes or coatings. Get in touch with us to examine your particular necessities.

Our gratings are commonly utilized as a part of Biomedical gadgets, HPLC frameworks, Telecommunication dynamic & uninvolved modules, Sensing gear, Control prepare screens, Laboratory spectroscopy frameworks, Colour examination instruments, Lasers, Life science items, Photovoltaic generation and control machines, Mineralogy controllers, Analytical science application, to give some examples.

Telecommunication Gratings:

Telecom applications require gratings with:

- very low polarization subordinate misfortune (PDL)
- high diffraction productivity
- high grinding to grinding repeatability
- insensitivity to extraordinary ecological conditions

A telecom producer of tenable wavelength items has decided that recreated gratings for thick wavelength-division multiplexers (DWDM) surpass Bell core 1221 prerequisites while giving a more practical and more repeatable arrangement than ace holoFigureic gratings. At holoFigurey, we deliver superb imitations, as well as the experts required for reproduction generation.

RELEVANT WORK

The literature analysis shows diffraction efficiency is low due to defects in the periodic microstructure replicated on polycarbonate. The material behaviour in the mechanical hot imprint process involves that due to variation of pressure and temperature deformation takes place on the thermoplastic materials. As a results the behaviour of materials leading to critical in the experimentally process and it is costly. The variation of temperature and strain rate lead to damage because materials are highly sensitive. Furthermore, practical values are calculated to essential to increase the limits of mechanical hot imprint to smaller length scales where precision id critical. The quality of microstructure replicated using with pulse wave excitation and arbitrary wave excitation according to temperature 148℃ and 152℃, and pressure 1 bar, 2 bar, 3 bar, 4 bar, 4 bar, 5bar and time is 10 seconds. the filling ratio of the polymer in mechanical hot imprint process based on Heating, imprinting, and demoulding steps in hot imprint process are investigated in detail calculated Diffraction Efficiency and Periodic Microstructure.

To Analysis Quality of microstructure replicated by mechanical hot imprint method using pulse and arbitrary excitation.

1. Literature review of polymers and diffraction gratings manufacturing methods.
2. Analysis of Mechanical hot imprint process.
3. To replicate periodic microstructure according to temperature and pressure with vibroactive pad using pulse and arbitrary excitation

4. To find the maximum diffraction efficiency using laser beam.
5. To show the Quality of microstructure defects per area on polymer using optical microscope.

2. ANALYSIS OF HOT IMPRINT PROCESS

2.1 EXPERIMENTAL SETUP OF MECHANICAL HOT IMPRINT PROCESS

Polymers are solid and fluid state. which are used in replication process. The polymers were used for CGH formation by Electron Beam Lithography technology. This kind of polymer (polycarbonate) were used in the experimental studies of hot imprint process. Their properties are mentioned above in the section 1.2.1.

Semiconductors (especially silicon), silicon dioxide (glass and quartz) and polymer are the most common materials for substrate of polymers. Silicon is cheap and available in different sizes with different properties. Silicon is used as the main material of the substrate for micro resist polycarbonate.

The experimental setup is used to replicate the diffraction gratings to make standard optimisation of microstructure which are replicate on the polymers using high frequency wave excitation within mechanical hot imprint method. Hot imprint is that the operation with high accuracy in replicating micro-features. the value of the embossing tools is comparatively low, thanks to this it's in widespread producing method. the extra tool generating high frequency vibration was created and utilized in the recent imprint method, that projectile properties were investigated victimization holo Figure interferometry technique. the recent imprint experiments were conducted on polycarbonate with variations in temperature, pressure, and imprint times. The comparative analysis of microstructure quality assessment (with and while not the usage of high frequency vibration) is given. because it is showed in following sections, the mechanical hot imprint with high frequency vibration methodology depends on mechanical and electrical characteristics of the fabric, vibration frequency, and voltage.

2.2 Equipments for Mechanical Hot Imprint Process

Diffraction gratings are manufacturing using different technique the wide range of application from macro to nanometre scales. The mechanical hot imprint technique is imprinting the microstructure on the polycarbonate using a master mold. Which is the enough technique to replica in order to best quality of microstructure with high frequency vibration are the technique which technique could use in order to make the best quality replica in mechanical hot imprint method.

Due to the behaviour of materials state changes in the mechanical hot imprint is different technology technique. Initially the mold is being heated regarding temperature. Once the microstructure is being replicated into polycarbonate. The polycarbonate was compressed with high range of pressure in the mechanical hot imprint process. Polycarbonate is plastic, so after released the pressure polycarbonate remains deformed.

The hot imprint scheme consists of main parts

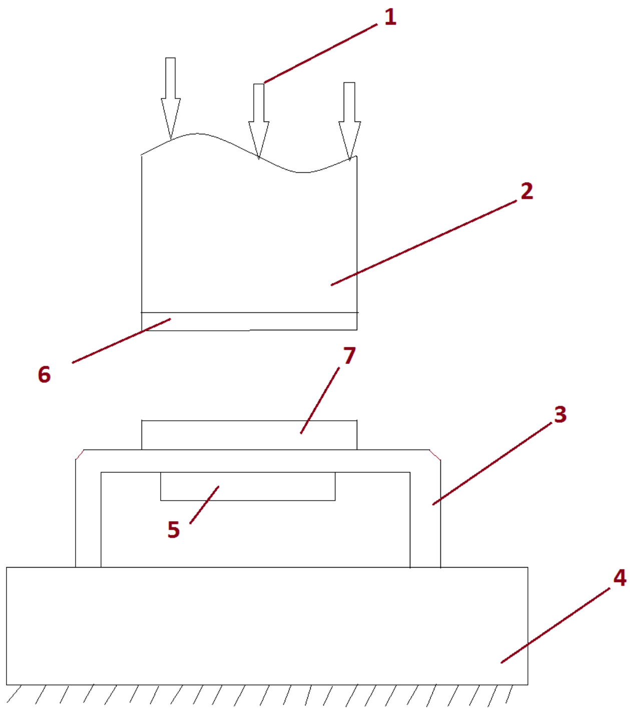


Figure 2.1 The schematic diagram of the hot imprint device: 1) Pressure and temperature, 2) head of the press, 3) the vibrating platform, 4) the base of the tool, 5) piezoelectric material, 6) the master structure, 7) glass coated by the polymer.

The manufacturing of grating with high quality on polycarbonate showing the figure 2.2 according to the companies characterised by the methods and technical achievements was designed in the MMI. The hydraulic hot imprint device was used for hot imprint experiment. The high frequency of vibration is connected to the hot imprint. The experiment setup of mechanical hot imprint is shown in the figure 2.2

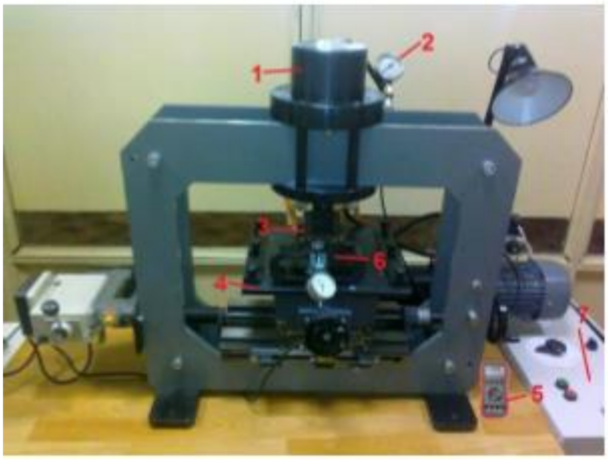


Figure 2.2 Hot imprint device: hydraulic hold (1), gauge of pressure (2), mold horn (3), controlled stage (4), thermometer (5), dynamometer (6), and control block of temperature, time, and pressure (7).[17]

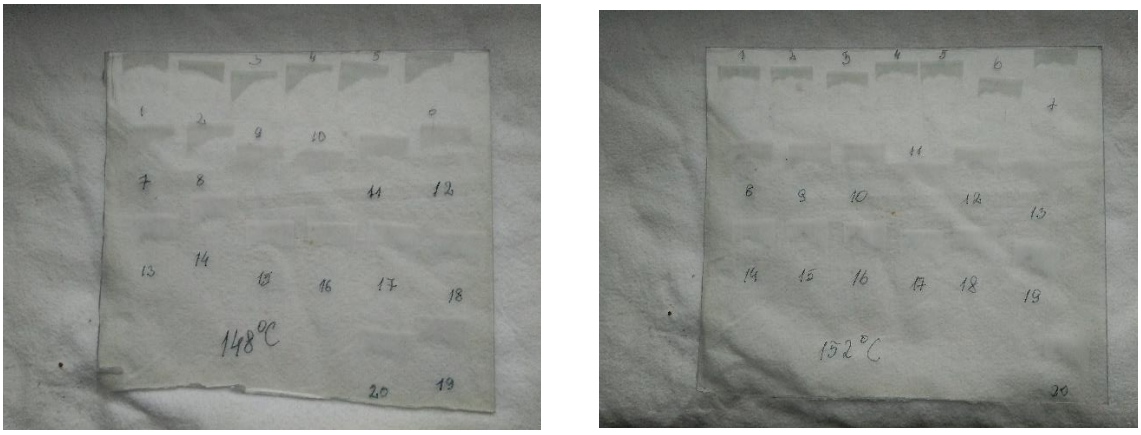
The main parameters of hot imprint device are presented in the Table 2.1

Range of temperature	20 -200℃
Range of pressure	$0 – 10^6$ N / m^2
Horn measurement	2 cm * 2 cm

Table 2.1 Parameter of Hot Imprint device. [17]

Many researchers evaluating the big variety of parameters, properties developed mathematical models supported finite part methodology. looking on the materials, their properties, temperature, resolved issues, a spread form of material models mathematical model are used for the new imprint method.

Polymers, looking on the temperature are often classified into 3 states: glass, semi-molten, and flow (Worgull et al., 2010). The temperature vary is that the answer to the question, that material model to be thought-about. Material properties and parameters typically are unknown. throughout the event of mathematical model researchers use the results, obtained by experimentation, or on the contrary – primarily the model is formed, by establishing parameters and material properties, throughout to be custom-made within the experiment. The polycarbonate material shown in the below figure.



(a) (b)

Figure 2.3 Polycarbonate sample, temperature at (a) 148℃ (b) 152℃

3. REPLICARION OF MICROSTRUCTURE

3.1 REPLICATION PROCESS

the secrete of the industrial success of chemical compound small fabrication in microfluidics lies within the establishment of a low cost manufacturing process. replication technologies are sensible for this application as a result of the principles behind these methods are already standard within the macro-world and within the case of injection molding, represent a regular technology foe microscopic chemical compound part producing. the underlying principles is that the replication of a micro-fabricated mould tool, that represents the negative structure of the specified chemical compound structure. the (expansive) small fabrication step is thus solely necessary once for the fabrication of this master structure, that then is replicated repeatedly into the chemical compound substrate. additionally, to the value benefits, this replication additionally offers the good thing about the liberty of style the master is fictional with an oversized variety numerous} small fabrication technologies that permits various geometries to be accomplished.

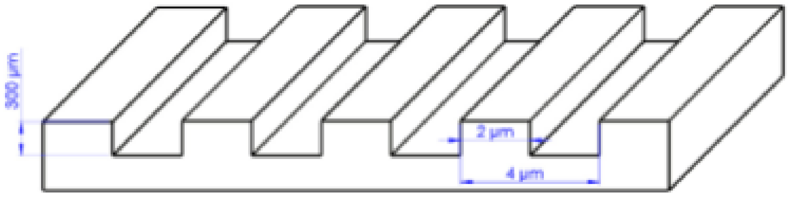


Figure 3.1 Schematic drawing of master periodic microstructure.

Duplicated Optics accomplish high optical exactness and resistances while understanding various advantages, especially bring down expenses and lessened many-sided quality. Suited to applications requiring anyplace from just a couple, to hundreds or even a large number of exactness optical segments, Replicated Optics incorporate mirrors of about any surface shape or abundancy gratings, and with a scope of coatings and substrates.

The replication fabricating process produces parts with a small amount of the handling time contrasted with traditional crushing and cleaning, yet holds the high exactness connected with granulating and cleaning. Besides, repeated optical parts can regularly fuse their own particular mounting gaps and tabs, an extra wellspring of critical cost, size, and weight investment funds for OEMs.

3.2 Replication Process Works

Once the optical outline for the OEM application is tried in model frameworks and settled, replication starts with assembling of an "ace". The ace is created utilizing average customary machining, pounding, and cleaning strategies. Except for recreating level surfaces, the ace is really a negative of the last segment since replication is a duplicating procedure where the last parts are made utilizing the ace as a device.

The ace is then tried and met all requirements to affirm that parts produced using it will meet the prerequisites of the application. Surface exactness and radii must be being confirmed to client particulars utilizing a laser interferometric measuring framework, profilometer, or other measuring framework relying upon the optic setup.

Once the ace is approved, a discharge specialist is connected to the ace is ab initio lined with a discharge operator to empower easy partition of the recurrent section toward the finishing of the procedure. Next, any coatings that square measure needed on the last half square measure connected, trailed by the intelligent layer.

In conclusion, a film of designed polymer epoxy is connected to either the ace or the recreated segment and the parts are joined for impermanent changeless grip. After the polymer epoxy cures the repeated part is isolated from the ace.

The vital components of the replications procedure are:

- Suited to volume generation (numerous parts from one or a couple approved bosses).
- Substrates don't require an exactness machined surface in light of the fact that the epoxy layer suits machining defects; the last surface matches the ace.
- Substrates can have worked in mounting gaps, tabs, and surprising shapes to streamline get together, minimize weight/idleness, and diminish one of a kind parts tally.

The process of Replication consists three steps:

Preheating: In the first step plate is heated with master mold attached it. The mold and polycarbonate 20℃ (ambient temperature) at initial temperature. Once The mold is reaches to the surface of polycarbonate during this step the heating begins up to selected temperature 148℃ and 152℃. The given temperature corresponds to glass transition temperature of polycarbonate. Because of once the polycarbonate with high temperature reaches to rubbery state of chemical compound, the chemical leaves glassy or brittle state and starts to be reversibly and irreversibly deformed beneath the action of mechanical stress. In alternative it becomes elastic. The heat of mold is transmitted to the polycarbonate during this step of heating and it starts to deform with the shape of the master mold.

Heat transfer conductivity during the process of heating is described by the formula:

$$\rho(T)c_p(T)\frac{\partial T}{\partial t}+\nabla(-k\nabla T)=q,$$

Where k is thermal conductivity; ρ is density; c_p is heat capacity; T is temperature; q is rate of the heat generation.

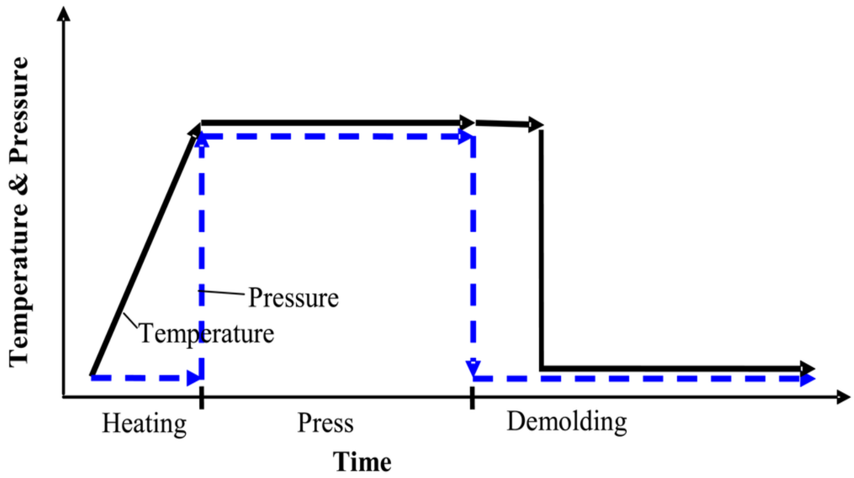


Figure 3.2 Deformation behaviour of thermoplastic polymer as a function of temperature. [15]

Imprinting: The mold is impressed according to the pressure 1 to 5 bar, that is being applied for 10 seconds on polycarbonate. The contact between mold and polycarbonate will increase. The plastic deformation takes place in the polycarbonate during imprinting process.

Demoulding: the mold is lifted up and polycarbonate cooled down till ambient temperature. The surface relief of master mold is that transferred on the polyvinyl chloride.

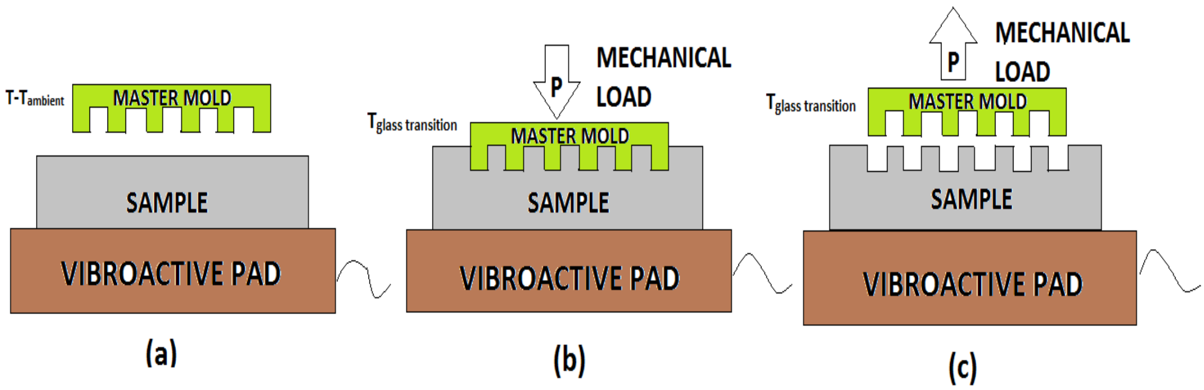


Figure 3.3 Steps process of hot imprint with connect to ultrasonic excitation a) heating b) imprinting c) demoulding.

Wave generator	Pressure	Temperature	Time
Pulse vibration (f-8.460 kHz, U-5.0000 V) Arbitrary vibration (f-8.460 kHz, U-5.0000 V)	1 bar 2 bar 3 bar 4 bar 5 bar	148^0C 152^0C	10 seconds

Table 3.1 Periodic microstructure replication process regimes

3.3 VIBROACTIVE PAD

The vibroactive pad are used in the mechanical hot imprint method because the operating frequency of vibroactive makes the use in order to enhance the quality of replica of development of periodic microstructure throughout the mechanical hot imprint method, which is numerically analysed during experiment. The piezoelectric element has attached along with vibroactive pads which are the same time for all construction amendment its renascent properties beneath by mechanical load. The vibroactive pad is connected to the wave generated system. It is necessary to research the properties of vibroactive pad during replication process. so as the improve the standard of replica once coming up with elaborated analysis and development in this field within the future. Through an experiment there is chance to see the frequency improved to be excited, so as the attain constant modes of forms, therefore modelling of the method was performed.

Figure 3.2 Vibroactive pad.

The frequency generator is connected to the amplifier then connected to vibroactive pad. In this experiment while replaction two types of vibration are given to vibroactive pad which are pulse wave excitation and arbitrary wave excitation. The frequency (f - 8.460 kHz) and amplifier (U - 5.000 V) is common to the both pulse wave excitation and arbitrary wave excitation.

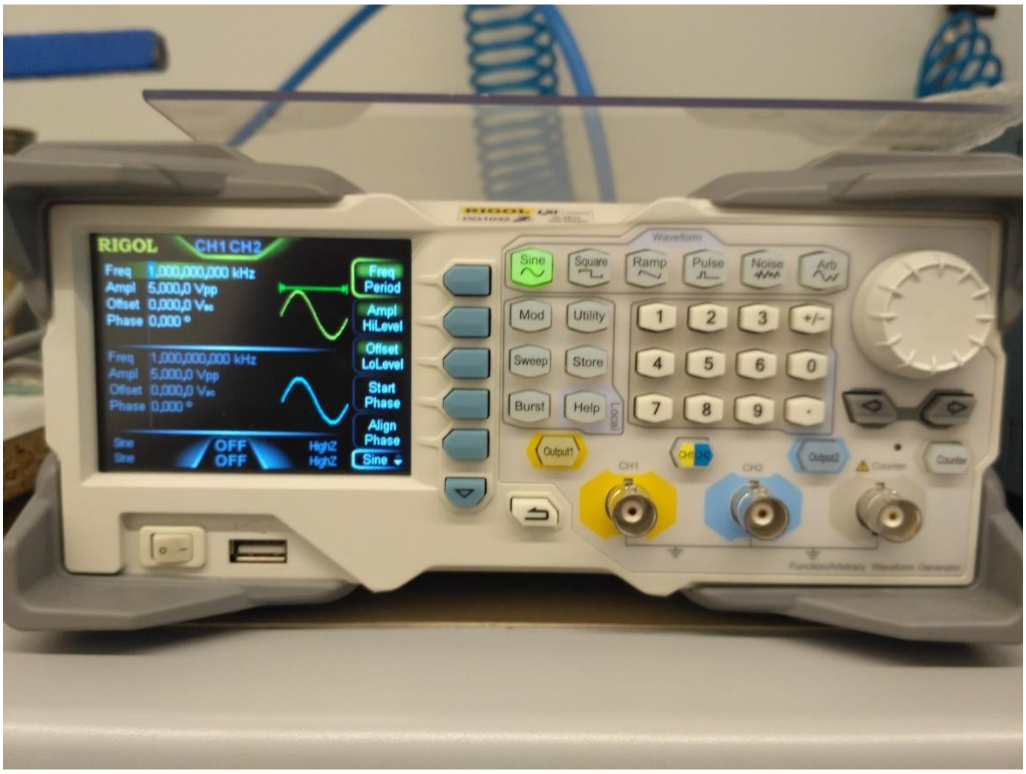


Figure 3.3 Waveform generator

The device can give different type wave form generator to the vibroactive pad. Dynamic characteristics amendment, once vibroactive pad is below the action of mechanical load. therefore, it's vital to seek out precise operative frequencies, below that vibroactive pads develop even displacements over the total operative surface, once pressure is applied on them

4. INVESTIGATION OF DIFFRACTION EFFICIENCY

4.1 Diffraction Gratings

Diffraction grating are main part of sensors which is optical component which deflects light into different beams shown in the figure 4.3. If associate opaque object is placed between a light-weight supply associated an observation screen, the sides of the shadow solid by the item can contain involved patterns that cannot be explained by easy geometric ray optics. This development was initial discussed in a very publication in 1665 by Francesco Grimaldi, an academic of physics and mathematics at the Jesuit faculty of Bologna, Italy. In Grimaldi's experiments, he allowed a tiny low pencil of sunshine to return into a dark area. He determined that the shadow solid by a rod control within the cone of sunshine was wider than the shadow foreseen by geometric optics. He conjointly noted that coloured bands bordered the sides of the shadow. Grimaldi named this development "diffraction" which accurately means that "breaking up". Grimaldi used the results of this experiment to be one amongst the primary to argue for the wave nature of sunshine. Grimaldi's original name for this development, "diffraction", is still used nowadays. optical phenomenon may be a general characteristic of wave phenomena. If a wave front encounters an interference object, the parts of the wave that pass on the far side the object interfere to cause the optical phenomenon pattern. an awfully vital application of diffraction is that if the interference object may be a repetitive array of diffracting parts that produce a periodic alteration of the amplitude or section of the transmitted wave. Such an object is claimed to be an optical device.

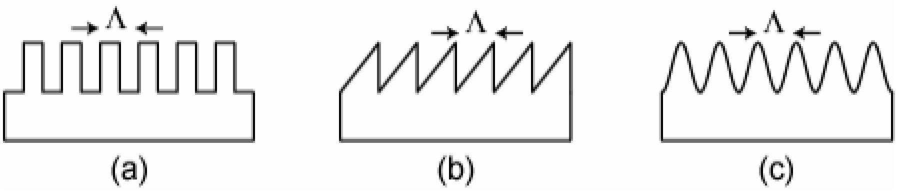


Figure 4.1 Example of surface relief gratings: (a) binary (b) blazed (c) sinusoidal [23]

The basic categories of diffraction gratings are divided into two types which are ruled grating replica and holographic grating replica. the physically shaping furrows are delivered on an intelligent using ruled grinding. The separation between adjoining grooves and the edge they frame with the substrate influence both the scattering and effectiveness of the grinding.

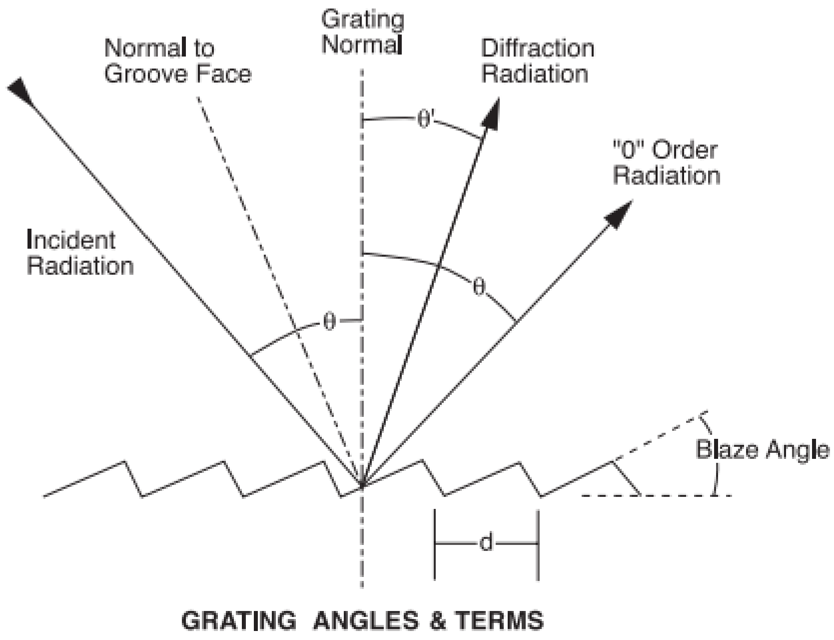


Figure 4.2 diffraction angles and terms [19]

A holographic grating, by contrast, is produced using a photo lithography Figureic process where an interference pattern is generated to expose preferentially portions of a photoresist coating.

The equation of grating generally may be written as

$$n\lambda = d\ (\sin\theta + \sin\theta')$$

where λ is the diffracted wavelength, θ is the angle of incidence measured from the grating normal, n is the order of diffraction, d is the grating constant (the distance between grooves), and θ' is the angle of diffraction measured from the grating normal.

4.2 Experimental setup of diffraction maxima

In this setup laser beam passes through the polycarbonate material which is replicated by mechanical hot imprint method. The photo diode connected to the ammeter when laser beam diffracted and fall on the photo diode the values of diffracted maxima can get on ammeter. The scheme of diffraction efficiency measurement stands shown in the below figure.

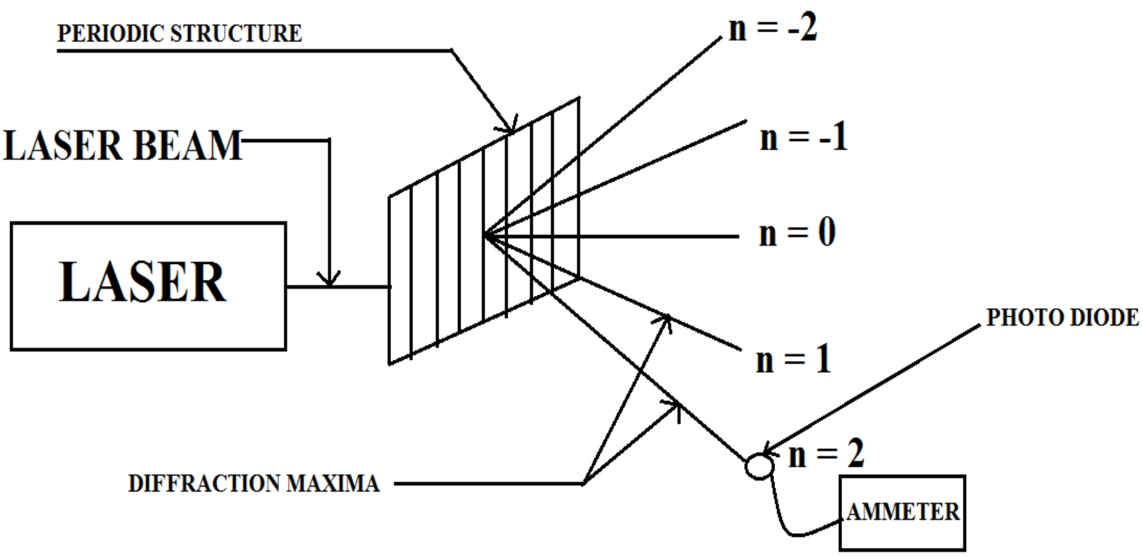


Figure 4.3 Principle scheme of diffraction efficiency measurement stand

the general proficiency of the gratings relies on upon a few application-particular parameters, for example, wavelength, polarization, and edge of occurrence of the approaching light. The proficiency is additionally influenced by the grinding outline parameters, for example, blast.

4.3 Diffraction efficiency

Quality of replicated microstructure was investigated by diffraction maxima. The diffraction efficiency measurement setup are used to find highest diffracted maxima to find the diffraction efficiency the setup was performed by using laser ($\lambda = 632.8$ nm) ,ammeter and phtodiode. The whole setup was showed in the figure 4.4 The diffractive efficiency is being calculated by using the formula:

$$SE_{i,j} = \frac{I_{i,j}}{I_j}$$

Where,

$$I_j = \sum_i I_{i,j}$$

Explanation of the formula: first of all, sum (I_j) of all currents (different diffraction angles) is being calculated, then particular current, obtained at particular maxima, is being divided from this sum and the relative value in percent’s is thus obtained. The diffraction efficiency is calculated theoretically, that diffractive grating, whose period is 4 µm and depth 150 nm, and it has 6 maxima’s values are considered.

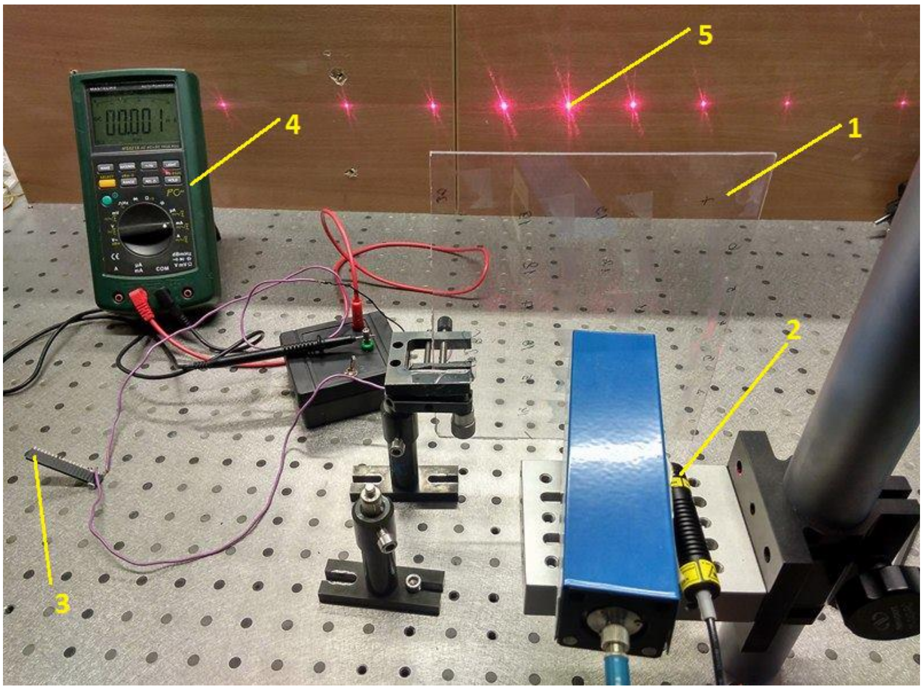


Figure: 4.4 Diffraction efficiency measurement setup: 1) sample 2) Laser light (red) 3) photodiode 4) ammeter 5) distribution of diffraction maxima.

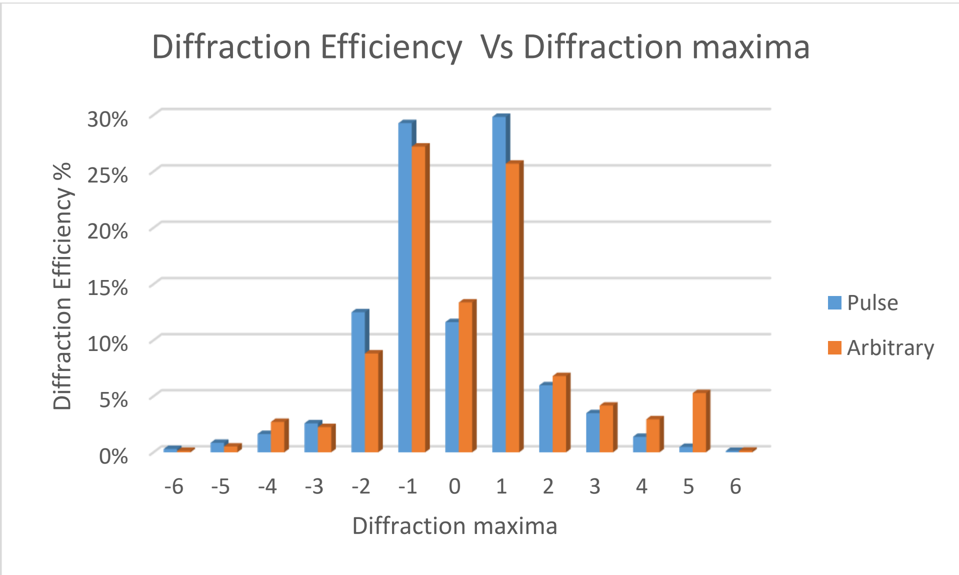


Figure 4.5 Diffraction efficiency Vs Diffraction maxima (148°C & 5 bar using red laser)

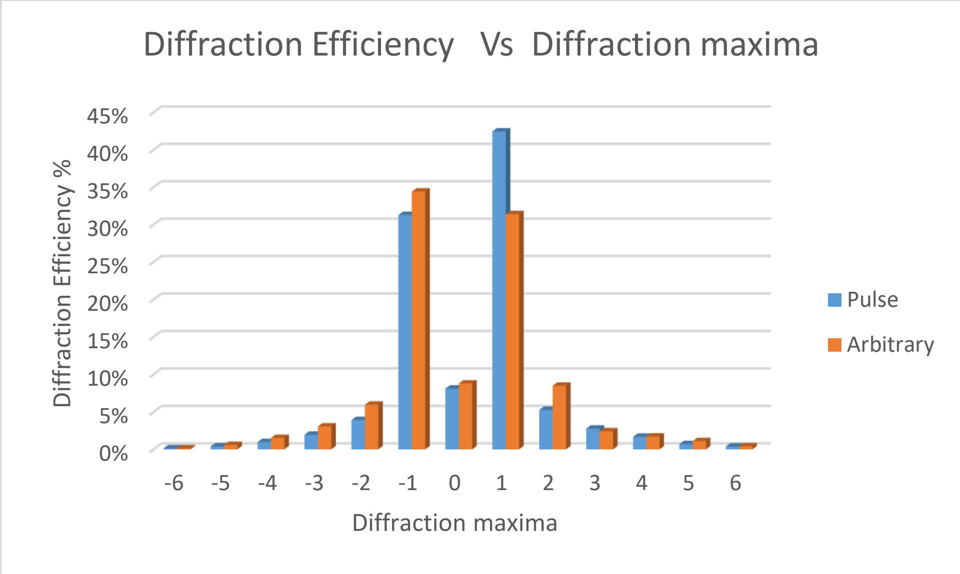


Figure 4.6 Diffraction efficiency Vs Diffraction maxima (152℃ & 5 bar using red laser)

same as red laser setup are arranged here green laser (λ = 532 nm) are using to find the distributed diffraction maxima.

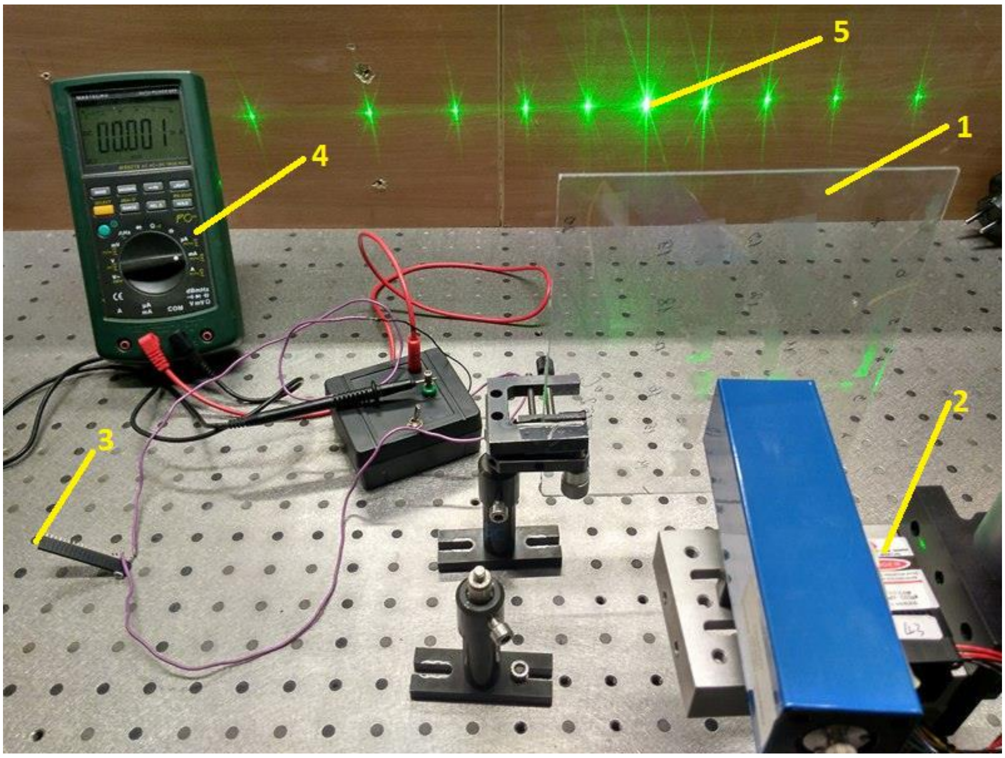


Figure 4.7 Diffraction efficiency measurement setup: 1) sample 2) Laser light (Green) 3) photodiode 4) ammeter 5) distribution of diffraction maxima.

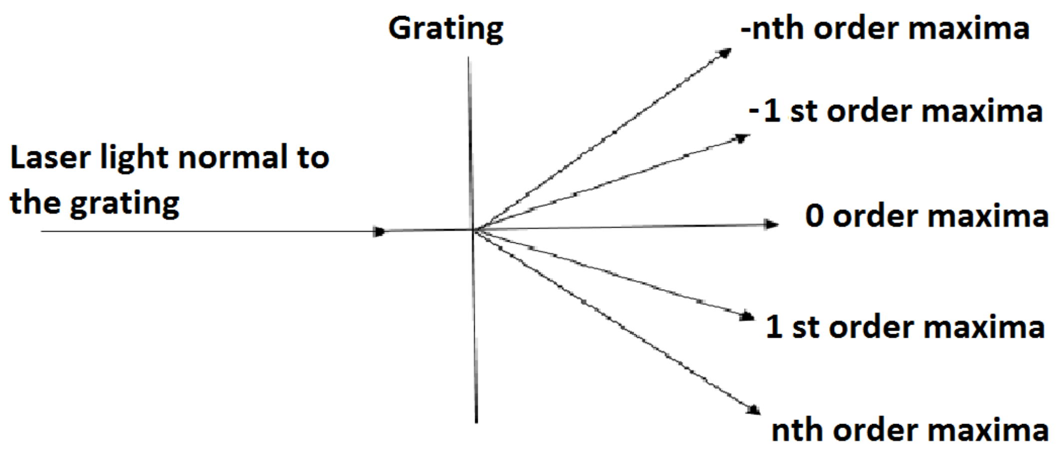


Figure 4.8 Schematic diagram of Laser beam diffracted through Polymer.

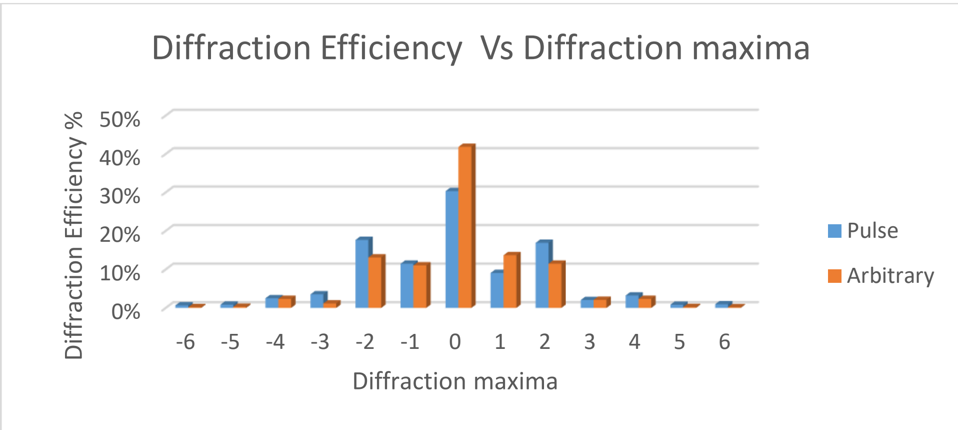


Figure 4.9 Diffraction efficiency Vs Diffraction maxima (148°C & 5 bar using Green laser)

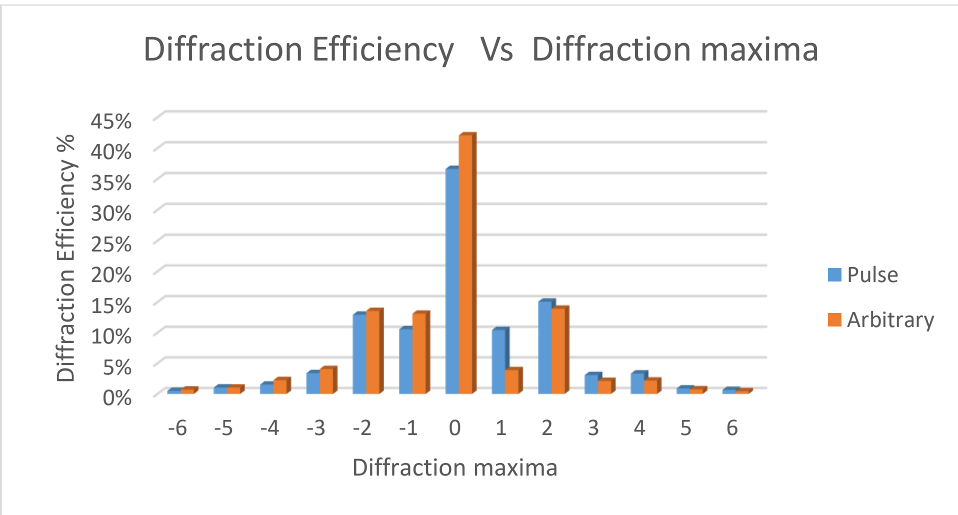


Figure 4.10 Diffraction efficiency Vs Diffraction maxima (152°C & 5 bar using Green laser)

The Laser beam is directed to the microstructure. because the beam passes through the microstructure, it's being diffracted into specific quantity of maxima, that reach the photodiode. the electrical current, that passes through photodiode is registered with meter. Electrical current, that passes through the photodiode linearly depends on the lighting, therefore no extra calculations square measure required so as to match results. optical phenomenon maxima square measure scattered, in order that they square measure measured by dynamical the position of photodiode so desired maxima would have photodiode.

5. INVESTIGATION OF MICROSTRUCTURE USING OPTICAL MICROSCOPE

5.1 OPTICAL MICROSCOPE

Microscopy could be a technical field of victimization microscopes for investigation of objects (or their elements) too little to be seen with the oculus. largely morphology investigations area unit performed to explore the object’s structure and conjointly form, size, position, relationship of its components either on surface or within.

There is a spread of microscopic techniques. However, the fundamental principles of every kind of research area unit nearly an equivalent and may be clearly explained by the instance of optical research, that involves actinic ray transmitted through or mirrored from the sample. most magnification provided by optical magnifier is 1500x. on paper, it's doable to form system with higher magnification. However, the most plan of research isn't to urge as high magnification as doable, however to outline the littlest components of the structure, i.e. to use the very best resolution. The last is restricted attributable to the wave properties of sunshine (diffraction) and for optical magnifier is about zero.2 μm.

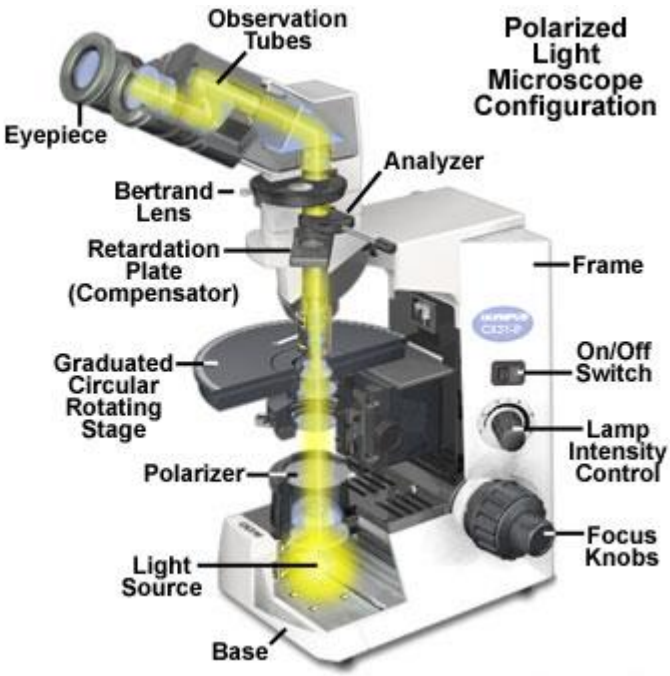
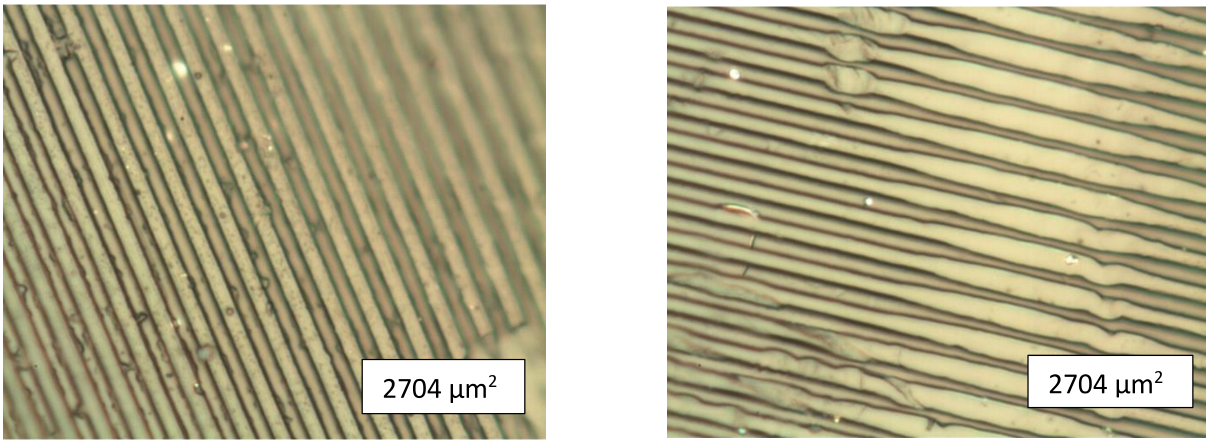


Figure 5.1 3D view of optical microscopy [24]

The object structure is often investigated provided that its components replicate or absorb the sunshine dissentient in several ways in which or differ from one another by index of refraction. These properties cause the distinction in section and amplitude of the sunshine waves that went through completely different components of object and then have impact on the image distinction. that's why the used distinction methodology ought to be chosen in keeping with the properties of the item.

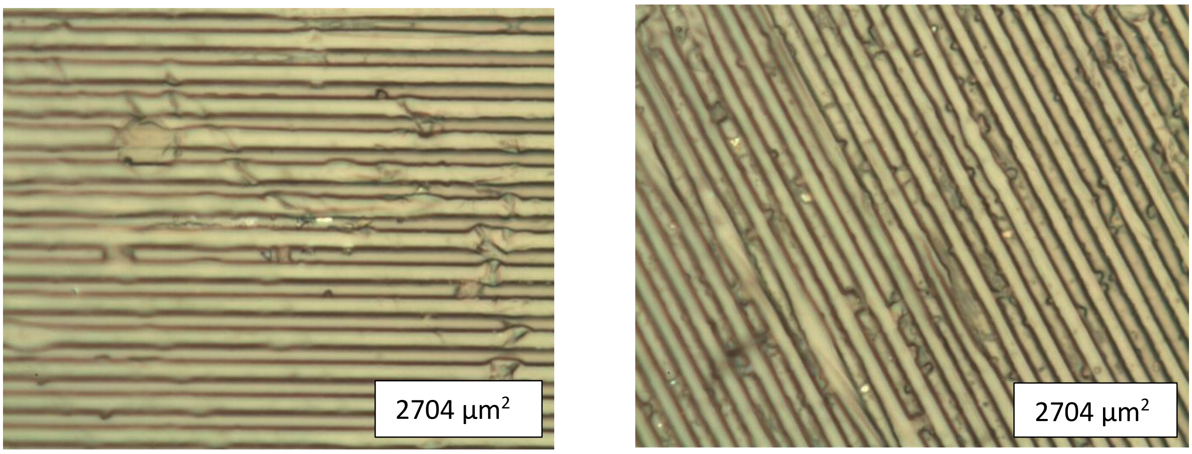
Polymers area unit examined by each transmitted- and reflected-light research. it's value to notice that pure polymers hardly absorb any lightweight, so bright field transmitted lightweight distinction methodology isn't terribly helpful for them. On the opposite hand, polymers develop part crystalline or amorphous structures, that area unit thought-about optically anisotropic and then, are often unconcealed by polarized transmitted lightweight. For this reason, polarization is that the most typical distinction methodology for the examination of polymers.

The optical microscope used to find the defects in the replicated microstructure. The microstructure is according to temperature and pressure.



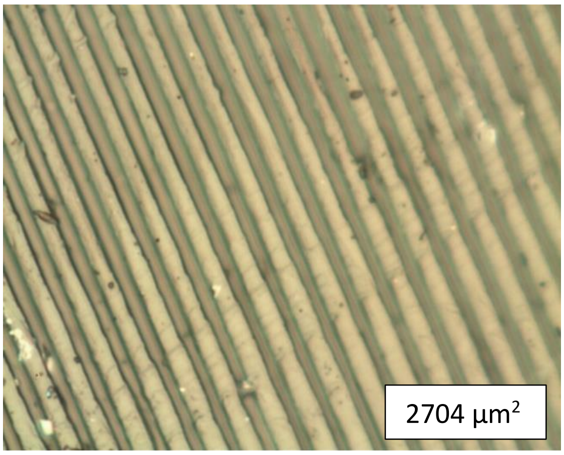
(a) (b)

Figure 5.2 Microstructure made with Pulse wave excitation (a) 148°C at 1 bar (b) 148°C 3 bar

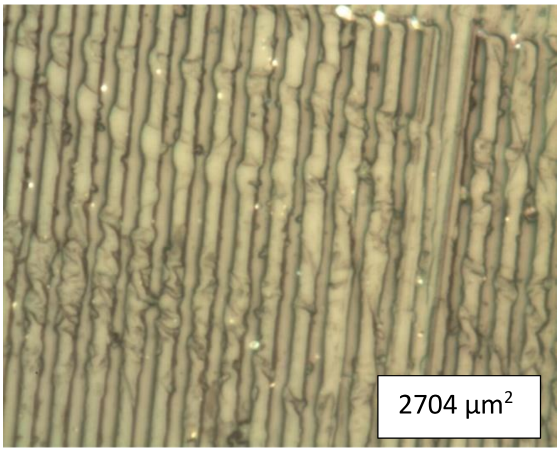


(a) (b)

Figure 5.3 Microstructure made with Arbitrary wave excitation (a) 148°C at 1 bar (b) 148°C 3 bar



(a)



(b)

Figure 5.4 Microstructures at 152℃ at 3 bar using (a) pulse wave (b) arbitrary wave

The replicated microstructure shown in the figure 5.4 at the teparature of 152℃, pressure 3 bar Which are imprinted by masterpad with pulse wave excitation and arbitrary wave excition compararion of microstructure evaluate the best quality of microstructure.

6. RESULTS AND DISCUSSION

6.1 Diffraction efficiency

Diffraction Efficiency of +1 and -1 maxima are the most significant criteria which determines the optical quality of the periodic grating. Highest value of the distribution maxima is strongly desirable in many applications. The main intention is highest distribution maxima consider in the Diffraction Efficiency.

Results of Measurement of Diffraction Efficiency (Figure 6.1) were analysed. After the Measurement values of Diffraction Efficiency, the Pulse and Arbitrary wave excitation are calculated using Red laser (λ-633 nm) according to Temperature 148℃ and Pressure (1 bar, 2 bar, 3 bar, 4 bar, 5 bar). Results of diffraction efficiency in the Pulse wave generator shows highest diffraction efficiency is 30% at Pressure 5 bar and the Arbitrary wave generator shows that highest diffraction efficiency is 26% at Pressure 5 bar and time is 10 seconds for both wave Excitations.

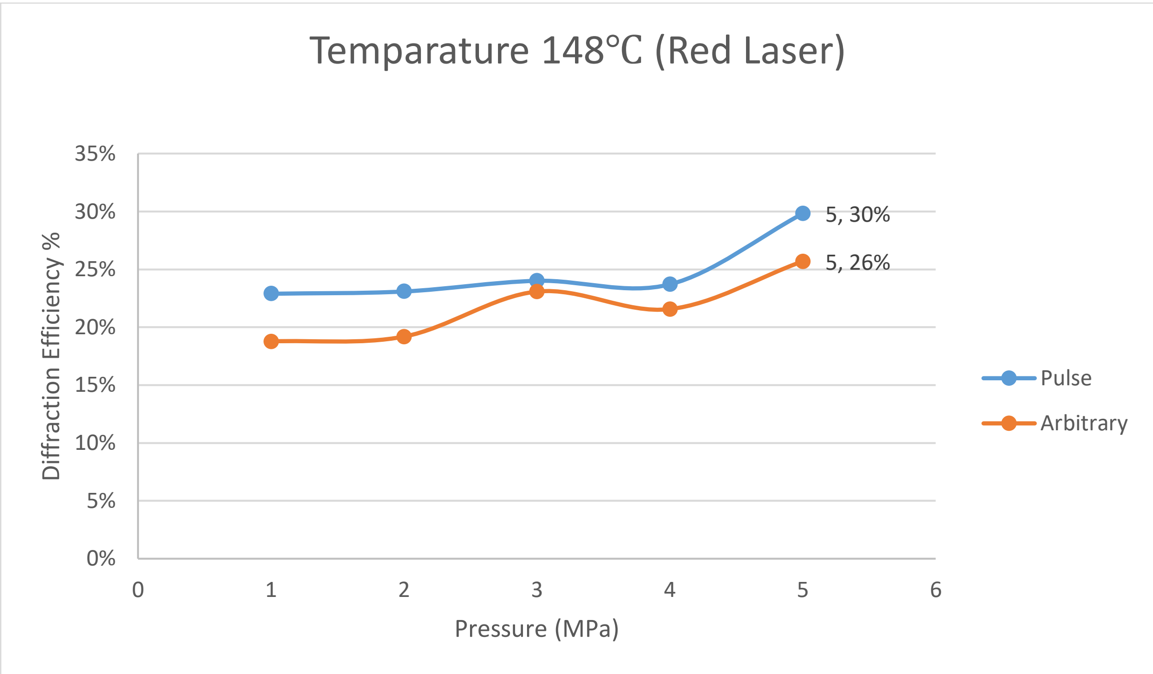


Figure 6.1 Diffraction Efficiency Vs Pressure (148℃ using Red Laser)

At temperature 152℃ using Red Laser Measurement of Diffraction Efficiency are calculated. The pulse wave generator shows 37% and Arbitrary wave generator shows 33% at Pressure 5 bar.

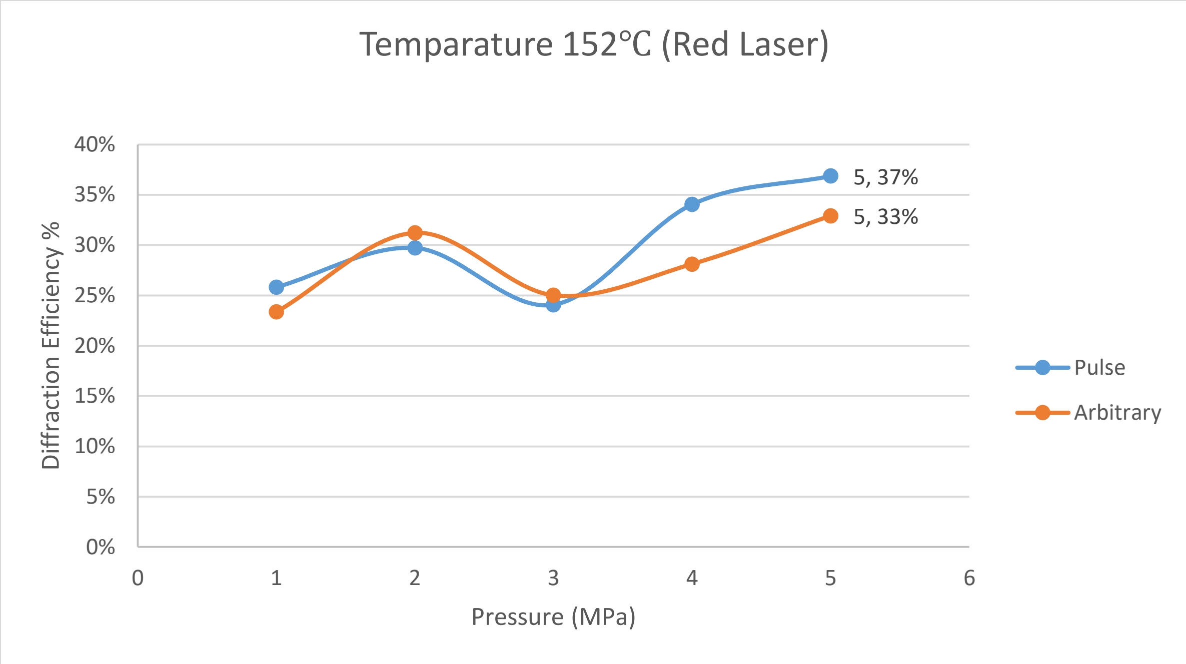


Figure 6.2 Diffraction Efficiency Vs Pressure (152℃ using Red Laser)

Diffraction Efficiency measurement using Green Laser (λ = 532 nm) at Temperature of 148℃ and Pressure 5 bar. The Pulse Wave Generator are shows 10% and The Arbitrary wave generator shows 12% time is 10 seconds.

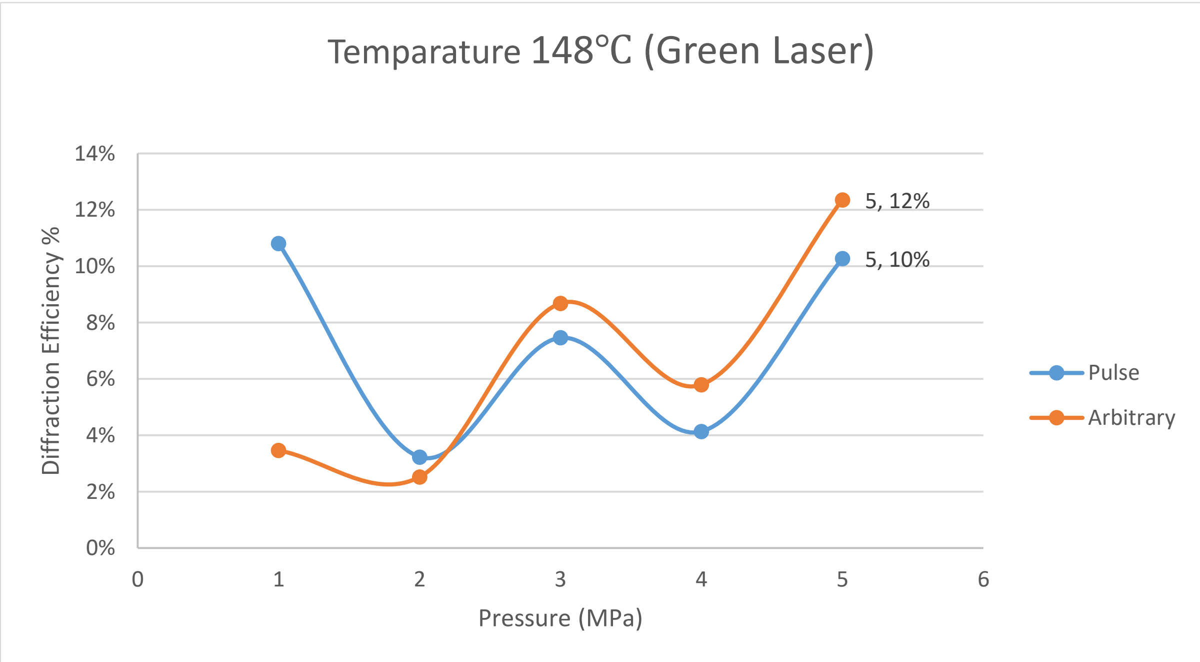


Figure 6.3 Diffraction Efficiency Vs Pressure (148℃ using Green Laser)

At Temperature 152℃ using Green Laser Diffraction Efficiency was calculated. The Diffraction Efficiency of Pulse Wave Generator 10% and The Arbitrary wave generator is 8% for both Pressure at 5 MPa.

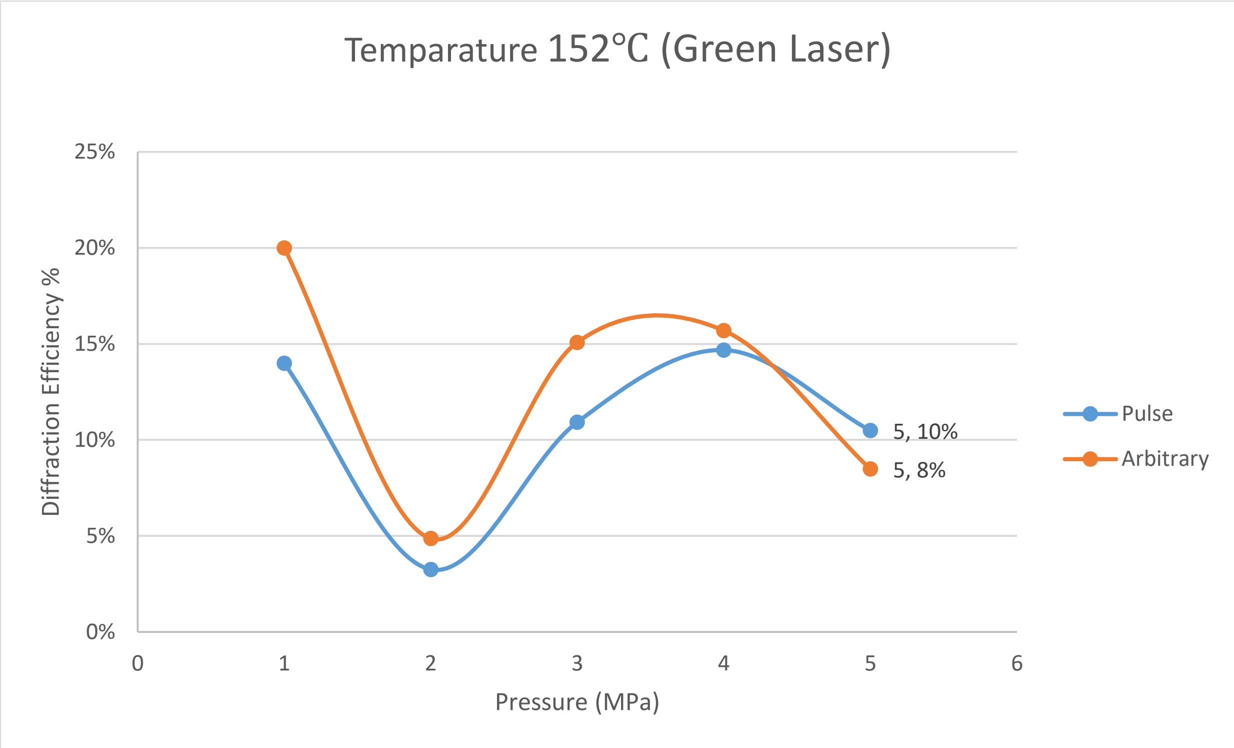


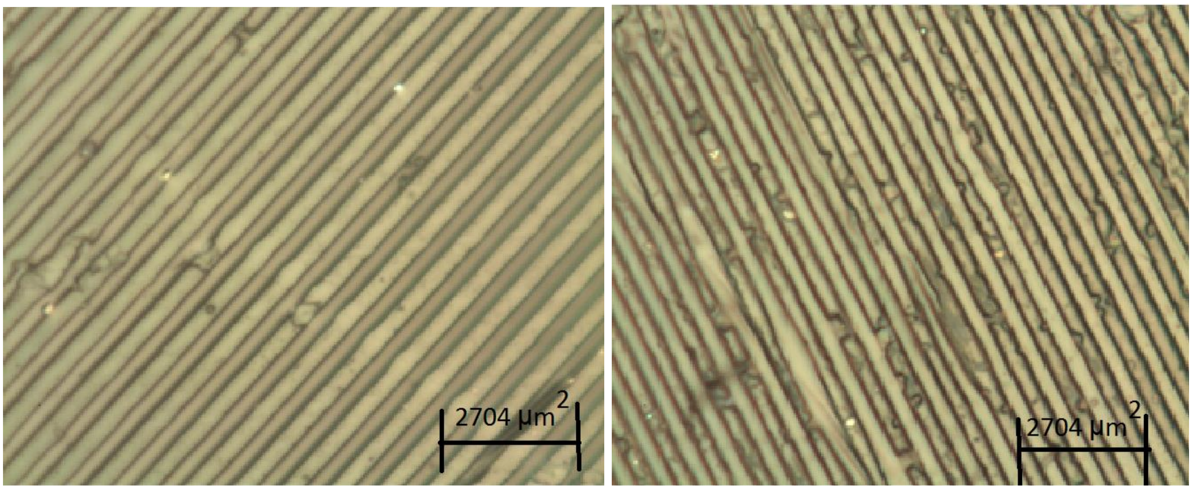
Figure 6.4 Diffraction Efficiency Vs Pressure (152℃ using Green Laser)

Above Measurement Results using Green Laser the Diffraction Efficiency of Pulse and Arbitrary wave generators are shown the figure () these results are low Diffraction Efficiency compare to Red laser. Mostly Diffraction Grating are evaluated using Red laser.

6.2 Optical microscope:

Optical microscope "NICON Eclipse LV 150" with CCD camera which is used for examine the visible defects on replicated microstructure in order to find the quality of microstructure. the number of defects are counted per area on the replicated microstructure by pulse and arbitrary wave excitation to analysis qualitative microstructure at 148 and 152℃ according to pressure (1 bar, 2 bar, 3 bar, 4 bar, 5 bar).

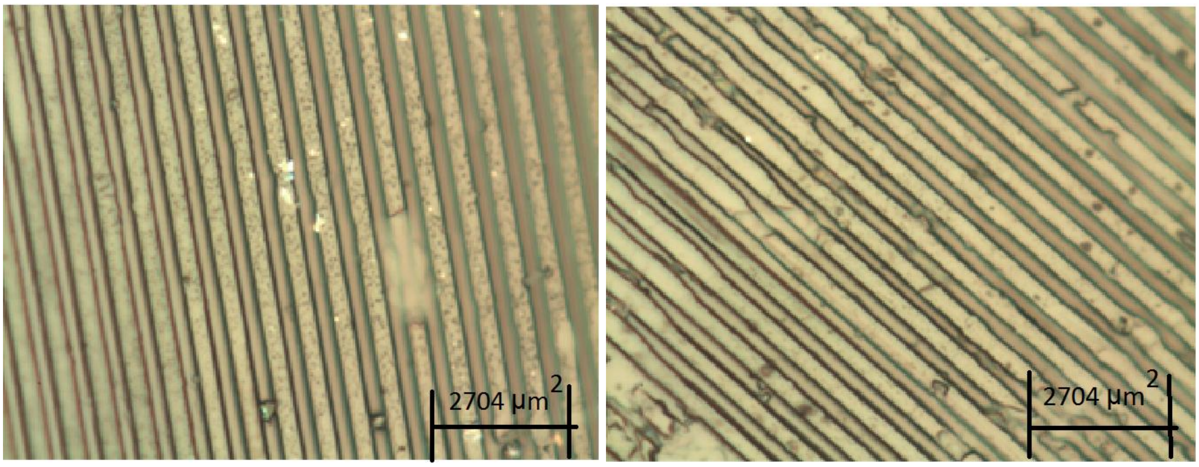
At the temperature of 148℃ 2500 defects/mm^2 made with pulse wave excitation and at the temperature of 148℃ 13500 defects/mm^2 made with arbitrary wave excitation after the analysis pulse wave excitation are 5.4 times better than arbitrary wave excitation.



(a) (b)

Figure 6.5 Microstructure at 148℃ made with (a) pulse wave generator (b) arbitrary wave generator.

At temperature 152℃ 2200 defects/mm^2 made with pulse wave generator and 12500 defects/mm^2 made with arbitrary wave generator after analysis the pulse wave generator are 5.6 times higher than arbitrary wave generator.



(a) (b)

Figure 6.6 Microstructure at 152℃ made with (a) pulse wave generator (b) arbitrary wave generator.

Above Experimental results of microstructure are quality are improved at high pressure as well as Diffraction Efficiency also high in Pulse wave generator. Which results proved by using Optical Microscope.

CONCLUSION:

1) In Literature review comparing various methods used for producing diffraction grating, it was found that mechanical hot imprint method is the very effective, low cost and reliable method which develops diffraction grating with better efficiency

2) The experiment setup of Mechanical hot imprint was studied and explained the methodology. This method is used to manufacturing diffraction gratings on polycarbonate with vibroactive pad.

3) Replicated the periodic microstructure on polycarbonate using Mechanical hot imprint method. According to temperature (148℃ & 152℃), pressure (1 bar, 2 bar, 3 bar, 4bar, 5 bar) and time is constant 10 seconds with pulse and arbitrary excitation.

4) The results of diffraction efficiency are obtained by pulse and arbitrary wave excitation using diffraction maxima setup. the Diffraction efficiency of pulse wave excitation is 37% at 152℃ and arbitrary wave form excitation 33% at 152℃. Compare to these results pulse wave excitation shows higher efficiency than arbitrary wave excitation.

5) Periodic microstructure are investigation using the optical microscope, the visible defects are counted on the microstructure. The number of visible defects on polycarbonate made with Pulse wave excitation is $2500/mm^2$ and made with arbitrary wave excitation is $13500/mm^2$. so Pulse wave excitation are 5.4 times better than arbitrary wave excitation.

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