LASER MARKING OF POLYMERS

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ABSTRACT

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Laser marking technology has been in use for the past 50 years, it has become very common and is being utilized in almost every field of industry, i.e., medical, garments, automobiles, aerospace etc. The main aim of this research is to provide an overview of the laser marking, polymer marking done by lasers, techniques involved in laser marking and elaborate the applications of laser marking. This is review-based research, the data was collected from the available publications. For this purpose, data from various online sources were used which include Google Scholar, Wiley Online, Springer, Elsevier etc. In this work, the technology of laser marking has been described from the point of view of the marking of polymers.
ACKNOWLEDGEMENTS

I want to acknowledge my teachers and professors for guiding me in this project and for providing this excellent research project. Further, I want to thank my parents and my teammates to help me in completing this project with the proper resources.
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1 INTRODUCTION

Marking is a technique used to produce the indelible and legible patterns and alpha numeric characters for the identification and tracking of different products and services. These characters include bar codes, logos etc. Number of techniques have been used for marking of materials specifically laser masking has been used for 50 years as discussed in a white paper. During the recent years laser marking have been using for automated reading of the data plotted on the specific parts of the individual products or components (Dahotre & Harimkar, 2008, p. 100). Laser marking can be defined as: “creating a readable mark on any object by using the laser. It also involves the process of laser engraving”. Unlike the traditional techniques no ink or tool kit is used to create a mark rather a laser beam is used to remove or modify the part of the object permanently that create permanent readable mark on that object that is called as engraving. Laser marking is also used for changing the color of the different products. Furthermore, several technologies of laser marking materials have been illustrated. Besides, laser marking criteria and materials has been described as well with its theories and the results of the findings of the applications of this marking.

1.1 Background

It has been reported that there are many laser marking materials are available on commercial scale which provide high quality marking and accuracy (Fang et al. 2022, p. 101). Different polymers are being marked by using different the laser marking technique, these polymers include polypropylene (Yang et al. 2022), polyvinyl chloride, polystyrene, high density polyethylene and low-density polyethylene etc. (Zelenska et al. 2016, p. 100).

It has been reported that addition of Sb$_2$O$_3$ or Sb$_2$O$_3$-g-PS in polypropylene showed dark graphic signs on white color surface of the product (Liu et al. 2018, p. 10). Research was carried out on effect of CNTs/PC powder on laser marking, it was reported that addition of CNTs/PC (carbon nanotubes/polycarbonate) powder greatly increases the difference between the patterns
that were attained by laser marking and the PP (polypropylene) sample surface (Yang et al. 2022). From this research it can be concluded that addition of some agents in the polymers greatly increase the marking process and make very clear marks and increase the responsiveness of the materials to laser beams. According to research it was concluded that laser marking should be done by using the high concentration of laser beams and low velocity because these produce fine marks on the surface of the products (Czyżewski, Sykutera & Rojewski, 2022, p. 22).

1.2 Research goals

The research goals are to find the following:

1. How polymers can be marked using the laser marking techniques?
2. What is the influence of dwell time, absorbents, surface treatment and complexity of code, on the marking process?
3. What are the applications of laser marking?
4. Why is there need of addition of some additive agents in the polymers?

1.3 Research methods

Secondary research was carried out. Data was collected from many online sources. These sources include springer, Wiley, Google, Elsevier etc. Mostly the research focused on laser marking of polymers. Laser marking is one of the most common industrial uses for lasers. It may be achieved through several physical processes involving the interaction of the laser beam with the material. Laser marking is often made in the form of a textual and 2D transposed pattern adhered to the device's surface, vector image such as the date of production, serial number, and so on. Key words used for the research were: laser marking, laser marking of polymers, types of the polymers marked. The present study provides a summary of the previous research.
1.4 Research rationale

The figure given below indicates that the share of demand of polymers. Demand for the polymers is increasing day by day. Polymers are being used in every field medical, industries, garments etc. so the marking of these polymers have become an issue of huge concern. Ink jet printing was used to mark the polymers, the issue with this technique was that it does not produce permanent marks on the polymers. Then UV curable inks were introduced for making process although these have various advantages, but these also release some toxic substance that leads to environment pollution. UV-LED has also been greatly used for marking of the polymers, but it also presents some limitations regarding adhesion and abrasion resistance of the marks. E-beams are also being used for marking purposes, but this is a very expensive technique and require expensive instruments. So, in context to polymer marking laser marking has gained the huge interest since the last decades. This technique is cheap and make the permanent and resistant marks on the polymers. So, laser is a good tool for marking of the polymers because it provides the permanent and resistant marks on the surface of the polymers. Moreover, it is cheap and does not release any toxic substances.

Figure 1. Use of polymers worldwide (Source: Statista.com, 2022)
2 LITERATURE REVIEW

The aim of this research is to provide an overview of the polymer marking, techniques used for polymer marking and the factors that influence the marking process. This research also aims to elaborate the applications of the laser marking of the polymers in different fields.

In this chapter many factors later to laser marking of polymers will be presented, such as the technologies used in laser marking, the methods and techniques, the equipment used in the process, and the applications used in real life.

2.1 Lasers used in Polymer Marking

The scheme used for laser marking is shown in the figure below.

![Figure 2. View of Technical System of Laser Marking (Wei et al. 2021).](image)
There are various types of laser that are being used in the process of laser marking most commonly used lasers are “Nd:YAG lamp-pumped lasers, which produce a light in the near infrared area at a wavelength of 1064 nm, and CO₂ lasers - at the wavelength 10600 nm”. Some of the laser sources that are used in laser marking are given below in the table along with their power and wavelengths.

Table 1. Laser Sources used in Laser Marking (Lazov, Deneva & Narica, 2015)

<table>
<thead>
<tr>
<th>Type of laser</th>
<th>Wavelength</th>
<th>Materials</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>10600</td>
<td>Metals and non-metals</td>
<td>Cutting</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>1060</td>
<td>Metals and plastics</td>
<td>Engraving</td>
</tr>
<tr>
<td>Fiber</td>
<td>1062-1064</td>
<td>Metals</td>
<td>Engraving</td>
</tr>
</tbody>
</table>

2.1.1 Types of lasers used

Continuous wave laser heats up the polymers evenly as compared to the pulse lasers. In a continuous wave laser as the whole material is heated evenly, this heat conduction evaporates the material and is useful for the marking process. On the other hand, pulsed laser has more optical depth and smaller the heat affected zone (HAZ) (Kumpulainen et al. 2011, p. 572). A comparative analysis of continuous wave laser and pulsed laser was done, according to this analysis it was proved that pulsed laser produce the smaller heat affected zones than that of the CW lasers (Muhamad, 2005).

Lasers can be produced by any medium either solid, liquid or gases. The lasers thus produced are of high energy and can be used for multiple purposes i.e. masking of polymers, machines, plastics etc. for marking of the plastics gas laser i.e. CO₂ and solid state Nd: YAG lasers are being used. The Transversal Excited Atmospheric pressure carbon dioxide laser (TEA CO₂ Laser or the CO₂ Laser), it works effectively at 10,600 nm (10.6 μm) wavelength. This laser is commonly used for marking the packages because it is easy to use, have low production
costs and can produce marks at high speed. The Nd: YAG laser uses a neodymium-doped YAG crystal as the medium for the production of laser. This laser works efficiently at the wavelength of 1064 nm or at 532 nm—a 100-fold lower wavelength than that of CO$_2$ laser. CO$_2$ lasers are mostly used for marking of the simple codes for example lot of numbers. While Nd: YAG laser is used for marking high quality graphics and images (Sastri, 2014, p. 56).

Table 2. Types, Nature and Excitation Sources of Lasers

<table>
<thead>
<tr>
<th>Type of Laser</th>
<th>Nature of Laser</th>
<th>Excited by</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>Mixture of gases</td>
<td>Electric discharge</td>
</tr>
<tr>
<td>Fibre lasers</td>
<td>Solid state lasers</td>
<td>Diode lasers</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>Crystal</td>
<td>Flash lamp</td>
</tr>
</tbody>
</table>

2.1.2 Beam-Material interaction

Laser boundaries and material properties both influence the progress of laser removal. Besides investigating the making of the laser radiates, the actual materials have been vigorously contemplated. Research has been directed on polymer materials that have promising applications in different fields like clinical, designing, and substance detecting. The materials expected in these fields limit the structure and consequently the material qualities that are indispensable to performing laser removal (Ghiasi, Sefidbakht and Rezaei, 2019). The polymers utilized for laser removal have been grouped because of a few rules like the accessibility, application, removal conduct, and decay conduct. The “Polymethyl Methacrylate (PMMA) depolymerizes” upon illumination while “polymides (PI)” disintegrate into parts upon light. Along with that, certain polymers are accessible promptly like PMMA, PET, and PTFE, while some are redone given explicit necessities of the application. Certain polymers, for example, PDMS and Polycaprolactone are utilized in biomedical applications like dishonest inserts and cell epitome. Polytetrafluoroethylene (PTFE), otherwise called Teflon, is a translucent engineered fluoropolymer of tetrafluoroethylene.
Figure 3. Combustion-free volatile decomposition zone of cellulose nitrate molecules for the polymer with a CW -CO2 laser in air (Source: Hassanien, Akl and El Radaf, 2021)

Polytetrafluoroethylene (PTFE) is an exceptionally flexible material utilized in a wide assortment of utilizations attributable to its security and solid qualities. Because of its great electrical opposition, it is utilized as an encasing for wiring and links. PTFE is utilized in mechanical designing applications in parts that have sliding activity, for example, pinion wheels and pulleys since it has a low frictional coefficient. PTFE is generally utilized in the food bundling industry and the substance business as a material for fixing forceful synthetics (Hassanien, Akl and El Radaf, 2021). This prompts the production of a few grades of PTFE given the filler material integrated into it.

2.1.3 Kinds of polymers that can be marked with Laser

It has been reported that laser marking is very prominent in different field which include marking of the plastics, cosmetics packaging materials, ceramics, metals, clothing and packaging of foods (Liu et al., 2018). There are various materials used for the marking of different materials these include: Neodymium-doped yttrium aluminum garnet (Nd:YAG) lasers i.e. used to mark
the plastics and metals, it is one of the most common laser that is used in medicines and laser processing (Ezra et al., 2016). Various polymers can also be marked at high temperature because of their high carbonization, these polymers include: “poly (ethylene terephthalate) (PET), polycarbonate (PC), and polystyrene (PS)” (Amutha, Tharakan & Sarojadevi, 2015.). Various other polymers i.e., High-density polyethylene (HDPE) and poly-propylene (PP) are being used but these are poor absorbers of laser wavelengths. Poly-propylene (PP) is a type of thermoplastic that is commonly used in automotive industries (Shimamoto, Sekiguchi, & Sato, 2016). It is very important for marking texts, QR codes, and graphics (Benayad-Cherif, 2009).

2.1.4 Reactions involved in Laser Marking of Polymers

It has been reported that three reactions are involved in laser marking of polymers these are:

1. Absorption of heat by the polymer.
2. Chemical change by the use of additives in polymers.
3. Absorption of heat by the colorant material added to the polymer.

First reaction takes place when the polymers surrounding material absorbs enough heat to rise the temperature of the polymer. This may lead to burning of the polymer in the sufficient supply of the oxygen, this results in the formation of black spots on the surface of the polymers. The darkness of the spot-on polymer depends on the heat absorbed and thermal degradation of the polymers.

Second reaction is the chemical change using the additives in the polymers. This addition of additives in the polymers causes the foaming of the polymers. So, by appropriate controlling of the laser’s high quality, durable marks can be produced.
Third reaction takes place by the absorption of the heat energy by the colorant materials added in the polymers. When these colorant materials absorb heat energy these induce a color change in the polymers (Sabreen, 2013).

2.2 Laser marking technologies

Various laser marking technologies are being used for creating readable marks on the products. These technologies include the combination of any of the following methods:

- Formation of the channel by evaporation with small depths in the materials.
- Modifying the surface by melting and subsequently solidification of the material.
- By making the changes in the colors of the materials.

2.2.1 Types of Laser Marking

There are three important ways used for laser marking these include: raster, vector and projection. In a raster marking, the laser beams move in a row just like the dot matrix in the printers but here instead of ink there are laser beams. This technique was mainly used for adding the alpha numeric data and rarely for marking the graphical data (Lazov, Deneva & Narica, 2015, p.10).

Figure 4. Method of Raster Marking
Vector marking is the most common method of marking. In this technique the marks are written with the aid of the laser beam that is focused and operated by the computer program. It can be used for marking all kinds of the data which include numeric codes, bar codes, logos etc.

![Figure 5. Method of Vector Marking](image)

Projection marking is a technique which is implemented with mask i.e., stencil. Laser beam passed through the mask and directed to the working product.

![Figure 6. Projection Marking](image)
2.2.2 Factors Affecting the Quality of the Laser Marking

In order to get the best results of the marking it is mandatory to attain the optimum combination laser attributes and the technological parameters of the materials. There are various factors that influence the quality of laser marking. These factors include: “properties of the material, properties of the laser beam, and parameters of the technological processes” (Angelova, Mežinska & Lazov, 2017, p. 188). The first factor is absorbance of laser beam. The metals surfaces cannot be coded with the aid of the CO₂ laser beam therefore there is a need coat the metal surface with an absorbent that absorbs the CO₂ laser beam. The second factor is dwell time. Dwell time also greatly influence the marking process. The laser beam is focused for some time on the substrate to mark that surface. It has an inverse relation, i.e., longer the dwell time slower will be the process of marking. Similarly different densities of energy are required by the different surfaces to be coded. The third factor is surface treatment. If a surface has been varnished, laser marking that surface will need to remove the varnish first. This will take a greater time and high energy density will also be used. This will ultimately slower down the marking process. The last factor is the amount of data. There is a direct relation in amount of data and speed of marking process. Greater of complex data will require the more time to be coded on the surface while the simple and smaller data will take short time to code that same surface under same conditions.

2.3 Marking Methods in laser marking

There are various marking methods used in laser marking, some of these are given below:

2.3.1 Laser Surface Modification

Some material is initially placed onto the surface to perform melting and diffusion on the laser surface (fig. 10). As a result of the impact a new alloy with various physical and mechanical qualities (e.g. corrosion-resistant and rubbing (wear) is produced. After the layer has dried, the
coating materials can be applied to the surface with a brush or by spraying them with an atomizer. The unmarked coating areas are then cleaned with a specific cleaner or with water. The marking symbol may be placed on the laser treatment region or directly on the untreated surface. On the surfaces of carbon steel and aluminum alloys, the process is well executed (Lazov, Deneva & Narica, 2015, p.116).

Figure 7. Laser Surface Modification (Lazov, Deneva & Narica, 2015).

2.3.2 Laser Coloring

The method is used to alter the color of metallic substrate material without causing the irradiated material to burn, melt, or vaporize. This is accomplished by moving a low-power laser beam gently across the surface at a set speed, changing the marking area (fig. 11). This laser marking technique produces a high-quality, high contrast marking without damaging the specimen's surface. A colored laser marking can be used to implement the process at levels of unevenness up to 12.7 mm since it can penetrate deep surface roughness. Laser color marking produces less harm to the surface in comparison with other methods and does not lead to corrosion of the surface and hence it can be used for the marking of some stainless steel. By carefully choosing the laser marking's parameters, these impacts can be reduced or even eliminated. This method of marking can be successfully observed at a magnification less than ten (10X) and cannot be removed by rubbing the surface with fingertips (Lazov, Deneva & Narica, 2015).

Research on polymer laser-induced coloring has been conducted extensively across the globe. The possible applications of the technology will be in products surface embellishment for
customized pictures, indicating product identification and corporate logos. All currently used techniques by using the infrared lasers, visible light lasers i.e., CO₂ and Nd: YAG lasers causes the polymer degradation. Laser irradiated areas were reported to be damaged due to the removal of the materials from surfaces. Moreover, it has been reported that single color has been induced on the polymer matrix (Zheng et al., 2002). Research was carried out to introduce more than one color on the polymer’s matrix. In this research red and green colors were produced on the CPV/PVA materials by using the UV laser induced photo chemical reaction (Zheng, Rosseinsky, & Lim, 2005).

Figure 8. Laser Coloring (Lazov, Deneva & Narica, 2015).

2.4 Equipment used for laser marking

Laser marking and scribing is a technique in which the focused laser beam is used to mark the surface of the product. Certain equipment is used in the process. An oscillator is used as a source of the laser beam then these laser beams are scanned with the aid of the mirror also called as scanning mirror. A lens is placed after the scanning mirror that focuses the laser beam to the targeted product and mark it by making changing in its surface.
Formerly, the manufacturers use the traditional methods of marking the products. Those processes were very costly, mostly damage the parts of the products and easy to remove. With the advent of laser marking in industries, it enabled the engineers to mark the products with focused laser beam instead of using the physical tools. It has become an important technique in every aspect of life as marking of the products is one of the main tasks in manufacturing industries. It has helped to keep the record of the products, track the products and to enhance the quality of the products.

There are many other applications and now a day’s laser marking technique is one of the essential parts of every industrial and manufacturing sectors. Recent advancements in laser technologies enables lasers to be used for surface treatment, cutting, partial cutting, and perforations of various scrap paper. Lasers can readily attain high slicing speeds. This reveals lasers as a viable tool to replace traditional cutting processes in the papermaking sector, such as water jet cutting as well as blade tools. The samples acquired during the injection moulding process were given in this study. This approach is among the two main essential thermoplastic processing methods that, according to Industrial revolution 4.0 principles, may be automated.
(Rimington et al. 2018). According to the premises, each moulded item may be recognized by automated laser labelling. This greatly simplifies the separating of old items throughout the recycling process. This technology also has the capability of replacing other known ways of putting graphic indications on the surfaces of moulded components, such as

- in-mould labelling
- pad printing
- hot stamping
- barcode adhering
- QR code labelling

The laser-marking approach lowers the usage of additional materials to name items, lowering CO$_2$ emissions and conforming to Eco-Design principles.

Present manufacturing uses of laser technology in paper processing of materials may be found mostly in art design and sophisticated geometry packages. Existing uses, however, are for small size quantities or even single goods. To expand the volume of laser processes used in the pulp and paper industry, the fundamental mechanisms involved in the combination of scrap paper and laser beams must be understood. Not only does the laser beam react with wood pulp and other nanoparticles in scrap paper, but it also interacts with the tiny 3D network architecture of paper loaded with porosity and air gaps. As a result, as understanding about laser cutting of paper products grows, new opportunities for using lasers in cutting, folding, and surface modification of paper-based products might emerge (Czyżewski et al. 2022). Numerous new lasers are now being developed; their emergence will result in decreased investment and operational costs, as well as improved product labeling quality. New green laser beams are being
designed for marking particular items such as silicon chips without destroying the underlying material, as well as lasers producing in the blue and purple ranges of electromagnetic waves, which might help to greatly reduce the quantity of labelling sign. As a result, the laser processing industry is constantly evolving.

2.5.1 QR Codes

The interest for QR code laser traceability is expanding for the auto and packaging markets. This is the reason that now a days laser marking of the QR codes is of main interest in the field of laser marking research (Fei, & Liu, 2016). Consequently, it is desirable to empower laser marking of QR codes on PP surfaces as proposed in this review. Nonetheless, PP itself can't be carbonized as it doesn't absorb the 1064 nm frequency. Thus, the additions of laser-sensitive substances or laser absorbents to PP can further improve the laser marking performance (Riveiro et al., 2016).

2.5.2 Bar Codes

These are present in the form of dark and light lines. These codes provides all the information about the product which include names of products, serial numbers, price, expiry date, manufacturing date, model and version of the products etc. there are two types of barcodes linear barcodes and 2D bar codes.

<table>
<thead>
<tr>
<th>Linear barcodes</th>
<th>2D barcodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code 128</td>
<td>Data Matrix</td>
</tr>
<tr>
<td>UPC</td>
<td>PDF417</td>
</tr>
<tr>
<td>Interleaved 2 of 5</td>
<td>Maxicode</td>
</tr>
</tbody>
</table>

Figure 10. Types of Barcodes
2.5.3 Other Uses of Laser Marking

Laser marking is also used in creating process of ID cards and smart cards because there are least chances of frauds and is a safe mean. Moreover, it is also used in many other fields of life i.e., “food, aerospace, medicine electronics etc.” It is also used in other industries like in the Aerospace Industry. In order to guarantee the durability, identification and traceability of different products the highly durable, noninvasive and repeatable processes are required. Among these processes laser marking is the most advanced and modern technology used in aerospace industries (Velotti et al., 2016). Laser marking provide a large number of advantages in aerospace industries as compared to the other traditional marking methods these include: “it provides the noncontact working, non-contact working, high repeatability, high scanning speed, a mark width comparable to the laser spot dimension, high flexibility and high automation of the process itself” (Modest, Ready, & Farson, 2001).

Laser marking is also used in the medical Industry In the medical industry FDA (Food and Drug Administration) requires all the manufacturers to label all the devices and packages with a unique device identifier i.e., a code for identification of the devices. This code provides all the information regarding that device i.e., it provides information about the model and version, labelers, producers details serial number, expiry date and many others codes (Henriksen et al., 2022).

In terms of the automotive companies, laser marking is also used for tracing. In case of any failure automotive companies use the laser marking for tracing the product so they may easily recall the products specification.

2.6 High Marking Speed Saves the Cost

It has been reported that adding laser additive formulations at very low concentration levels, typically 0.01 percent to 2.0 percent, can result in statistically significant quicker marking
speeds. When compared to non-optimized material formulations, laser additives that have been carefully designed often saves costs up to 25% and faster marking rates (Hoult, 2012). For example, some plastics transmit the CO₂ laser beam and do not code. In this case addition of additives help the plastic to absorb the light of different wavelength and get marked (White paper).

A thermal gravimetric analyses (TGA) plot for two high-density polyethylenes used in 28mm liner less beverage closures is shown in the Figure. Thermal degradation, which produces the laser mark, occurs at different temperatures in the two polymers. To get the same mark appearance on the higher temperature polymer, more laser energy will be required that slower down the marking rate.

![TGA Plot](image)

**Figure 11.** Thermal Gravimetric Analyses (TGA) Plot (Hoult, 2012)

Some well-known industrial products could not be produced cost effectively without the additions of additives in laser. "On-the-fly" laser marking for under cap promotions on linerless beverage closures is a very interesting use. Turnkey systems can make distinctive graphics and alphanumeric text at the rate of 1500–2,000 closures per minute.
2.7 Crystallization Rate

It is one of the most important characters of the polymers studied during the marking of polymers. If lower than appropriate temperature throughout the heating process is used, a quick crystallization as a characteristic influences the marking process. According to the figure, polyethylene is the very fast crystalizing material i.e., it stabilized at 0.23 min when tested for 103°C and thus it affects the marking process to greater extent. So, it can be inferred that higher rate of crystallization of the polymers is highly favorable for the marking process when the large dimensional marks need to be formed (Savu, Savu & Sirbu, 2014).

Figure 12. Rate of Crystallization of Polyethylene (Savu, Savu & Sirbu, 2014).
3 CONCLUSIONS

Current research provides an overview of the laser marking, use of lasers for polymers marking and the factors that affect the laser marking of polymers. There were several problems that were facing regarding the marking process of polymers several techniques were in used for marking process all those techniques could not mark the polymers permanently. This research is a review which concludes that laser marking is the best way to mark the polymers because it produces the permanent marks, moreover, it is easy to use and cost effective as compared to the traditional marking processes. Several applications of the laser marking of polymers have been discussed in this research. As laser marking have make the marking process convenient and easy this is the reason that laser marking of polymers have been using in every field of life i.e., medical field, automobiles industries, aerospace etc. Moreover, it can also be concluded that addition of several additives in the polymers may increase the marking and make very clear marks on the materials. A huge interest is shown by the researchers to the marking of the polymers, several polymers and their marking techniques have been discussed in this research that can be marked easily. On the other hand, there are still some polymers and marking techniques that have not been discussed in this research this includes micro and Nano-processing of the polymers. Moreover, application of the polymers has discussed in this research i.e., the applications areas are also increasing these include marking of food products, medicines etc. still there is a need to discuss the applications of the polymers that have been modified by using the laser technology.
References


Fang, L., Xie, Y., Sun, S. and Zi, W., 2022. Large-scale synthesis of polyynes with commercial laser marking technology. Chinese Physics B.


Sastri, V.R., 2014. Polymer additives used to enhance material properties for medical device applications. Plastics in medical devices, pp.55-72.


**Website**

ias.ac.in, 2022, elaboration of the effect of polymers according to scientists, viewed on 26th May, 2022, from: <https://www.ias.ac.in/article/fulltext/boms/011/02-03/0225-0238>


sciencedirect.com, 2022. Laser Marking. Available at: