Laser Micromachining of Engineering Materials—A Review

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1 Introduction

Conventional machining has formed the backbone of machining processes in industries for ages. This type of machining is achieved by chip removal process generated as a result of direct contact between the tool piece and surface of the workpiece. Nevertheless, recent advancements in the use of high-strength material, environmental aspects, and exponential evolution of micro-level products have given rise to a newer concept in metal machining. Consequently, nontraditional machining processes have emerged to overcome the complications caused by the conventional processes. Laser micromachining is one such technique which produces intricate shapes with the help of lasers.

Laser basically is a coherent, monochromatic light emission radiation that can spread in a straight line with insignificant divergence and happen in an extensive variety of wavelength (ranging from ultraviolet to infrared). Lasers are widely used in manufacturing, communication, measurement, and medical. Energy density of the laser beam could be altered by varying the wavelength. This property has made the lasers proficient for removing extremely small amount of material and has led to the use of lasers to manufacture very small features in workpiece materials. The production of miniature features (dimensions from 1 to 999 μm) in sheet materials using laser machining is termed as laser micromachining. Laser, an abbreviation for light amplification by stimulated emission of radiation is without a doubt one of the

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best and significant developments of the twentieth century. Its continued advancement has been an exciting chapter in the history of science and technology. Development of engineering materials, intricate shape, and irregular size of workpiece confine the utilization of customary machining techniques. Laser beam machining is a standout amongst the most broadly utilized thermal energy based noncontact compose advanced machining process that may be utilized for all scope of materials. The establishment of the laser was laid by Einstein in 1917 when he initially presented the idea of photon discharge, where a photon interacts with an energized particle or atom and causes the outflow of a second photon having a similar frequency, direction, and phase [1].

The laser beam is generated by providing energy to lasing medium from an external source. The electrons at ground state of lasing medium get excited, which causes electrons to move from a lower energy level to a higher energy level and due to very high instability at higher energy level, it comes back to its ground state within a very small time by emitting a photon. The frequency of this emission is then amplified by using two mirrors one with 100% reflective surface and the other with partially reflective one. Laser beam machining is used to perform various operations such as drilling, cutting, turning, milling, etc. [2].

Micromachining with the help of lasers provides a wider wavelength range, extended pulse (from femtosecond to microsecond), and iterative rates (from single to megahertz pulse). This system transmits the pulsed beam with a power of below 1 kW. It is characterized with high precision, minimal collateral damage, applicability to all materials along with fast, and bulk production.

Laser micromachining techniques such as metal micromachining, ultrashort pulses, and femtosecond pulses are used in microfabrication. Metal micromachining includes microdrilling and micromilling. Ultrashort pulses are used in machining glass and in fabrication of waveguides in silicon. Ultrashort pulses provide high intensified beams which produce minimal thermal deprivation [3]. Femtosecond laser micromachining technique is used in the fabrication of optical devices (resonators, splitters, and waveguides), Shape Memory Alloys (SMA), and micromachining of polyuria aerogel [4]. This solution has high structural properties along with its porous structure, which makes its conventional machining complex.

Laser micromachining has also been instigated in the manufacturing of the microsized MESM parts, precision cutting of glass, small-hole drilling in PCB, and laser cutting of various polymides. Many factors contribute toward the effectiveness of laser machining such as pulse duration, intensity of beam, relative velocity, and the pulse number.

2 Literature Review

Researchers have suggested that any arbitrary surface can be generated by using laser ablation. Ablation refers to the process of removing material from the surface of an object by erosive means. Their study showed that fabrication using the beam path approach and profiled path approach techniques of laser micromachining help to create various surfaces of high quality and precision. The beam path approach is characterized by a pulse of shorter wavelength, of the order of 250 nm, depending upon the material. Profiled path of micromachining uses multiple pulsations, generating improper erosion depth without any significant change in laser profile intensity. Klotzbach et al. focused their study toward the effectiveness of laser micromachining. It focuses on the adaptability of short pulse laser systems in the industrial fields. They are highly effective in operations such as drilling and cutting of ceramic and other metals [5, 6].

Knowles et al. termed ablation as a combination of evaporation and melt expulsion, causing irradiating conditions. These conditions can be molded to facilitate high-quality micro-level drilling and cutting [7]. A short pulse laser intensifies the target area of the surface and increases the material properties to critical limits. Brettschneider et al. presented their study on the implementation of laser micromachining as a metallization tool for microfluidic polymer stack [8]. Microfluidic approach piles up multifaceted fluidic procedures, which can be utilized in the modern industry. Laser micromachining builds metal foils into a pile of polymeric layers which sticks the metallic foil together and joins them. Their study depicted the compatibleness of laser machining with various polymers without any chemical additives. Patel and Patel studied the implementation of laser micromachining as a nontraditional cutting process for aluminum based alloys [9]. Laser cutting is basically a thermal process in which a slot is cut by focused traversing of the laser beam. Their studies of different laser cutting processes have been cited as the future scope of machining. Rejab et al. studied the laser micromachining of microelectromechanical components (MEMS) by using FEM technique to build its elemental models. Their work has provided some useful parameters which could help this process replace the conventional machining methods [10].

Parashar et al. discussed the use of laser processing for improved performance and micro-level component developments [11]. Their work related to short pulsated lasers, micro and nanosecond lasers and ultrafast laser showed their widened implementation. Manjaiah et al. have stated the enactment of femtosecond laser in the machining of Titanium based Shape Memory Alloy (SMA) [12]. Femtosecond laser is characterized by high ablation rate, producing high-quality work, and precised dimension components. Agrawal has termed laser micromachining as a miniaturization technology which enables material processing with a high accuracy and flexibility. He studied the direct wiring, mask projection, and interference techniques which would mechanize the material removal through ablation and etching. His precise work throws a shadow on how ultrafast laser pulse can machine material to produce minimal cracks and improve the material properties [3].

Bian et al. explained the application of femtosecond laser in machining of polyuria aerogels [4]. Polyuria aerogel incorporates high thermal and mechanical and thermal properties. Traditionally diamond saw is used to cut this substance which damages the surface and alters its mechanical properties. Femtosecond laser is a noncontact type of material removal process, hence it minimizes the collateral damage and provides an alternative way to cut the polyuria aerogel. Long et al. has made a compound process of collecting a laser beam from the help of an electrolyte process [13]. In this experiment, stainless steel is etched by Laser-Induced Electrochemical Micromachining (LIECM) with a form of ultraviolet laser beam known as excimer laser beam in solution of NaCl. The process has few advantages like little damage characteristics, high etching-rate, and low temperature. Wavelength 248 nm of excimer laser is very short, pulse breadth is narrow, photon energy is quite great with the power of 108 W/cm^2, divergence angle is small and energy density is large. Thermal effects of 248 nm KrF laser are quite small, energy is very great. One of the effects of laser is inducing electrochemical dissolution, another is directly etching materials. He proved through the experimentation that the single-step method of transferring pattern without a mask is practical, but the etching rate is less. Etching rate could be improved by supplying electrolyte and a close distance in between the cathode and anode.

Akhtar et al. recommends that excimer laser, otherwise called the ultraviolet micromachining, is a dry manufacture procedure that speaks of an incredible option for the rapid prototyping and generation of microwave transmission lines, circuit components, and whole miniaturized hybrid microwave integrated circuits with high accuracy [14]. Microwave circuits and transmission lines help in the miniaturization for increasing the performance at high frequencies having lower power, space necessities. Sen et al. explored the fiber laser removed miniaturized scale grooves on Ti-6Al-4V of 0.11 cm thickness in air condition with numerous parametric mixes, and furthermore to establish out the parametric impacts on the groove geometry as far as depth, surface roughness, and width. Ti-6Al-4V is utilized broadly in the hip and dental inserts for its low cytotoxicity and corrosion protection, biocompatibility, fatigue, and wear-resistance [15]. It goes to the understanding that the parametric impact of the miniaturized scale grooves, different process parameters are considered for the test investigation, for example, Number of passes of 1–8; examining rate of 40–1000 mm/s; Pulse frequency of 50–100 kHz; normal power utilization of 2.5–30 W. Groove geometries are estimated utilizing optical microscope and the surface roughness is estimated utilizing AFM (atomic force microscope).

Shalahim et al. mentioned that increasing demands in microelectromechanical systems (MEMS) fabrication are moving to newer demands in manufacturing technology and industry [16]. Laser micromachining accounts for many technological plus points as compared to traditional methods and technologies, which also includes fabrication of complex shape, rapid prototyping being possible and also offers design flexibility. Laser micromachining of acrylic sheet is simulated with finite element models which are developed specifically for them. The temperature plots which are generated through these simulations are equated and debated. The significant aspect of finite element modeling is to reasonably simulate laser micromachining.

Walker et al. have introduced a new laser micromachining technique for manufacturing high-quality, low-cost waveguide structures for frequencies up to 10 THz [17]. He calculated that with this process, the waveguide components of different height and width can be machined to 1 μm accuracy. Through this test beam pattern measurement on a 2 THz corrugated feed-horn can be made. Slatineanu et al. suggested that material removal machining process can be performed in many ways one of them is based on impact phenomena [18]. Mechanical phenomena of microcracking and microcutting lead to the removal of minute quantities of the workpiece material this is how removal is done.

Mishra et al. gave a review on the Laser Beam Micromachining (LBMM) [19]. An overview is given so as to obtain current scenario of LBMM so as to know its capabilities and constraints. Various research activities are performed related with time in Nano, Pico, and femtosecond. The fundamental understanding of the main parameters involved in LBMM process has been discussed. Shalahim et al. carried out a finite element simulation for virtually studying laser micromachining of acrylic material. After performing FEM, they suggested some of the results which are essential to produce defect-free edges in given processing time [16]. They concluded that for proper simulation, proper material model, perfect thermal properties under processing, and mesh design in finite element modeling is required.

Klotzbach et al. refer to the effects of short pulse laser system in various applications. Because of easy installation, moderate cost, high efficiency, it is having a wide scope of applications [5, 6]. Some of the applications include drilling, cutting, material removal, etc. With the help of novel technique, they were able to join two distinct materials polymer and ceramic. It comprises of two steps, one preparation of ceramic surface and another laser-based partial melting of polymer. Malcolm C. Gower et al. discussed aboutthe industrial applications of laser machining [20]. The use of pulsed laser is being carried out in several industries and has various applications in the field of microvia, catheter hole drilling, and nozzle of ink jet printer. Research deals with the accuracy and effectiveness of laser machining in various fields.

Though material rate by pulsed light sources is being examined from the time of the creation of the lasers [21, 22]. During the year 1982, polymers carved by excimer lasers stimulated broad examinations went for utilizing the procedure for micromachining. In the prevailing years, logical and modern inquiries about in this area and field has multiplied to a stunning degree, presumably stimulated by the surprisingly little highlights that can be carved with little harm to encompassing an area of material [23, 24].

Lately, fabricating industry has watched a fast increment demand for small-scale items and miniaturized scale segments in numerous mechanical segments including the hardware, optics, therapeutic, biotechnology, and car parts. These micro-system-based products are an important contributor to a sustainable economy. The laser pulses used in micromachining processes are divided into two groups, one is short (nanosecond) laser pulse and other is ultrashort (picoseconds, femtosecond) laser pulse. Because of the short pulse duration, peak forces of more than 15 GW can be achieved, which offers access to advance removal components, as multiphoton ionization. Because of the short association time, just the electrons inside the material are warmed amid the pulse duration and heat-influenced zones are immaterial [25].

Laser micromachining or ablation phenomenon can happen amid laser—polymer association in two different systems: one of them is photothermal and the other one is photochemical removal. Since polymers display solid absorption in ultraviolet infrared wavelengths, however, powerless absorption at visible and nearly-infrared spectra, in this way, the removal system is a blend of photochemical and photothermal procedures. The compound obligations of the polymer material decay by the photon vitality of the laser light, though in photothermal mechanism, polymer removal happens by quick liquefying and vaporizing. For photochemical removal to happen, the energy of the photons at that wavelength ought to surpass the intermolecular bond energies of the polymer [26]. The photon energy diminishes as the wavelength increments. In this manner, the high vitality of the UV photon breaks the atomic bonds and results in direct photochemical ablation.

The excimer laser has wavelengths accessible at 308 and 248 nm when utilizing gas blends of XeCl and KrF separately. The frequency changed over Nd: YAG lasers with a major wavelength of 1,064 nm have wavelengths of 355 and 266 nm for the third and fourth harmonics, individually. Pulsed Nd: YAG laser beam were utilized by Lau et al. for experimentation to see the impact of HAZ on 2.5 mm thick carbon fiber composite plate with a few parameters [27]. They found that HAZ increments with increment in pulse width, pulse energy, and pulse frequency and diminishing with the feed rate. They likewise watched that heat-influenced zone will be greater when compacted air utilized as assisted gas while argon utilized as assisted gas have smoother cut surface and less HAZ.

As opposed to the UV laser, a CO_2 laser emanates infrared radiation at a wavelength of 10.6 μm which implies that the laser bar dependably removes the basic material photothermally. The region in which focused laser pillar meets the workpiece surface, temperature of the lighted spot rises so quickly that the material first melts and after that decomposes, leaving a void in the workpiece. Laser power, pulse length, cutting rate was utilized as fundamental parameters by [28] for cutting mild steel cutting utilizing beat Nd: YAG and CO_2 laser to perform tests. It was seen by their examination that the CO_2 laser can cut quicker than Nd: YAG, however, Nd: YAG laser serves better surface roughness. It has additionally been watched that the two parameters, i.e., pulse length and cutting rate likewise influences the surface roughness.

3 Types of Lasers Used in LBMM

There is a range of industrial lasers available in a present scenario for micromachining applications. Generally, two types of laser are used for micromachining metals—short pulse laser which emits short pulses of light, of the order of picoseconds to nanoseconds and ultrashort pulse laser which emits ultrashort pulses of light, of the order of femtosecond to ten picoseconds [29]. These lasers are so-called based on the duration of their beam pulses. Consider an example, the pulse produced by a femtosecond laser only lasts femtosecond (a femtosecond is one-millionth of a nanosecond or 10–15 of a second). Similarly, each pulse emitted by a picoseconds laser lasts picoseconds and each pulse released by nanosecond laser lasts nanoseconds. The short pulse means the energy is localized at small depth.

The laser beam can be demonstrated as a radiant energy source with a self-assertive spatial and temporal intensity distribution. The fraction of aggregate beam energy absorbed at the erosion front relies upon the radiation properties of the workpiece and the geometry of erosion front. The power of the incident beam is expressed by Io. The decrement in the laser intensity with the depth is given by Eq. (1)

$$I_x = I_o e^{-\alpha x} \tag{1}$$

where α is optical absorptivity of the material and x is depth into the material. The optical absorptivity (α) of the material records for the decay of laser intensity with depth inside the material. The absorption coefficient relies upon the temperature and wavelength but at constant α, decay of laser intensity with depth is given by Beer–Lambert Law as Eq. (2)

$$I(z) = I_o e^{\alpha z} \tag{2}$$

where I_o is the intensity mainly inside the surface after considering reflection losses. Lambert's law states that absorption of a particular material sample is directly proportional to its thickness (path length). The depth to which the intensity of the laser drops to *1/e* value of its initial value at the interface is its optical penetration or absorption depth (δ) given by $\delta = 1/\alpha$ [19].

4 Methodology and Mechanism

Laser micromachining takes place with the help of ablation technique. Ablation means the removal of material either thermally or using photochemical erosion [15]. In photochemical or nonthermal ablation, the energy coming out from the incident photon results in the directly breaking of the bond of the molecular chains in the organic materials removal with the help of molecular fragmentation without any thermal damage. So the photon energy during thermal ablation, the excitation energy rapidly converts into heat, causing temperature increase (Fig. 1). Thus, the temperature increase can result in the ablation of material by surface vaporization or spallation which is caused due to thermal stresses [3, 10]. A thermal ablation mechanism is much more useful for the material removal during micromachining of both ceramics and metals. Absorptive coefficients and thermal diffusivity determine the ease of ablation. The large value of absorption coefficient and low value of thermal diffusivity increases ablation efficiency. The ablation of material by internment of laser energy can be aided by using shorter pulses. For longer pulses,

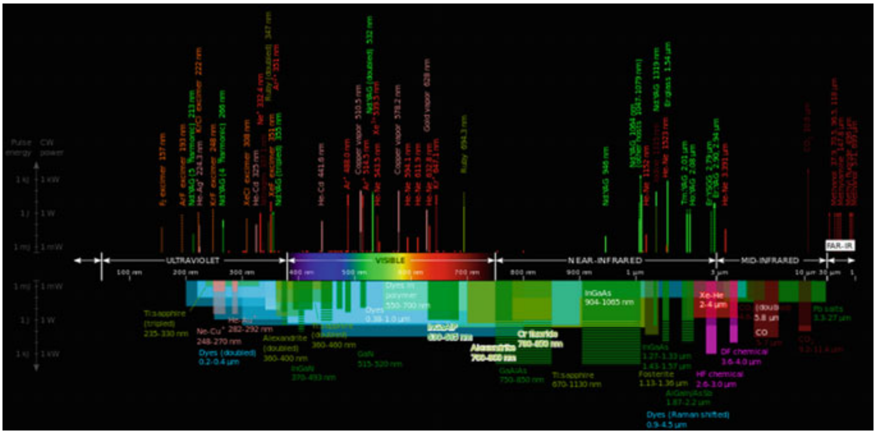

Fig. 1 Schematic diagram of laser micromachining

the absorbed energy will be released to the surrounding by transfer of heat. The ablation process is described by the ablation threshold. Ablation threshold differs from material to material. Laser parameters such as wavelength, eloquence, density of pulse, and material properties govern the ablation process. Excimer lasers and femtosecond lasers feature significantly in power sourcing the machining process. The excimer laser is an ultraviolet laser that is used to micro-machine number of materials without the need of heating them. The photon energy generated by excimer lasers and that of the molecular plastic bonds are comparable. Hence, they are used for plastic and similar metal and not for any metal. When excessive power is applied, the removal phenomenon includes a combination of heating and photon attack. Femtosecond lasers have high power and short pulse duration. These methods generate diminutive heat affected layer which leads to machining of micro-shapes with high precision and lesser defects [3].

Laser ablation is the process of removal of material from a solid surface by irradiating it with a laser beam. At lower energy density, no material removal takes place till a point is reached where material removal starts to happen that is called the ablation threshold [30]. A noteworthy removal of materials happens over a specific threshold power density, and the ejected material structures a luminous ablation plume. This threshold power density required to shape plasma relies upon the retention properties of the given material, the wavelength of laser utilized, and pulse duration [31]. The removed material is directed toward a substrate where it recondense to form a film. The total mass ablated from the target material per laser pulse is called as ablation rate. To improve the reactivity of the background gas with the removed species, either a RF-plasma source or a gas pulse setup are utilized [31].

5 Applications of LBMM

The pulsed lasers are being used for microprocessing materials in several engineering industries. Biomedical catheter hole drilling, microelectromechanical system (MEMS), microvia ink jet printer head, and thin-film scribing are some of the important applications of LASER micromachining.

5.1 Hole Drilling

The capacity of drilling small holes to 1 µm width is a key empowering innovation to fabricate cutting-edge items. Laser micromachining provides answers for key issues in assembling incorporated circuits, interconnects, PC peripherals, hard disks, and telecommunication. The prerequisite for material handling with micron or submicron determination at high speed and low-unit cost can be satisfied by this innovation. The combination for high-determination, precision, speed, and adaptability is permitting laser the growing importance. The combination of high-determination, precision, speed, and adaptability gave laser micromachining to pick up acknowledgment in numerous industries.

5.2 Microvia Hole Drilling in Circuit Interconnection

Microvia drilling in printed circuit boards and adaptable circuits is a gigantic business with several lasers (for the most part in Asia) drilling billions of microvias yearly. A microvia is a little opening bored for electrical conductivity in printed circuit boards. As diameter decreases (below 100 µm), lasers are preferred over mechanical drills. Since copper is very reflective along these lines, Q-switched Nd: YAG lasers are utilized to penetrate the metal, though CO_2 lasers are used to drill the dielectric material. Drilling microvias by removal were initially examined during the mid-1980s utilizing pulsed Nd: YAG and CO_2 lasers [12, 32]. Excimer lasers drove the path in applying it to volume creation when Nixdorf PC plant presented polyimide ablative drilling of 80 µm dia across vias in MCM's—were used to interface silicon chips together in PCs [29]. Other centralized server PC makers, for example, IBM quickly took after suite and introduced their own special generation lines for this application.

Stage 1. Trepanned hole in top copper conductive layer by Nd laser.
Stage 2. Fiber-reinforced composite drilling by CO_2 laser [27, 33].

With less process ventures than different techniques, laser drilling is viewed as the most flexible, solid, and high return innovation for making microvias in thin-film packages.

5.3 Inkjet Printers Nozzle Drilling

It contains a line of little-tapered holes by which ink droplets are squirted into paper. By at the same time diminishing the nozzle dia across and by diminishing the hole pitch and extending the head, increased printer quality can be accomplished. Current printers like HP's Desk Jet 800C and 1600C have nozzle of measurement equivalents to 28 μm giving a resolution of 600 dots for every inch (dpi). At average yields of over 99%, excimer laser mask projection is currently routinely utilized for drilling varieties of nozzles each having indistinguishable size and divider point [34]. The greater part of the ink jet printer heads as of now sold in Asia and US are excimer laser penetrated.

5.4 Biomedical Devices

Lasers make a huge part in the manufacturing of disposable medical devices since the market for these is immense. Microdrilling by excimer lasers is utilized for delicate tests for analyzing Arterial Blood Gases (ABG's) [35]. These comprise of spiral rectangular holes of 50×15 μm machined in a 100 μm dia across acrylic (PMMA) optical fiber by a laser. The clean cutting capacity of the laser gives the essential quality that counteract sinking and blockage when embedded into the artery. In intensive care units, choices on patient's ventilator conditions and the organization of various medications are made based on ABG comes about.

5.5 Hole Drilling in Aircraft Engine Components

Jet engine motors which are used nowadays, have up to a huge number of holes bored into different parts, for example, turbine blades, combustion chambers, and nozzle guide vanes. These gaps are under 1 mm in dia, few are through-holes and few are molded holes. Near infrared lasers (for example, high pulse energy Nd: YAG or fiber lasers) are normally utilized as a part of either a trepanning mode or percussion. Such gaps enable a layer of cooling air to cover the parts; which expands life, diminishes maintenance, and accomplishes prevalent performance qualities.

6 Numerical Analysis of Laser Microdrilling

Laser drilling is an extensively used process for fabrication of microvias and micro nozzles as discussed above. After being exposed to short pulses, material is removed by ablation, leaving a crater. By this means, well-shaped micro-hole can be drilled into the material bulk. It is experimentally observed that time delay between pulses has great influence on the shape and machining quality [36]. There is a threshold time at which abrupt shape degradation occurs. To achieve good machining quality and desired shape, longer time delay is preferred. The effect of the time delay can be explained by coupling of residual heat between successive pulses. In this section, our focus will be on quantitative investigation of accumulation of residual heat.

1. The heat dissipation after laser irradiation will be described by a mathematical model.
2. FEM method will be used for the analysis of temperature at the bottom of the crater ablated by a train of pulses.

In FEM, the whole problem domain is subdivided into simpler parts, called finite elements, and it minimizes an associated error function by using vibrational methods from the calculus of variations to solve the problem [37]. Dissimilar to the possibility that joining a few small straight lines can estimate a bigger circle, FEM incorporates techniques for interfacing a few straightforward elements equations over numerous little subdomains, named finite element components to approximate a more complex equation over a bigger area. The threshold-like time delay has been observed for various lasers, including Nd-YAG laser and femtosecond laser. Through this research optical specification for lasers, especially ultrashort laser, used for micromachining can be found.

6.1 Laser Direct Writing

The flexibility offered by laser-based direct-write techniques is one of a kind as it gives an opportunity to include, evacuate, and customize distinctive sorts of materials without physical contact between the tool and the material [38]. Laser pulses used to produce patterns can be manipulated to control the creation, structure and properties of 3-dimensional volumes of materials crosswise over length scales traversing six magnitudes of size, from nanometres to millimetres. Laser direct writing is used to produce 2D and 3D structures with the help of two approaches. One of them is direct etching from PMMA sample and other one is replication from metal insert that has been carved by direct laser etching. The laser beam scans in XY plane through a two-axis galvanometer. A high-speed precision translational stage is used to move the sample in Z-axis. The knowledge gained through studies on laser ablation will be used to attain high resolution and excellent quality of machining. The system will be used to manufacture fine parts used in aircrafts and miniaturized satellites.

6.2 Submicron/Nano Machining Using Ultrashort Laser

The most recognizable characteristic of ultrashort laser micromachining is that the ablation threshold is clearly defined [39]. Thus, feature size smaller than the laser spot-size can be achieved by controlling the fluency of the laser pulses. However, at the scale of few micron and submicron the quality of machining, throughput and reliability are not acceptable for industrial applications. In this research we aim at developing an ultrashort laser submicron machining, replacing the costly and complicated beam machining in some applications.

7 Recent Advancements in Laser Micromachining

Various micro-electronic industries have shifted their attention towards miniaturization, producing smaller features and holes working with their materials hence implicating higher tolerances (Fig. 2). Laser micromachining has proven to be an optimal tool in delivering high precision, consistent results, faster throughput, higher yields and lower manufacturing cost. Lasers with shorter wavelength such as Ultraviolet rays results in a low peripheral heating, hence have gained popularity.

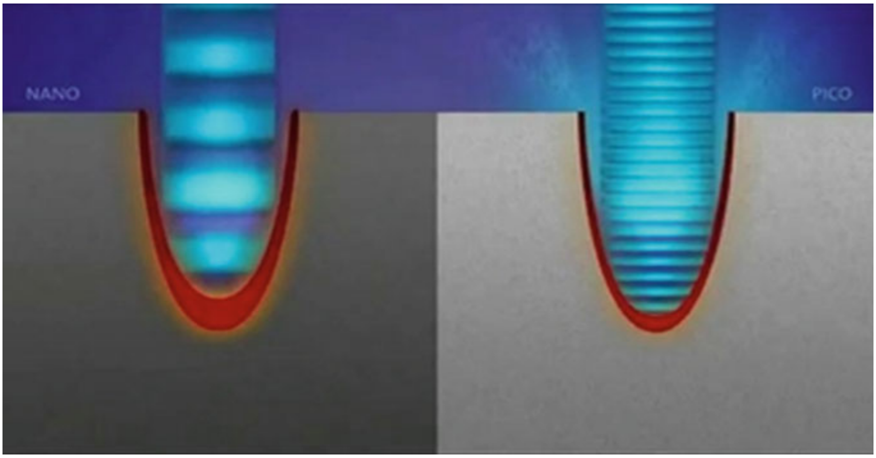

Fig. 2 Advancement in laser micromachining

Fig. 3 Nano and pico pulse

Thermal loading of materials can be reduced by using pulsating lasers (Nanosecond laser) (Fig. 3). Nanosecond laser gives high peak power using only modest average power thereby consuming only few watts of overall power. But this method leaves some heart affected zones which may not be good enough for some applications. Picosecond pulsed lasers are being preferred precisely because it does not create any heat zones and produces less heat. Most advanced form of laser machining is the Talisker. It is a two-stage laser which consists of a fiber laser and a free space amplifier. It covers all the drawbacks of previous models and provides fast and accurate machining at an affordable manufacturing cost.

8 Conclusion

Laser micromachining technique has proved to be a sustainable tool in the miniaturization era. Laser ablation is confined to only small areas which absorbs energy. The key for the success of laser ablation is the intensity of pulse, wavelength, and proper shape. Femtosecond and ultrafast lasers produce highly accurate and intricate shaped components. Ultrafast laser pulses produce minimum contamination to the surrounding and fast. Because of its flexible nature laser machining has found wide applications in the fabrication of micro-electronic and mechanical components. They can generally machine any material from metal to glass, ceramics, and many polymers. This study shows a comprehensive study of various laser machining processes and their role in replacing the conventional machining processes. As technology grows, their need will increase. Furthermore, there are certain parameters which can be optimized. The research in the optimization area could further grow the stature of laser machining.

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