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Micromachining of Metals with Copper Vapor Laser

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Abstract: ***Laser micro machining is an advanced manufacturing method found expanded use in automotive, aerospace electronics, telecommunications & medical device industries. Copperbromide (CuBr) lasers with their excellent beam quality offered observable advantages and improvements in high precision and material processing at the microscale .In this paper the application of 8 W copper bromide laser for micro machining has been demonstrated. Micro machining experiments involved laser marking and micro drilling of metals such as copper and aluminum. It has been found that micro machining was greatly influenced by the optical and thermal properties of the materials. The laser marking and drilled holes are fine in aluminum as compared to copper because of its lower absorption and lower thermal conductivity.***

Keywords: Micro machining, Laser micro drilling, Laser marking, copper vapor laser

1. Introduction

Laser micro machining is an advanced manufacturing method found expanded use in automotive, aerospace electronics, telecommunications & medical device industries [1]-[2].Micro-machining encompasses many manufacturing techniques such as drilling, cutting, welding, ablation, and material surface texturing. These techniques allow for the creation of extremely tiny surface features that fall into the micrometer range. Such processes require a rapid heating, melting and evaporation of the material. In order to reduce heat effects like melting and burr formation and avoid the necessity for post-processing steps, very low nano, pico, and even femto second pulse durations are used [3]. The potential to create small and unique structures that are difficult to do with traditional technologies and its adaptability to materials that have historically been difficult to deal with, such ceramics, glass, and composite materials, are the key reasons for the advancement in laser micromachining [4].

A variety of laser types are used in laser micro machining. The copper vapor lasers, excimer lasers & Nd solid-state lasers are the most commonly used laser for micromachining. Focus ability of a laser beam is one of the most important characteristics of a laser micro machining system. For the purpose of creating a small, circular laser focus spot with an acceptable focal depth (20-30 times the spot size), the laser beam must be in the visible or ultraviolet range and be close to diffraction limit [5]. The laser pulse duration must be smaller than a few microseconds in order to minimize the heat-affected zone and minimize the amount of heat conduction to the material during machining. For the removal of material for more controllable fashion, multi-kHz operation is recommended. This ensures that each pulse removes a modest amount of material while maintaining processing speed due to the high pulse rate [6].

2. Copper Vapor Laser for Micromachining

In the class of pulsed metal vapor lasers, the copper vapor laser (CVL) is the most useful laser, which are inherently high gain, self-terminating lasers. The excitation process in this laser produces a pulsed laser output ranging from 10 to 50 nanoseconds(FWHM) at repetition rates of upto 100 kHz. The main wavelengths for the copper vapor laser are at 510 nm & 578 nm. These lasers yield pulsed energies of the order of 1 mJ or higher, leading to average powers of 10 to 100 W [7].

The CVL's high operating temperature (1500° C) makes it difficult to design a sealed off laser system with a long lifespan. This high temperature is required to maintain copper density in the discharge volume. In Copper bromide lasers Copper atom density in the discharge volume is produced by dissociation of CuBr. The dissociation of CuBr takes place at much lower temperature and so in copper bromide lasers the operating temperature of the laser tube is lowered to about 400° C [8].

Due to the low laser peak power of CW or long pulse CO2 and Nd:YAG lasers, which are widely used in industries, the majority of material removal in laser machining occurs through melting and ejection. Due to long interaction time these lasers leads to heat affected zone [9]. In addition, the material removal during laser machining is less controlled at longer wavelengths (i.e., 10.6 μm) because of the intense plasma-beam interaction caused by inverse bremsstrahlung. Also, the reduced focus ability of the infrared laser beam makes it more difficult to produce micron scale machining. Although YAG laser systems have a lower wavelength (1.06 μm) and less noticeable plasma-beam interaction, their beam quality is usually poor due to laser rod heating. In order to solve these issues, laser ablation, which produces very minimal melt formation, must be the primary material removal process. The material removal in this fashion can then be well controlled within the area illuminated by laser light [10].

The copper vapor laser is the best tool for precise micro machining because of a number of features [11].

- The radiation of the CVL's wavelength is naturally absorbed by metals and hard materials which gives

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extremely effective material removal at almost any angle of incidence.
- The CVL have ability to machine metals, diamond, silica, glass, silicon, ceramics and many other materials that are difficult to machine by traditional techniques.
- The CVL excels at high-aspect-ratio drilling.
- The very high peak power density removes the material either by vaporization or ablations resulting in clean and precise machined features that do not require finishing procedures.
- Thermal effects are minimized by the small amount of energy contained within the short pulses.
- The high pulse rate gives high machining speeds.
- The excellent beam quality produces extremely small spots with very high power densities enabling the machining of small features from 1 µm upwards.
- The frequency doubling of the CVL produces a similarly pulsed laser beam in the ultraviolet region of the spectrum which can be used for the precision micro machining of the plastics.

It is possible to treat every metallic, ceramic or very hard material with copper vapor lasers. Typically, drill hole diameter or cut kerf width shows values in the range of the focal diameter [10]. The area of the machinable work piece thickness ranges from several micrometers to some millimeters.

Possible areas of use and special applications are listed in table 1[12]:

Table 1

Industrial branch	Typical tasks
Medicine	Scratching or cutting of ceramics. Cutting of implants.
Automobile	Scratching of piston rods.
Aeronautics	Perforating of airplane wings.
Micro-electronics	Cutting of SMD-screens.
Marking	Drilling of ink jet print heads.

3. Experimental Setup

The experimental set up for the study of micro machining consists of an 8 W sealed off copper bromide laser, a beam delivery system including a 45° inclined plane mirror and a 25 mm focal length focusing lens and a 2 – axis CNC work station. The ray diagram for experimental set up is shown in fig. 1. The experiment is performed on metals namely copper and aluminum. Experimental parameters include laser pulse width of 40 ns and pulse repetition rate of 19 kHz. The samples made are analyzed by scanning electron microscope.

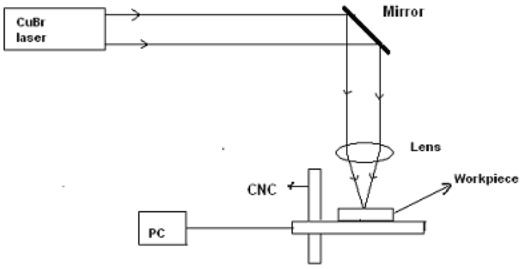


Figure 1: A schematic layout for the experimental set up

4. Measurement of divergence of the beam:

The experimental set up for the measurement of divergence of the beam in unstable resonator configuration is shown in the figure 2. The laser beam has been folded with the help of two 100 % reflecting mirrors and then allows passing from the lens of focal length of 2 meter. The pinhole is placed at the focal position of the lens and the beam is scanned with the help of pinhole. The power of the scanned beam is allow falling on the detector and measured with the help of well-calibrated power meter.

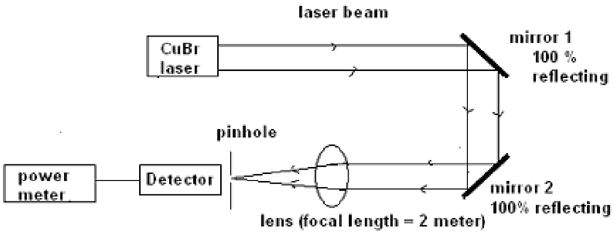


Figure 2: Measurement of divergence of laser beam

The experimental observations are taken for three different diameters of pinholes and for these three pinholes first the power is measured without passing through pinholes and after that the power is measured after passing through the pinholes. The graph is plotted between the diameter of the pinhole and the fraction of power passing through the pinhole (Fig: 3). The focal diameter of the beam is taken for the pinhole from which the $1/e^2$ of the maximum power is passed and from the graph the focal diameter is found to be equal to 1.3 mm. And from the relation,

Focal diameter = Focal length of the lens × Divergence of the beam.

The divergence of the beam is equal to 0.65 mrad.

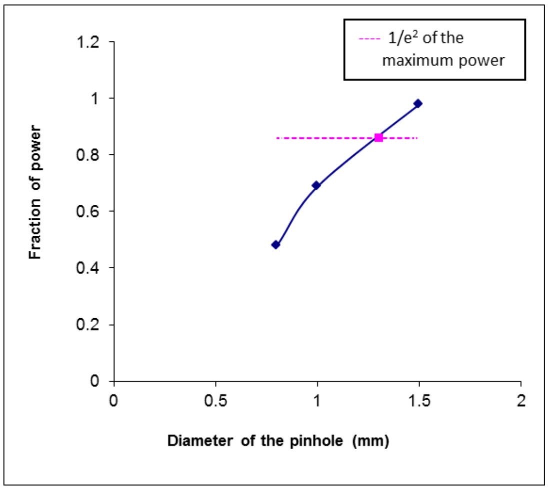


Figure 3: Graph for the measurement of divergence of the beam

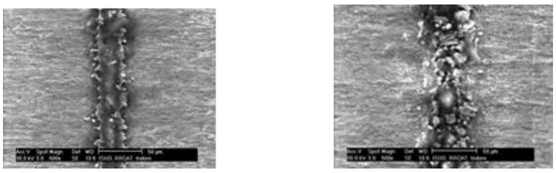
5. Experimental Results and Discussions

The experimental study of micro machining with copper vapor laser involves laser marking and laser drilling on copper and aluminum. The experimental result obtained has been discussed as follows.

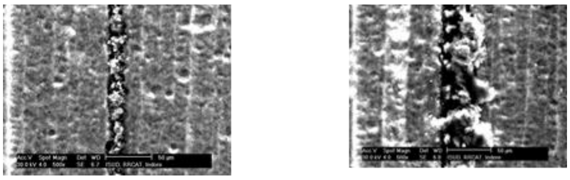
5.1 Laser Marking

In laser marking the beam irradiance is such as to allow only a small amount of material removal from the surface. This make it possible to create a visible mark which may be used to engrave identifications, numbers or logos etc. on particular objects. Materials that are transparent to the laser wavelength may still be marked if they are coated with a material that is absorbed [13].Laser marking is a surface process. Typically the light absorbed during the optical pulse (which can be very short e.g. < 0.1 μs) is transferred in to heat thereby creating a high “instantaneous” temperature rise in the material, resulting in surface melting and resolidification, carbonization, chemical decomposition or explosive ejection of the material.

The experiment of laser marking has been performed by making grooves on copper and aluminum.The groove width for copper and aluminum is found to be 30 and 24 μm respectively for optimum scanning speed 20 mm/sec. The groove width for copper is higher than aluminum due to its higher thermal conductivity and high absorption of the beam in visible range of the spectrum.. Due to high peak power density signatures of superficial melting (“beach marks”) seen in the surrounding regions. The viscous oxides of these metals formed during laser treatment frustrate efficient melt ejection from the grooves. In these metals broad heat affected zone is seen on both sides of the groove. The groove width found to be increases with decreasing scanning speed due to long interaction time. The scanning rate below the optimum scanning speed results in filling a groove with resolidified metal due to long laser beam dwell time. This is because the melt ejection is easier from the surface but with deepening of groove force required for melt ejection increases. However, the greater defocusing on the bottom of the groove, resultant recoil pressure reduces, leading to inefficient melt ejection. The SEM pictures of laser marking on copper and aluminum is shown in fig. 4.



(a) Cu, Speed = 20mm/s **(b)** Cu, Speed = 2 mm/s



(c) Al, Speed = 20 mm/sec **(d)**Al, Speed = 2 mm/sec

Figure 4: Grooves in Copper and aluminum

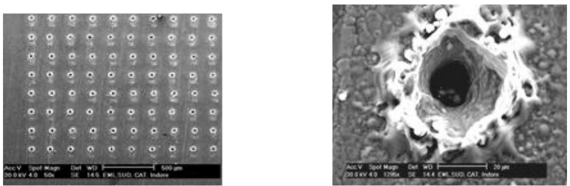
5.2 Micro drilling

Laser drilling involves a stationary laser beam, which uses its high power density to melt or vaporize material from the work piece. This method is sometimes called percussion drilling. Laser hole drilling is a material removal process involving complex laser interaction, heat transfer, fluid flow and phase change. There are two forms of material removal; vaporization and liquid expulsion. When the surface of a work-piece is heated beyond its boiling point, vaporization occurs and a recoil pressure is generated. This pressure ejects the melt from the interaction zone, and a cavity is formed as a result. Wei and Chiau showed that the evaporation rate was only 1/200 of that of melting [14]. Therefore, the hole formation takes place largely in the form of liquid melt ejection rather than evaporation. Due to incomplete expulsion of the ejected material from the drilling zone, spatter is formed which adheres to the work piece surface around the periphery of the hole entrance. Because melt ejection is the dominant material removal process in laser percussion drilling, spatter formation is an influential factor of hole formation and hence the hole geometry. The shape of percussion-drilled holes is determined by the spatial characteristics of the laser beam. Repeatability of percussion-drilled holes is as good as the repeatability of laser pulse-to-pulse energy output.

The experiment of micro drilling was performed by making fine drills on the thin foils of copper and aluminum of thickness 100 μm. The experimental results are summarized in table2. As compared to copper, finer laser-drilled holes were produced in aluminum foil of same thickness. The drilling time for aluminum is also less as compared to that of copper. This is because of higher thermal conductivity of copper. In copper the drilled holes are more tapered as compared to aluminum due to its higher thermal conductivity. The SEM picture of the laser drilled hole matrix in copper foil of thickness 100 μm is shown in fig 5 (a) and its magnified view of single laser drilled hole is shown in fig 5 (b). The SEM picture of the laser drilled holes in aluminum foil of thickness 100 μm are shown in the fig (6).

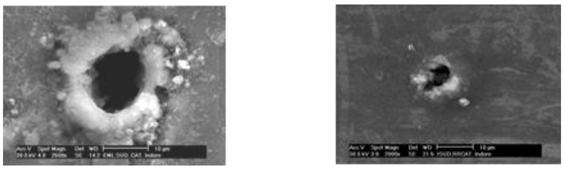
Table 2

S. N.	Material	Drilling time (Approx.) (Seconds)	Hole diameter (Entrance side) (μm)	Hole diameter (Exit side) (μm)
1.	Copper	1	40	12
2.	Aluminum	0.6	15	8



(a) 100 holes in 4mm^2 (b)

Figure 5: Laser drilled holes in copper foil of thickness 100 μm



(a) Entrance side (b) Exit side

Figure 6: Laser drilled hole in aluminum foil of thickness 100 μm

6. Conclusion

The laser micro machining on various metals such as copper and aluminum has been demonstrated with 8 W copper bromide laser. The micro- machining applications are greatly influenced by the optical and thermal properties of the materials. The groove width for copper is larger than that of aluminum due to its higher thermal conductivity and high absorption of the beam in visible range of the spectrum. The groove width found to be increases with decreasing scanning speed due to long interaction time. In aluminum the fine holes are drilled because of its lower thermal conductivity and lower absorption as compared to copper. The laser drilled holes are tapered. In copper the holes are more tapered as compared to aluminum.

References

[1] H. Treusch and G. Herziger, "Metal precision drilling with lasers," SPIE, Vol. 650, pp. 220-225,1986.
[2] S. Mishra, V. Yadava, "Laser beam micromachining (LBMM) – a review," Opt. Lasers Eng., vol. 73, pp. 89–122, 2015.
[3] W. Steen and J. Mazumder, "Laser Material Processing," Springer- Verlag London, 2010, pp. 131–198.
[4] van Krieken, J. Schaarsberg, and H. Raterink, "Laser micro machining of material surfaces," SPIE, Vol. 1022, pp. 3437,1988.
[5] M. Kocik, A. Dabrowski, T. Kasperkowicz, J. Mizcraczyle,"CuBr laser system for precision micro machining of the materials", SPIE, vol 4184
[6] J. J. Chang, M.W. Martinez, B. E. Warner, E. P. Dragon, G. Huete and M. E. Solarski, " Precision micro drilling with copper vapor lasers", ICALEO (1994), pp 323-331.
[7] O. Svelto, Principles of lasers, Third edition, Plenum press.
[8] M. Kocik, A. Dabrowski, T. Kasperkowicz, J. Mizcraczyle,"CuBr laser system for precision micro machining of the materials", SPIE, vol 4184
[9] Hans W. Bergmann, Martin Hartmann, Tomas Slunecko, Eric Gan, Karsten Schutte, " Copper vapor laser for fast precision machining", SPIE, vol 2789, pp 281 – 292.
[10] W. M. Steen, Laser material processing, second edition.
[11] Alison C. J. Glover, David W. Coutts, Donald J. Ramsay and James A. Piper, " Progress in High speed UV micromachining with high repetition rate frequency doubled copper vapor lasers", ICALEO (1994), pp 343-351.
[12] Martin Hartmann, Jurgen Koch, Adolf Lang, Karsten Schutte, Hans W. Bergmann, "Industrial aspects of precision machining with copper vapor lasers", SPIE, vol 3097, pp 260 –266.
[13] George Chryssoluris, Laser machining – Theory and Applications, Springer-Verlag publishing, 1991.
[14] Wei PS, Chiau L., "Molten metal flow around the base of a cavity during a high-energy beam penetrating process", Int. J Heat Transfer, 1988; 110:918-23.