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Effect of laser beam conditioning on fabrication of clean micro-channel on stainless steel 316L using second harmonic of Q-switched Nd:YAG laser

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ABSTRACT

Laser micromachining of metals for fabrication of micro-channels generate ridge formation along the edges accompanied by ripples along the channel bed. The ridge formation is due to the formation of interference pattern formed by back reflections from the beam splitter and other optical components involved before focusing on the work piece. This problem can be curtailed by using a suitable aperture or Iris diaphragm so as to cut the unwanted portion of the laser beam before illuminating the sample. This paper reports an experimental investigation on minimizing this problem by conditioning the laser beam using an Iris diaphragm and using optimum process parameters. In this work, systematic experiments have been carried out using the second harmonic of a Q-switched Nd:YAG laser to fabricate micro-channels. Initial experiments revealed that formation of ridges along the sides of micro-channel can easily be minimized with the help of Iris diaphragm. Further it is noted that a clean micro-channel of depth 43.39 μm, width up to 64.49 μm and of good surface quality with average surface roughness (R_a) value of 370 nm can be machined on stainless steel (SS) 316L by employing optimum process condition: laser beam energy of 30 mJ/pulse, 11 number of laser scans and scan speed of 169.54 μm/s with an opening of 4 mm diameter of Iris diaphragm in the path of the laser beam.

1. Introduction and literature review

Laser micro-machining (LMM) is widely used for precision fabrication of the critical parts required in micro electro mechanical systems MEMS [1,2], biomedical instrumentation [3–5] and optical instruments [6,7], waveguides [8,9] and micro-channels for micro-fluidic devices [10,11].

In LMM, a high intensity laser beam is focused on to the substrate. This results into the ablation of material and laser induced plasma formation in the focal region. Laser micromachining has advantages of fast material processing, absence of tool related issues and ability to achieve high precision. It also has the capability to machine all types of materials irrespective of their hardness [12] and thermal and electrical conductivity [13].

Laser micro-machining has been reported on a variety of materials such as ceramics [14,15]; polymers [16–19] and metals [20–22]. There have been several reports on process modelling [23,24] and effect of process parameters in laser drilling and micromachining [10]. Experimental investigations have been carried out to study the effect of process parameters such as pulse duration [25,26], wavelength [27,28], and laser beam energy [29] on the performance parameters viz. material removal rate; dimensional accuracy of machining; and surface quality. Pulse duration is one of the key parameters that affects the precision of laser machined components. Liu et al. [30] have reported that ultra-short lasers pulses results in comparatively better precision in micromachining in terms of minimal heat affected volume. On similar front, Leitz et al. [25] conducted a systematic comparative study on laser micromachining with laser pulse durations of micro, nano, pico and femtosecond. They reported that pico and femtosecond laser offers best quality in terms of material processing compared to micro and nanosecond laser. Jandeleit et al. [26] reported that picosecond laser generates more precise micro features than that of nanosecond laser due to its capability of unit material removal during laser ablation. However, the material removal rates of micro and nanosecond laser is higher compared to that of femtosecond and picosecond laser which facilitates faster material removal during micromachining.

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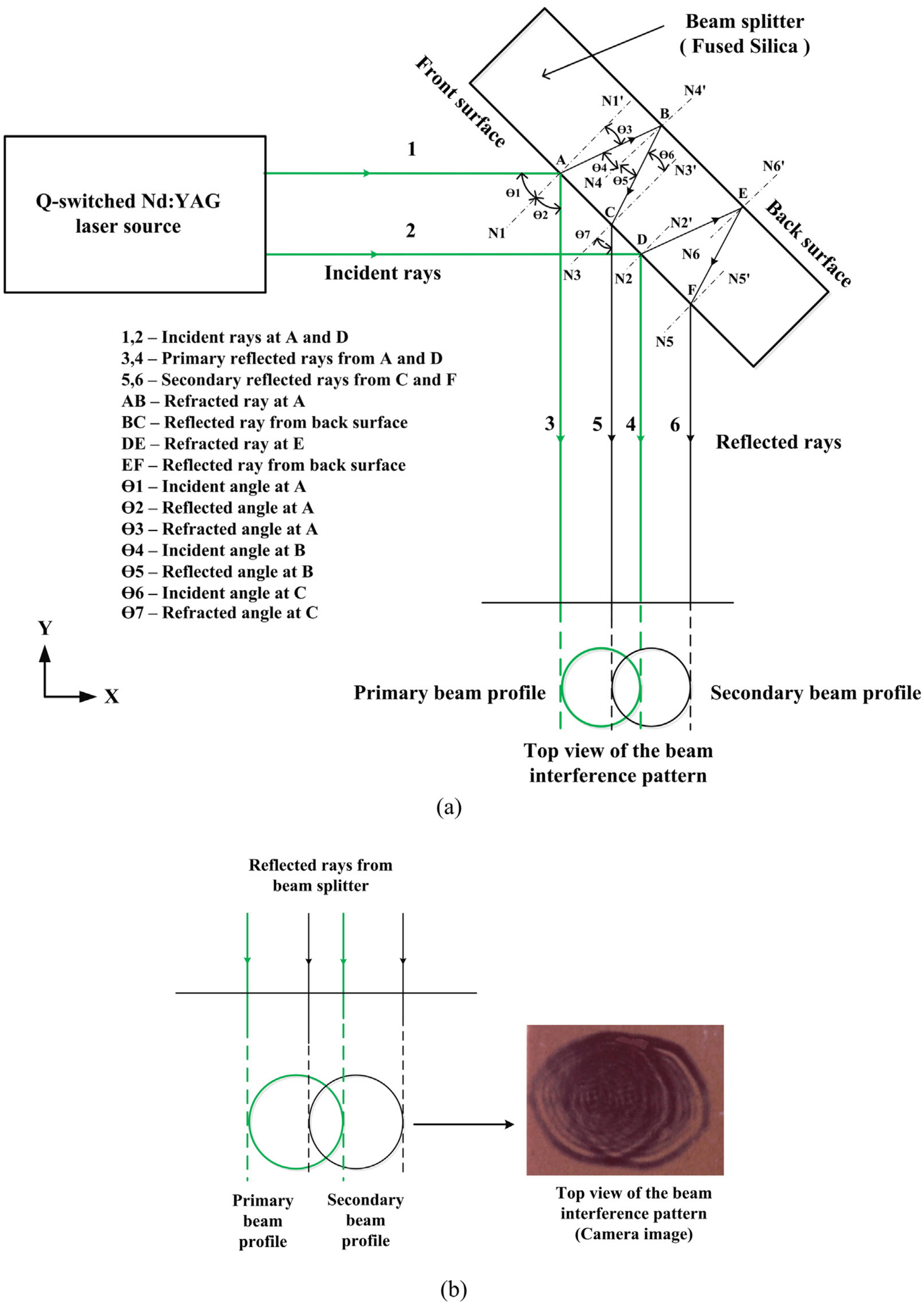

Fig. 1. (a) Travel of laser beam and formation of interference pattern; (b) camera image of the beam interference pattern.

Wavelength of the laser beam interacting with the material also affects the precision of micromachining. The diffraction limited focus spot is proportional to the laser wavelength and hence, shorter wavelength results in improved optical resolution. For this reason, shorter wavelength such as excimer laser is recommended for precision in micromachining [30]. Tunna et al. [27] investigated the micromachining of copper with Nd:YAG laser of 1064 nm and its harmonics, 532 and 355 nm. They observed that processing at wavelength of 355 nm and 532 nm produces higher material removal rate as compared to that of 1064 nm due to poor reflectivity at longer wavelength. Chen et al. [31] reported that laser micromachining with 266 nm results in more ablation rate per pulse than that of 355 nm owing to higher energy absorption and dominant photochemical nature of ablation at shorter wavelength. Tseng et al. [32] suggested that Excimer laser easily generates clean and precise micro-features on polymer and glass materials. Laser micromachining of glass or polymer material with longer pulse duration (more than nanosecond) and longer wavelength