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AM 변조된 레이저 펄스를 이용한 금속 Drilling

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Metal Drilling using Amplitude Modulated Laser Pulse

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Abstract

An amplitude modulation technique for increasing the laser penetration efficiency for metals has been studied. By chopping electro-optically Nd:YAG laser pulse, the threshold energy for reliable hole drilling was decreased significantly and the penetration depth was increased. It was observed that the effect of chopping was optimal at 8-12 kHz with 60% duty cycle. It is believed that this improvement is due to an increase in the vapor recoil pressure and reduced plasma screening.

1. Introduction

There can be no doubt that the laser is a versatile material processing tool. No other single manufacturing method offers the processing flexibility of the laser. A single laser system produces sufficient heat to weld, cut, drill, machine, heat treat, and melt materials. Among these applications, laser drilling was one of the first applications of laser technology and there is a high demand for effective techniques for microhole drilling. It is important to design a laser drilling system which can produce reliable deep holes with minimum energy. One of the problems that prevent efficient driiling of these holes is decoupling of the laser beam from reaching the target surface by optically dence plasma generated by the vaporized material. This plasma is called laser-supported detonation (LSD) wave[1]. This phenomenon, so-called plasma screening effect, was observed and pictured using fast cameras by several groups[2-5]. In order to eliminate this decoupling phnomenon, and so to increase drilling efficiency, a combined cw or free running laser and pulsed laser system was proposed [6,7]. Eventhough drilling efficiency increased substantially, it is inconvenient and expensive to use this two laser system.

Another way to avoid the plasma screening effect is using perodic pulse radiation[8,9]. It was found that average hole depth per pulse was enhanced by factor of 2 using a few hundreds of shots of a 500 Hz CO_2 laser for stainless steel target[8,9]. In this periodic pulse regime, the temperature of the surface on arrival of the next pulse will be, in contrast to the application of single pulse, much higher than room temperature. In addition, the average heat loss into the surrounding material is considerably less than in the cw regime. However, in this frequency range, surface temperature will be much lower than melting point of the material because of long time intervals (>2 msec) between pulses. It was suggested by Hamilton et al. [12] that periodic pulses of about 10 kHz would produce a considerable coupling effect in order to maintain sufficiently high surface temperature and to avoid plasma screening effect. More recently, Kim et al.[10] reported that the drilling efficiency was improved by a factor of 2 or 3 using a single free running Nd:YAG laser pulse which is chopped electro-optically at 10 kHz.

In this paper, this chopped laser pulse drilling technique is studied in detail and it is shown that higher reliability in hole drilling can be achieved with this technique.

2. Experiments and Results

The experimental setup based on a pulsed Nd:YAG laser is shown in Fig.1. M1 is a 100% flat mirror and M2 is a 70% reflective flat output coupler. L is a lens with 250 mm focal length. POL is a Glan Tayor polarizer and PC is a Pockel cell. When a quaterwave voltage (3.1 kV) is not shown in Fig.3, the greatest improvement in drilling efficiency occurs at 60% duty cycle at 10 kHz chopping frequency. When the duty cycle is too small, the temperature of the liqufied material cools to much to make the next initial spike effective. On the other hand, when the duty cycle is too large, the intensities of the initial spikes are too low to enhance the vapor recoil pressure.

When the FR pulses are used for the drilling, one of the problems is the resolidification of the liquified material inside or around the holes because of insufficient vapor recoil pressure. Since the initial spikes generate higher vapor recoil pressure, it is expected that deeper hole can be drilled using IC pulses. In order to investigate the effect of the chopped pulse on the drilling depth, holes were drilled on the thicker material. In this experiment, 2 pulses were shot on the same point of the target surface and drilling probability was measured as before. Targets were 0.89 mm thick carbon steel, stainless steel and 1 mm thick aluminum plate. 100% drilling probability could not found with one pulse for any materials in this energy range. However, as shown in Fig.4, 2 shots of considerably low energy IC pulses could produce through-holes reliably for all materials.

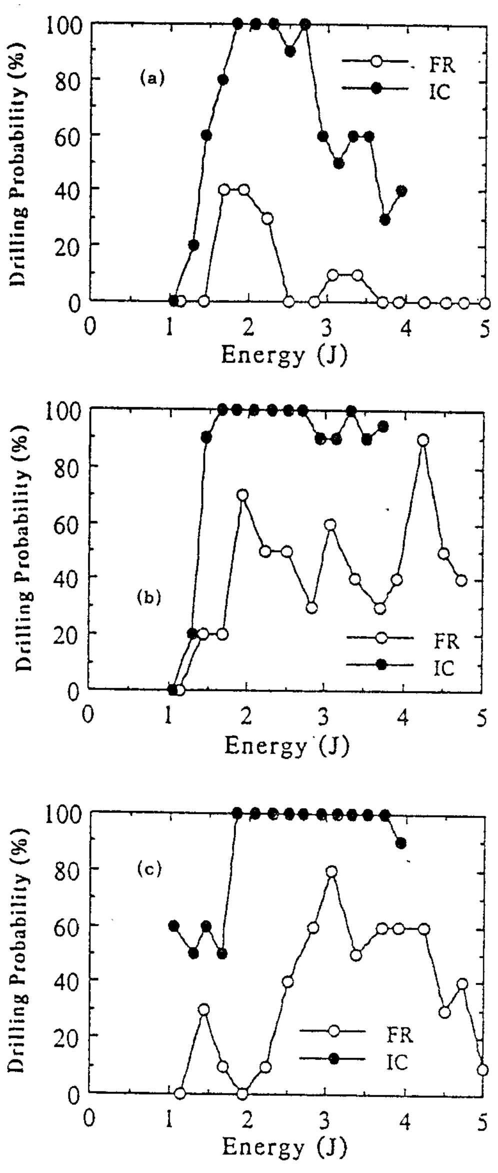

Fig.4 2 pulses drilling probability for (a) 0.89 mm carbon steel, (b) 0.89 mm stainless steel, and (c) 1 mm aluminum.

3. Conclusions

As shown in this paper, drilling efficiency was improved by more than a factor of 3 in terms of drilling probability. Duty cycle of 60% was shown to be optimal at 10 kHz chopping fraquency. In spite of insertion losses of the components used for the internally chopping operation, an improvement in drilling effciency overcame these losses. Furthermore, for the drilling of thick metals, reliability and efficiency of the drilling process with internally chopped pulses were improved drastically compared that it was impossible to drill through-holes with conventional free running pulses.

This work had been done at State University of N.Y. at Buffalo.

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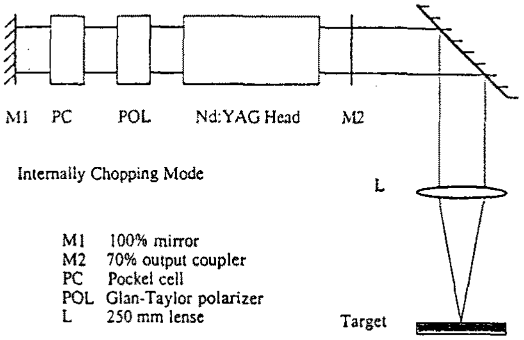

Fig. 1 Experimental setup.

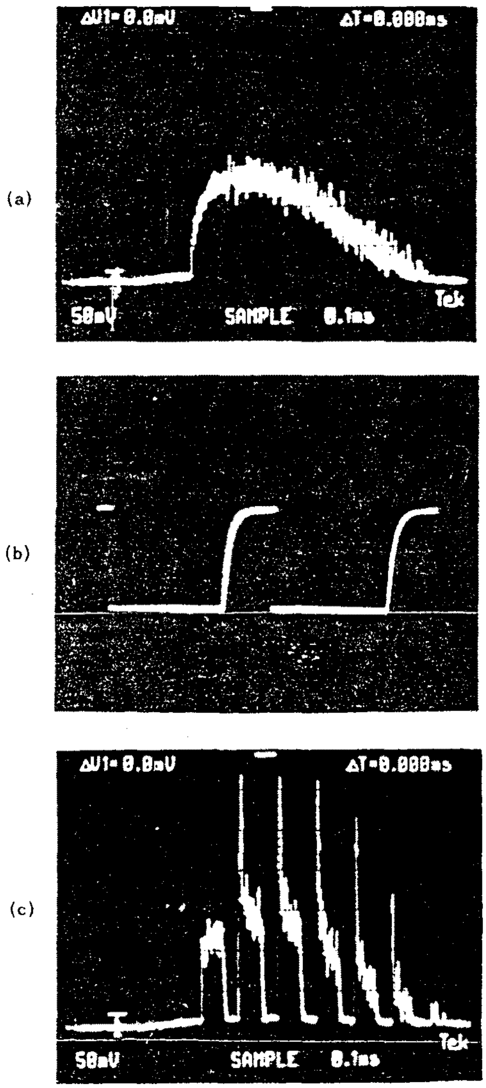

Fig. 2 (a) Temporal shape of the free running (FR) pulse. Horizontal scale: 0.1 ms/div. (b) Temporal shape of the quaterwave voltage train. Horizontal scale: 20 μs/div. Vertical scale: 1 kV/div. (c) Temporal shape of a pulse chopped at 10 kHz. Horizontal scale: 0.1 ms/div.

applied to Pockel cell, the output is a free running (FR) polarized multimode beam with a pulse width at half maximum of 500 μs as shown in Fig. 2(a). However, when quaterwave voltage train (3.1 kV) shown in Fig. 2(b) is applied to Pockel cell, the output pulse is internally chopped pulse (ICP) as shown in Fig. 2(c). Note the initial Q-switch-like spikes of each subpulses. The falltime of a voltage pulse suould be less than 5 ns, otherwise initial giant spikes of the subpulses disappear. As a fast high voltage transistor switch, HTS-50 of Frank Behlke was used.

The laser beam was focused onto the metal targets with a 250 mm focal length lens L. For each laser energy, the probability was measured by drilling 10 holes on ten different spots. The onset of 100% hole drilling was defined as the threshold. The improvements in the drilling efficiency for the 0.18 mm thick commercial razor blade were reported in Ref. 19. As mentioned in Ref. 19, the improvements are due to (1) a reduction of the plasma screening on the arrivals of subpulses, (2) an increase of the vapor recoil pressure caused by the initial spikes, and (3) higher target's surface temperature on the arrivals of subpulses. In order to increase the peak power of the spikes, the time interval between the subpulses is to be enlonged since it requires more stored energy like the Q-switch mechanism. However, the time interval between the subpulse should be reduced for the subpulses to arrive at the higher surface temperature. It is reasonable to think that there is an optimal duty cycle at fixed chopping frequency. In order to examine the effects of the duty cycle of the chopped pulse, the duty cycle has been varied from 30% to 80%. As

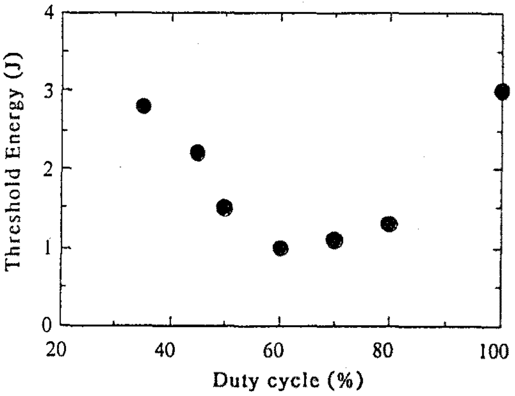

Fig. 3 Dependence of threshold energy on the duty cycle at 10 kHz for razor blade.