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Remote processing of metals by radiation from two lasers

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***Abstract*.** **The possibility of an efficient remote processing (drilling and cutting) of metals using simultaneously a cw CO_2 laser and a repetitively pulsed Nd : YAG laser is shown. The specific energy input obtained experimentally is close the energy spent upon processing by a sharply focused beam from a repetitively pulsed CO_2 laser.**

Keywords: *remote processing, CO_2 laser, Nd : YAG laser.*

In some cases of drilling and cutting metal objects with laser radiation, one has to place a laser at a considerable distance from the target, and a gas jet cannot be used for removing the molten metal from the interaction region. The properties of the metal cutting process using a cw CO_2 laser under such conditions (remote cutting) were studied experimentally and theoretically in papers [1 – 3]. In particular, it was shown that, if a target is oriented vertically, the cut width increases with the target thickness, slightly depends on the melt removal mechanism considered (under the action of the gravity or thermocapillary forces), and tends to a constant value determined by the properties of the target material. For example, for a 6-mm-thick steel 3 sample, the cut width is 1.9 cm.

In paper [4], upon remote cutting of thermally thin plates by a repetitively pulsed (RP) CO_2 laser, the melt was removed by the vapour recoil momentum. As compared to the cutting by cw laser radiation, the cut width decreased by an order of magnitude and, as a result, the efficiency of this process became several times higher. However, as the mean power of the RP CO_2 laser required for cutting thicker plates increases, an optical discharge arises near the target surface and the efficiency of the cutting process abruptly decreases. Therefore, a comparatively low efficiency of the remote cutting of metals by cw lasers is caused by a large cut width and, when using an RP laser, the low cutting efficiency is caused by the screening of the target by a near-surface laser plasma.

This work is devoted to an experimental study of the possibility of performing an efficient remote cutting and drilling of metals by two relatively low-power lasers: a cw CO_2 and an RP Nd : YAG laser. We assume that, during the interval between the pulses of the Nd : YAG laser, the radiation from the CO_2 laser with a higher output power melts a thin metal layer, and the action of the next Nd : YAG laser pulse leads to its partial evaporation and removal of the remaining part of the layer by the recoil vapour pressure. A hole or a cut forms as a result of a multiple repetition of this process. Note that the problem of interaction of laser radiation with a metal target in a similar formulation was studied in papers [5 – 8]. However, two pulsed lasers in [5, 7] and multiple-pulse generation of a CO_2 laser in [6] were used for this purpose. In paper [8], upon simultaneous irradiation by a cw CO_2 laser and an RP Nd : YAG laser, the melted metal was removed from the interaction region by an air jet.

In our experiments, we used a multibeam CO_2 laser [9] with a controlled mean power $W = 1 - 3$ kW irradiating a target for 0.1 – 4 s and a Nd : YAG laser with the pulse energy $E = 0.35$ J, the pulse duration $\tau = 100$ μs, and the pulse repetition rate $f = 50$ Hz. The CO_2 laser beam was focused by a lens with a focal length of 408 mm into a spot 1 mm in diameter and was directed normally to the surface of a vertically oriented target (samples of the X18H9T stainless steel of thickness $h = 3 - 12$ mm served as targets). The Nd : YAG laser beam oriented in the horizontal plane at an angle of 15° to the CO_2 laser beam was focused to the centre of the CO_2 laser spot into a focal spot with diameter of 0.2 mm.

Fig. 1a, b shows typical photographs of the solidified melt obtained after irradiation of the target by the CO_2 laser only. No melt removal by the CO_2 laser radiation occurs irrespective of t and W, and the melt has a distinct bell-shaped form. This shape of the melt probably appears due to the development of two thermocapillary vortices in its bath [10]. The dependences of the melt depth $h_{\rm m}$ on t and W are presented in Fig. 2a (curves *1* and *2*). If the energy input for metal melting is negligibly small compared to the energy spent for its heating from the initial temperature, then the melt depth at $t = 0.25$ s is estimated as $(\chi t)^{1/2} \sim 1$ mm, where $\chi = 0.04$ cm^2 s^{-1} is the thermal diffusivity of stainless steel. This estimate corresponds to the melt depth measured at the initial segment of the dependence of $h_{\rm m}$ on t.

A simultaneous irradiation of the target by the two lasers at the same t and W leads to the formation of a cavern (Fig. 1c) or a hole (Fig. 1d) in the sample. The dependences of the cavern depth $h_{\rm c}$ on t and W are shown in Fig. 2a (curves *3* and *4*). As the power of the CO_2 laser increases, the rate of the cavern depth growth also increases, and the

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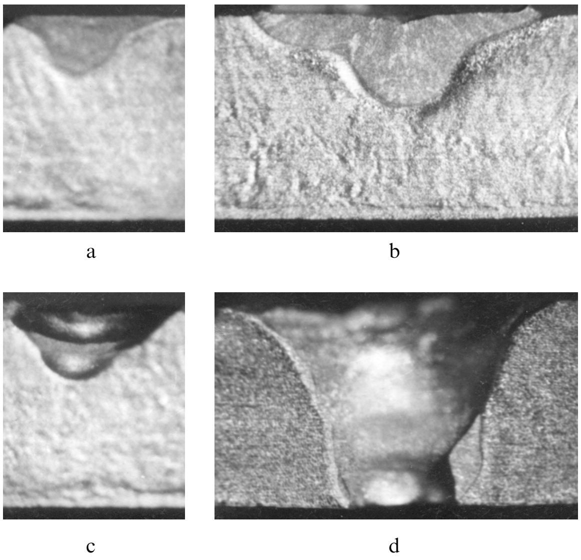

Figure 1. Photographs of the solidified melt (a, b), cavern (c), and hole (d) at $t = 0.25$ (a, c) and 1 s (b, d); $W = 2.4$ kW and $h = 3$ mm.

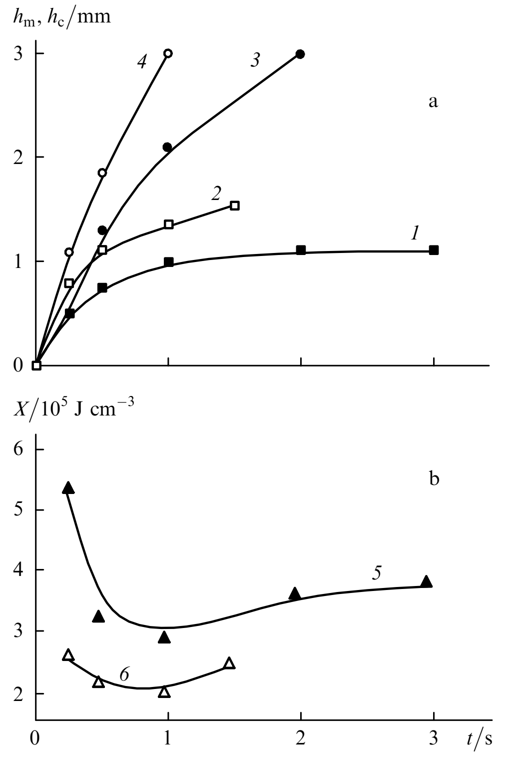

Figure 2. Time dependences of (a) the melt depth h_m (*1*, *2*), the cavern depth h_c (*3*, *4*), and (b) the specific energy input X (*5*, *6*); $h = 3$ mm, $W = 1.75$ (*1*, *3*, *5*) and 2.4 kW (*2*, *4*, *6*).

total radiation energy E_t required for the hole formation decreases. For example, at $W = 1.75$ and 2.4 kW, we have $E_t = 3.5$ and 2.4 kJ, respectively. Comparing these energy inputs to the total output energy Etf of the Nd:YAG laser, we see that, for the E_t values mentioned above, the fraction of the energy input of the Nd:YAG laser Etf/E_t is small (~ 1 %).

The specific energy input $X = (W + Ef)t/V \approx Wt/V$ (V is the volume of the removed metal) required for the formation of a cavern or a hole in the metal by this method is of practical importance. The plots of the function $X(t)$ are presented in Fig. 2b. Note that the minimum values $X = (2 - 3) \times 10^5$ J cm^{-3} are close to those obtained when drilling metals by the sharply focused beams from pulsed or RP CO$_2$ lasers [11]. An increase in X with decreasing t in a region to the left from the minimum is associated with the beginning of the drilling process, a larger heat removal to the cold target, and a lower absorption coefficient of the cold target compared to that of the heated target.

A tendency to an increase in X with increasing t (to the right from the minimum) is related to the fact that, as the channel in the target becomes deeper, an ever increasing part of the CO$_2$ laser radiation is lost at its walls. In addition, because of the initial noncoaxiality of the laser beams, the focal spot of the Nd:YAG laser shifts to the edge of the melt where the temperature is lower than at the centre of the melted region. As the plate thickness increases, this shift becomes larger, and the spatial coincidence of the focal spots of the laser beams requires the continuous target motion towards the CO$_2$ laser. This displacement was performed during the interval between the target irradiation cycles, and, as a result of several cycles, holes were drilled in plates 6, 8, and 12 mm thick. In addition, using the layer-by-layer metal-removal technique, we succeeded in cutting a plate 7.5 mm thick and obtained an average cut width of ~ 1.5 mm with a length of 8 mm.

Thus, the simultaneous irradiation by the cw CO$_2$ and repetitively pulsed Nd:YAG lasers makes it possible to perform an efficient remote processing (drilling and cutting) of metals. The CO$_2$ laser output required for processing samples ~ 10 mm thick is a few kilowatts, and the existing CO$_2$ lasers can be used for this purpose. By increasing the CO$_2$ laser power and proportionally increasing the RP Nd:YAG laser power, it is possible to perform the efficient remote cutting of thicker metal objects. As to the melt removal mechanism under our conditions, due to a significant difference (~ 25 times) in the areas of the focal spots of these lasers, this mechanism evidently differs from that described in papers [7, 11, 12] for experiments on drilling by a sharply focused beam from a single laser, when the melt is squeezed out through a circular slot by the vapour recoil momentum after the boiling of the entire melt surface. Revealing the melt removal mechanism requires additional experimental studies and their comparison with theoretical calculations.

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References

1. Likhanskii V.V., Loboiko A.I., Antonova G.F., Krasyukov A.G., Sayapin V.P. *Kvantovaya Elektron.*, **26**, 139 (1999) [*Quantum Electron.*, **29**, 139 (1999)].
2. Antonova G.F., Gladush G.G., Krasyukov A.G., Kosyrev F.K., Sayapin V.P. *Teplofiz. Vys. Temp.*, **37**, 865 (1999).
3. Antonova G.F., Gladush G.G., Krasyukov A.G., Kosyrev F.K., Rodionov N.B. *Teplofiz. Vys. Temp.*, **38**, 501 (2000).
4. Gladush G.G., Drobyazko S.V., Rodionov N.B., Antonova L.I., Senatorov Yu.M. *Kvantovaya Elektron.*, **30**, 1072 (2000) [*Quantum Electron.*, **30**, 1072 (2000)].
5. Maher W.E., Hall R.B. *J. Appl. Phys.*, **47**, 2486 (1976).

6. Borkin A.G., Gladush G.G., Drobyazko S.V., Kazakov V.N. *Vzaimodeistvie izlucheniya, plazmennykh i elektronnykh potokov s veshchestvom* (Interaction of Radiation and Plasma and Electron Flows with Matter) (Moscow: Central 'Atominform' Research Institute, 1984) p. 97.
7. Arutyunyan R.V., Baranov V.Yu., Bol'shov L.A., et al. *Vozdeystvie lazernogo izlucheniya na materialy* (Action of Laser Radiation on Materials) (Moscow: Nauka, 1989).
8. Basiev T.T., Kravets A.N., Kraynov A.S., Fedin A.V. *Kvantovaya Elektron.*, **25**, 525 (1998) [*Quantum Electron.*, **28**, 510 (1998)].
9. Babanov I.V., Glova A.F., Lebedev E.A. *Kvantovaya Elektron.*, **20**, 216 (1993) [*Quantum Electron.*, **23**, 184 (1993)].
10. Antonova G.F., Gladush G.G., Kosyrev F.K., Krasyukov A.G., Likhanskii V.V., Loboiko A.I., Sayapin V.P. *Kvantovaya Elektron.*, **25**, 443 (1998) [*Quantum Electron.*, **28**, 430 (1998)].
11. Vedenov A.A., Gladush G.G. *Fizicheskie protsessy pri lazernoi obrabotke materialov* (Physical Processes upon Laser Processing of Materials) (Moscow: Energoatomizdat, 1985).
12. Rykalin N.N., Uglov A.A., Zuev I.V., Kokora A.N. *Lazernaya i elektronno-luchevaya obrabotka materialov* (Laser and Electron-Beam Processing of Materials) (Moscow: Mashinostroenie, 1985).