INTERACTION OF A QUASI-STATIONARY LASER BEAM WITH A METAL

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A free-running solid-state laser (no Q switch) can radiate under two different conditions, which are dependent on the cavity parameters: 1) the peak mode (adequately described in the literature), 2) the quasi-stationary mode. Much less is known about the latter, and a characteristic oscillogram is shown in Fig. 1.

Here we give results concerning the effects of the quasi-stationary emission on a metal. These indicate that the interaction mechanism is qualitatively different from that for the peak mode, and the quasi-stationary state holds promise for welding and melting metals.

1. A traditional plane-parallel Fabry-Perot laser system gives an emission with a complex structure; the total length of about 1 msec is divided up into about 100 randomly distributed short pulses (peaks) each about 0.5 μsec in duration and having a repetition rate of about 10^5 Hz, so the power in a peak is greater by 1–2 orders of magnitude than the mean pulse power.

Such radiation, which often has a flux density of over 10^{12} erg/ /cm^2-sec [1], produces a crater in the metal, with ejection of plasma jets and molten droplets up to a weight of many mg. Each peak acts on the metal as a separate micropulse [2], and the time of interaction between the radiation and the metal does not exceed the duration of a peak.

High-speed photographs show that the intensity of the plasma jets begins to fall around the middle of the pulse, on account of absorption and reflection of the beam by the escaping products. The main part is played by the liquid, since a plasma of density about 10^{19} cm^{-3} (such as occurs in such processes) has an absorption coefficient of only 10^{-3} to 10^{-4} cm^{-3} at 6943 Å.

Figure 2 shows the effects of a pulse on iodide Zr, especially the screening by droplets of molten metal, which move at 10^3–10^4 cm/ /sec, so droplets formed at the start have moved only a few millimeters from the surface by the end. The recording shows droplets that have not had time to escape from the beam and are evaporated by subsequent peaks, the gas jets thereby altering their tracks.

The metal is heated at rates up to 10^{10} deg/sec, and the temperature gradient attains 10^6 deg/cm. The effective heating depth during a peak is of the order of the size of the radiation absorption region. The material is disrupted by thermal explosion at pressures of 10^3–10^6 atm [2], because conduction and evaporation cannot completely remove the heat during a peak. The hardening in the damaged area [3] is therefore ascribed not only to heat but to deformation.

2. Peak suppression tends to occur in a laser with spherical mirrors (concentric or confocal) [4], and we get continuous oscillation, sometimes with some periodic variation. The total oscillation time is still about 1 msec, and the output energy is of the same order, but the power is no longer that of a peak but that of the whole pulse and is lower by at least an order of magnitude.

We used a laser with a concentric cavity having spherical mirrors of radius 175 mm, whose reflection coefficients were 99 and 50%. The ruby rod (length 120 mm and diameter 12 mm) was exactly at the center. The pumping was provided by an IFPP-7000 lamp. The output energy was 10 J, and the flux density was 10^{12}–10^{13} erg/cm^2-sec.

The interaction with a metal was substantially different from that considered above. Photographs showed only a thin and uniform film of vapor near the surface. Jets and droplets were absent. The emission intensity indicated that the vapor density was much less than that in the previous case; only a little material evaporated (~0.1 mg). The metal was not screened by escaping products, and much more of the energy was absorbed by the metal.

The surface was not damaged, though there was a melted area whose diameter was 2–3 times that of the crater produced in the previous case.

Figure 3 shows such a surface, which has areas with various crystalline structures (in particular, a columnar structure) due to purely thermal factors. The surface relief is due to solidification of the molten patch. There was no pronounced increase in hardness in the patch.

3. The interaction time is 1 msec in the quasi-stationary case; the flux density is reduced by a factor of 10–100 while the laser energy is unaltered, and the rate of heat supply becomes comparable with the rate of removal by conduction, which plays a major part in the energy transfer.

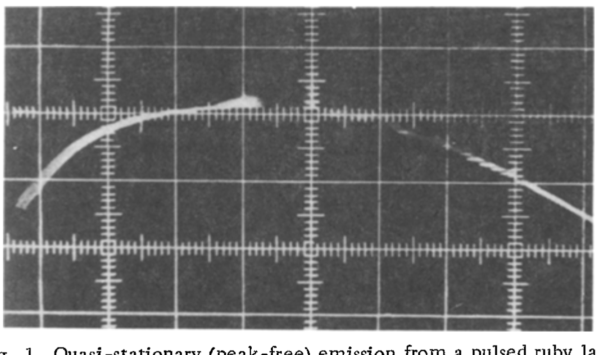

Fig. 1. Quasi-stationary (peak-free) emission from a pulsed ruby laser. Sweep 10^{-4} sec/cm.

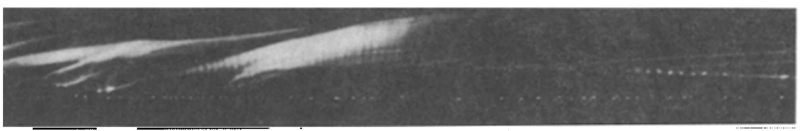

Fig. 2. Interaction of a peak pulse with a metal at the middle of the process, time increasing from left to right. Speed 15 000 rpm.

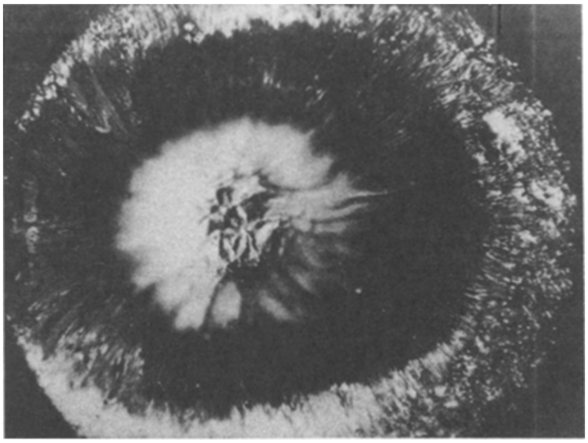

Fig. 3. Surface of iodide zirconium after interaction with a peak-free pulse, ×30. Focal spot 10^{-2} cm^2.

Peak-mode oscillation will give good results when it is required to evaporate or damage the material but is of little use when conduction dominates the processes, as in welding or melting metals. Here the peak-free mode is better.

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