SPECTROSCOPIC STUDIES OF THE LASER-PRODUCED MICROPLASMA ON THE SURFACE OF V_2O_5 SINGLE CRYSTAL AND V-METAL

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The microplasma produced by Q-switched ruby laser on the surface of V_2O_5 single crystal and V-metal targets has been investigated. The plasma temperature has been determined from the relative intensities of spectral lines. The differences observed in the line broadening and self-absorption point to differences in plasma densities.

Introduction

By focusing a high-power laser beam on a small area on the surface of a solid target, above a given threshold, a plasma is produced. Investigation of this plasma gives valuable information on the plasma itself as well as on the plasma producing material, which is also part of the plasma. Two different methods of investigation are of particular importance, *viz.* a time-integrated and a time-resolved one. By using photographic techniques, interferometric methods, spectroscopic studies, X-ray emission, mass spectrometric measurements, charge collection studies, such important plasma parameters as plasma pressure, density, temperature, ionisation degree, velocity of shock-waves, velocity of plasma particles can be obtained [1, 2].

We studied the properties of the plasma produced on the surface of V_2O_5 single crystals (a semiconductor material of interest in petrochemical industry as a catalyst), and compared these with that of V-metal. This crystal proved to be effective in producing plasma under the action of a powerful CO_2-laser [3], and Nd-glass laser [4]. The present paper reports on the time-integrated and spectroscopic investigation of microplasmas produced by Q-switched ruby laser. When measuring the relative intensities of spectral lines, the temperature of the plasma was determined with the two-line method. The plasma densities were compared on the basis of the quadratic Stark-broadening.

Experimental

Experiments were conducted using laser energy from a LOMO OGM 20 type ruby laser, delivering an energy of 0.4 J, in a pulse duration of 40 ns. The schematic diagram of the experimental arrangement is shown in Fig. 1. The laser light was focused on a V_2O_5 single crystal, or V-metal planar T target by means of the $L1$ lens, with a focal length of 3.5 cm. The focal area was determined in a photographic manner, and was found to be $4.8 \cdot 10^{-4}$ cm^2.

The targets were in the air. A LOMO STE-1 type spectrograph was used to record the spectrum on ORWO NP 27, 400 ASA photographic film. The $L2$ and $L3$ lenses focused the total volume of plasma light (maximal length ~1 cm) on the slit, which was adjusted to 20 μ. The optical axis of the spectrograph was aligned perpendicular to the axis of the laser beam. Spectral lines were identified using a Hg—Cd spectral lamp and the well-known lines of V, with the aim of wavelength tables given by SAIDEL et al. [5]. Wavelength and line intensity measurements were made with an Abbe comparator (Carl Zeiss Jena) and a Fast Fotometer (Carl Zeiss Jena type G II), respectively. The spectrographic film was calibrated with the plasma light itself, using a stepped sector, which produced ten steps in each spectral line with transmission of 100%, 50%, 25%, 12.5%, ... Twenty shots were sufficient to obtain a good spectrum. The laser pulse shape and the temporal development of the plasma were investigated by focusing the light of the laser and the plasma on the surfaces of fast photodiodes *PD*1 and *PD*2 (Instrument Technology Ltd. type HSD 1850) with two beam-splitters (*B*1 and *B*2). The trace of photodiodes were analysed by a storage oscilloscope (Tektronix type 466 DM 44). The energy of the laser pulses was measured with the aim of calibrated thermopile (Laser Instruments Ltd. type 14 NO), connected with a Model 142 Indicator. Laser power was observed to be stable within 5%. The flux density was ~$2 \cdot 10^{10}$ W/cm^2.

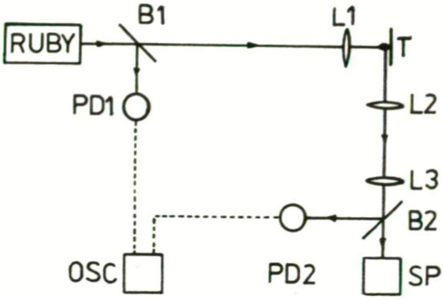

Fig. 1.

Results and Discussion

Fig. 2 shows the shape of the laser pulse. The temporal stability of the pulses with the duration of exactly 40 ns was very good. The pulse-produced plasma was also sufficiently stable in time on both targets. On Fig. 3 the temporal development of plasmas can be seen. The upper trace refers to a plasma originating from the V-metal, and the lower trace to that of a V_2O_5 single crystal. The plasma lifetime (the time

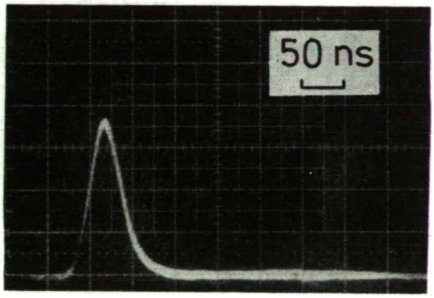

Fig. 2.

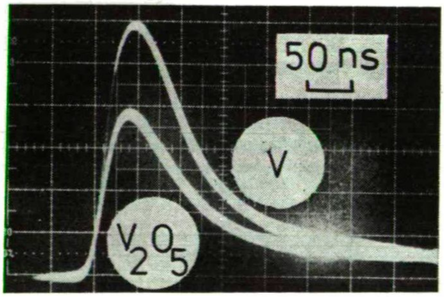

Fig. 3.

belonging to $I_{\max}/e$) proved to be 130—140 ns, and equal in both cases. This suggests that the V ions are of fundamental importance in determining the temporal characteristics of the plasma.

The properties of the plasma being in local thermodynamic equilibrium can be studied by the two-line method. READY [6] pointed out that in the time scale of Q-switched laser pulses (in the regime of nanoseconds) the plasma is in local thermodinamic equilibrium because, for laser-produced plasmas, the electron densities typically are high and the electron-ion collision time may be less than 10^{-9} s. We calculated the plasma temperature from the intensity ratio of lines belonging to the same ionisation stage but the different wavelengths. From this ratio follows Eq. (1).

$$\ln \frac{IA_0 g_0 \lambda}{I_0 A g \lambda_0} = -\frac{1}{T}\frac{E-E_0}{k}, \tag{1}$$

where λ, λ_0; I, I_0 and A, A_0 denote the wavelengths, intensities and transitional probabilities of lines, respectively, g and g_0 are the statistical weights of levels, E and E_0 the excitation energies, T and k the temperature and the Boltzmann-constant respectively. For calculations, the same lines were selected from both spectra, and $\lambda_0 = 3990{,}57$ Å line was used as a reference line. The values of Ag and E were taken from SAIDEL's work [5]. The results are shown on Fig. 4, where $\varepsilon = IA_0 g_0 \lambda / I_0 A g \lambda_0$,

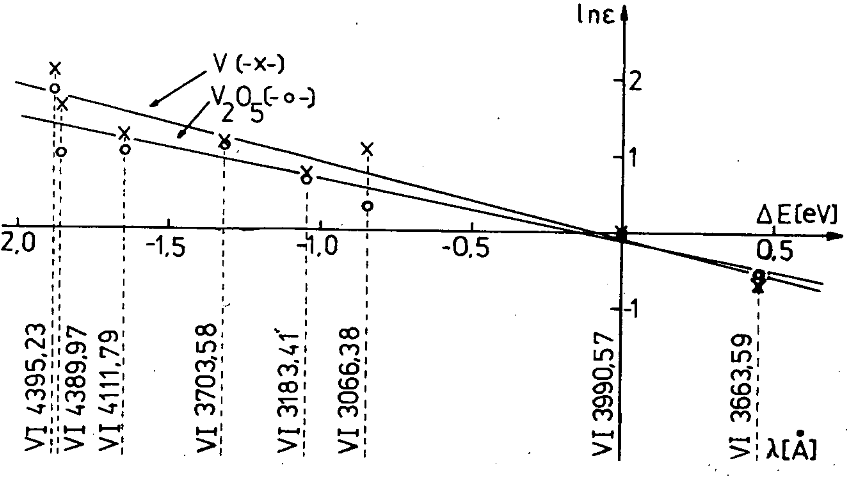

Fig. 4.

and $\Delta E = E - E_0$ are given in electronvolts. The temperatures lie in the same energy range, namely T(V) = 1.02 eV, and T(V_2O_5) = 1.26 eV. BOLAND et al. [7], and SINHA [8] showed, that the temperature of the plasma depended on the distance from the target surface; when moving away from the surface, it decreased strongly. From theoretical calculations, HAUGHT and POLK [9] observed, that the maximum temperature occured at the end of the rise time of the laser pulse, and it might decrease by a factor of 10 at the end of the pulse. Since our measurements were time-, and space-integrated, it was reasonable to assume in terms of the arguments given above, that the plasma temperature (defined as the temperature of the hottest zone) was one order greater than what was calculated, *i.e.* ~10 eV. This conclusion is in good agreement with other results summarized in READY's book [10].

We have observed that besides the similarity of the plasmas (the equality of the lifetime and temperature), there are some significant differences between them. In the V_2O_5 plasma, the width of the V-lines were essentially greater than that of the same lines observed in the V plasma (Fig. 5). It is well known that in dense plasma (*i.e.* in laser-produced plasma) the line-broadening caused by the quadratic Stark-effect becomes dominant. Comparing the widths of a given line for different plasma — since $\Delta\lambda \sim nT^{1/6}$ —, the ratio of plasma densities can be obtained. We measured the half-width of lines, and found that this ratio was $n(V_2O_5n)/n(V) = 7 \div 10$.

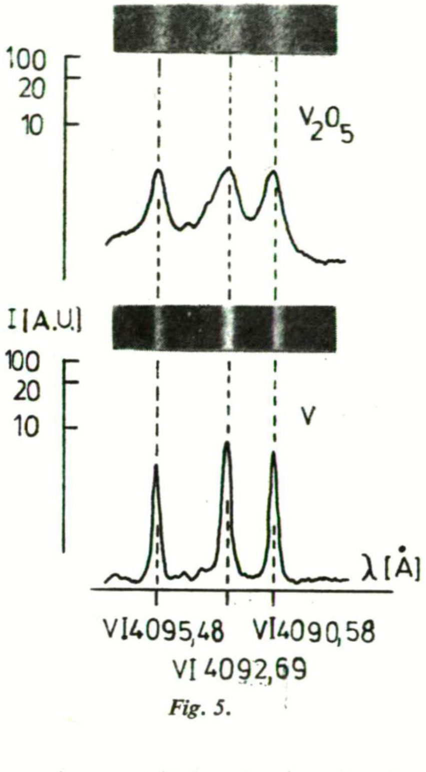

Fig. 5.

Beyond the line-broadening, a strong self-absorption of VI and VII lines occured in the V_2O_5 plasma. Fig. 6 represents typical parts of both spectra. Such a strong appearance of self-absorption supports the abovementioned estimation of the plasma concentration. These last two statements underline that not only is the V_2O_5 single crystal effective in inducing plasma when radiated by CO_2-, and Nd-glass laser [3, 4], but also when under the influence of a ruby laser.

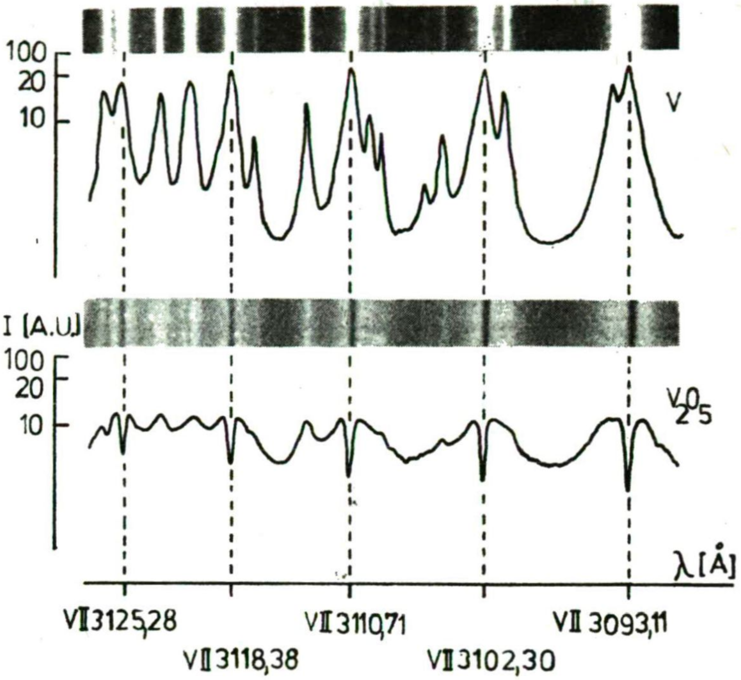

Fig. 6.

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СПЕКТРОСКОПИЧЕСКОЕ ИССЛЕДОВАНИЕ СВЕЧЕНИЯ ПЛАЗМЫ, СОЗДАВАЕМОЙ НА ПОВЕРХНОСТИ МОНОКРИСТАЛЛА V_2O_5 И МЕТАЛЛА V ЛАЗЕРНЫМ ИЗЛУЧЕНИЕМ

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Проведено спектроскопическое исследование свечения плазмы, создаваемой на поверхности монокристалла V_2O_5 и металла V лазерным излучением в режиме с модуляцией добротности. Опредена температура плазм по относительным интенсивностям спектральных линий. Установлено различие в плотностях электронов в плазмах на основе уширения и самопоглощения спектральных линий.