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CARBON SPECTRA FROM CO$_2$ LASER-PRODUCED PLASMAS


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Ultraviolet spectroscopy is a useful technique for the study of plasmas heated by intermediate laser power densities ($\sim 10^{8}$ W/cm$^2$). In this work, the emission of solid carbon targets irradiated with 10.6 µm laser pulses was measured and calculated.

The gain-switched pulses consisted of a 70 ns FWHM spike containing 0.4 of the energy followed by a 1 µs tail. The focal area for normal incidence on planar graphite targets in vacuo was 1 cm$^2$. Average power densities were near $5 \times 10^8$ W/cm$^2$. The plasmas were observed parallel to the target plane with an open shutter camera and a 1 meter near-normal-incidence grating spectrograph operating in the 30-300 nm range. The time- and space-integrated spectra were recorded on Kodak 101 film. Figure 1 shows data from part of the spectral range. Strong line radiation is evident.

Standard wavelength tables were employed to identify the observed lines. Radiation from CI through CIV was noted, with most lines from the two highest ionization stages. For example, many lines from CIII triplet systems (with principal quantum numbers $n<5$ and $\Delta n<2$) and from CIII singlet systems ($n<5$ and $\Delta n<3$) were observed. CIV doublet-system lines ($n<5$ and $\Delta n=1$) were also identified. The most intense is the CIV line at 155 nm. The CIV 4d-5f and 4f-5g transitions, at 252.4 and 253 nm respectively, suggest that electrons recombined with CV (He-like) ions. The existence of CV ions implies temperatures near $10^5$K.

A stationary, local-thermodynamic-equilibrium (LTE) model was developed to compute radiation emitted from the plasma. The electron density in the excitation region ($\sim 10^{19}$ el./cm$^2$ for CO$_2$ lasers) and the temperatures ($>10^4$K) justify the use of an LTE model. The effects of thermal conduction and radiative cooling were included, but hydrodynamic flow and radiation transport (opacity) were not computed.

The time history of the total line output was calculated for each ionization stage, as shown in Figure 2 for an irradiance near $2 \times 10^8$ W/cm$^2$. During the spike of the laser pulse, a large fraction of the ions exist as CV, and the CIV radiation decreases. It recovers as the plasma cools and recombination occurs. CIII and CII emission appear sequentially. CI emission, not shown in Fig. 2, occurs late in the pulse. The computed relative intensities agree qualitatively with the measured spectra, that is, CIII and CIV are predominant.

Absorption lengths were estimated to be less than 100 µm for CIII lines (2p-3d at 57.4 nm and 2s-2p at 97.7 nm). This indicates the need for more complex calculations, including radiation transport, in order to use line ratio techniques for temperature determinations. The analysis of the measured carbon spectrum will be discussed from the point of view of these opacity considerations and comparisons made against calculated emission spectra.

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Figure 1: Densitometer traces of carbon ultraviolet spectra excited by CO$_2$ laser pulses. Contamination lines from oxygen and nitrogen occur above about 12 eV.

Figure 2: Computed radiative power for the indicated ionization stages. See text.