Ensanchamiento, Asimetría y Traslado de Líneas Spectrales Atómicas Observadas en Microplasmas Producidos por Láser de Nitrógeno

Broadening, Asymmetry and Shift of Atomic Spectral Lines Observed in Microplasmas Generated by Nitrogen Laser

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Resumen

Medimos en este trabajo el ensanchamiento, traslado y asimetría de las líneas espectrales producidas en plasmas generados por un laser de nitrógeno, demostramos que estas características de las líneas espectrales son producidas por absorción de la radiación.

Abstract

Measurements of broadening, shift and asymmetry of spectral lines in micro plasmas generated by nitrogen laser in brass are reported. It is demonstrated that the collisional broadening is the principal cause of the features observed, with a possible contribution from resonant self-absorption of the radiation.

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When a high power laser pulse is focused on a solid surface the high temperature generated is capable of vaporize the material. The vapor thus ejected from the surface presents species with different degrees of excitation and ionization which emits electromagnetic radiation with a broadband spectrum and spectral lines characteristic of the elements present. A number of works shows the possibility of use of such micro plasmas in elemental analysis [1]. This technique has also been used in technological applications such as thin film deposition [2] and photolithography [3].

The formation and evolution of laser generated micro plasmas depend on the physical proprieties of the sample and of the gas present. In particular the characteristics of the laser used, pulse energy and duration, transversal mode structure and wavelength, are factors that have great influence on the micro plasma dynamics, i.e., micro plasmas generated by different lasers can be very different [1]. A great number of studies have been done to understand the physical mechanisms which are important for laser ablation with different lasers. In general the lasers used were Nd, CO₂, ruby, excimers and dye lasers. In 1982 Kagawa and Yoki [4] have reported the generation of micro plasmas by focusing a nitrogen laser in copper, brass, steel and glass. They have shown that a linear analytical plot could be obtained between the concentration and intensity of spectral lines for the different elements of steel. However, in spite of this promising result few works have been done in micro plasmas with these lasers.

In this work we present measurements of broadening, shift and asymmetry of spectral lines in micro plasmas generated by a nitrogen laser focused on brass samples. Our experiment is shown
schematically in Fig. 1. The 3371 Å pulses with a width of 10 ns and 2 mJ of energy of a nitrogen laser (NL) were focused at normal incidence on the surface of brass (S) by quartz lens (L₁) with a focal distance of 5 cm. The spot size was approximately 50 x 100 μm, which results in an irradiance of 4.10⁹ W/m². The sample was rotated by a small DC electrical motor (M) to show a fresh surface to each pulse. The measurements were made in air at, atmospheric pressure. The light emitted by the micro plasma was collected at 90° with respect to the laser beam direction by another quartz lens (L₂) with a focal distance of 15 cm. It was focused on the entrance slit of a 1 m spectrometer (Spex-1704)(SP). A RCA 8253 photo multiplier (PM) was coupled to the output slit of the spectrometer. The amplitude of the electrical pulses of the photomultiplier were measured through an acquisition data system (AS) built in our laboratory. The same system controlled the step motor of the spectrometer. The temporal evolution of the signal was measured through a PAR-162 boxcar (BC) with a PAR-163 sampling head unit. The resulting time resolution of this measurement set up was 20 ns.

Figure 2 shows the spectral emission of the plasma for the region from 4000 Å to 5500 Å. This spectrum was measured with a resolution of 2 Å. The most intense lines of copper and zinc are identified. It is interesting to note that lines from the ions of zinc or copper are not observed. Figure 3 presents spectra obtained with time resolution for the region around the zinc line which is observed at 4810.53 Å (vertical line) in hole cathode discharge [5]. From top to bottom we have spectra measured with time delays of 150, 200, 250, 300 and 350 ns between the laser pulse and the gate aperture of boxcar. For delays of 100 ns or less we observed only a broad band emission
spectra without atomic emission lines. The spectral resolution used was 0.2 Å. It is clear from this figure that the line presents broadening, shift and asymmetry. The widths of the line measured at half maximum are respectively 10.1, 3.7, 3.0, 2.7 and 1.8 Å. The shifts of the maximum of the line from 4810.53 Å are 1.4, 1.2, 1.2, 0.6 and 0.4 Å. These features are also observed for other lines presented in the Fig. 2.

We begin the discussion of our results pointing out that in laser generated micro plasmas the condition of local thermodynamic equilibrium (LTE) is observed [6], i.e., collisional events determine the behavior of the system and a temperature can be defined. Three processes may contribute to the features here observed: Doppler effect, collision (pressure) broadening and self-absorption. The ionizing potential of copper and zinc are respectively 7.726 and 9.394 eV, therefore the temperature necessary for an appreciable degree of ionization in the plasma is in the order of several tens of thousands of degrees. An observation of Fig 2 shows no evidence of ionic lines, therefore we conclude that the temperature of our plasmas is not so high. The Doppler broadening calculated [7] for T = 50,000 K is .094 Å, much smaller than the value measured. Thus the Doppler effect cannot be responsible for the broadening. On the other hand, it is well known that under high pressure conditions spectral lines can be broadened, shifted and deformed due to interaction of the emitting atom with other particles. The width and shift of the line are linearly proportional to the pressure [7]. Figure 3 shows the temporal evolution of the line profile for the zinc transition at 4810.53. Because the plasma expands, the pressure in the plume decreases with time. Therefore this figure can be interpreted as representing the line profile evolution with pressure (from bottom
to top). From the observed increase of the width and shift with pressure, we can conclude that collisional broadening has an important contribution to the observed phenomenon. However, due to the high pressure of the plasma, the mechanism of self-absorption of the radiation can contribute to the broadening observed. The light radiated from the inner part of the plume can be absorbed and reemitted many times before escaping from the edge of the plasma. Because the probability of absorption and emission is higher in the central part of the line than in the wings, this mechanism limits the intensity of the center of the line. The result is that the line is effectively broadened many times over the natural resonant width. The high width (10 Å) observed at 150 ns can be a result of this process, although this observation cannot be conclusive.

In summary, we presented in this work measurements of broadening, shifts and asymmetry of spectral lines observed in micro plasmas generated by focusing the beam of a nitrogen laser on the surface of brass. We concluded that collisional broadening is the principal physical mechanism which causes the observed line profile, although self-absorption can also have a contribution. We believe that with a better characterization of the feature here reported quantitative results can be obtained for the pressure in the micro plasma. Further experiments are in order and new results will be published in due course.

References


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Fig. 1: Experimental arrangement.
Fig. 2: Micro plasma emission spectrum of brass in the interval from 4000 to 5500 Å.

Fig. 3: Spectra for time delays of 150, 200, 250, 300 and 350 ns (top to bottom) of brass for the region around 4810 Å.