P1-1 Laser Induced Shock Wave Plasma and its Application to Spectrochemical Analysis

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Introduction

The study of Laser Atomic Emission Spectrochemical Analysis (LAESA) was first made by Brech et al[1], and this LAESA became the most typical application of Laser. Presently, two strategies are being pursued in LAESA developments. One is Laser Induced Breakdown Spectroscopy (LIBS) which has been developed by Cremers et al[2]. In this method, in order to remove the interfering background from the high-density plasma, a gated OMA system is incorporated to the detection system. They proved this method can be successfully applied to quantitative analysis of many kinds of sample, but the physical mechanism of the plasma generation still not be well understood.

Another method is Laser Induced Shock wave Plasma Spectroscopy (LISPS) which has been developed by our group[3]. We proved a characteristic plasma is produced when the short pulse laser is focused onto a solid target in the reduced gas pressure of around 1 Torr. The laser plasma consists of two distinct regions. The first is the small area of high temperature plasma (primary plasma), which gives off an intense continuous emission spectrum for a short time just above the surface of the target. The second area (The secondary plasma) expands with time around the primary plasma, emitting sharp atomic line spectra with extremely low background. The secondary plasma has a characteristics quite suitable for the emission spectrochemical analysis. In particular, the low background emission intensity and the linear relationship between the emission line intensity and the content of the element are most advantageous. Based on the time-resolve experiments, we have proved that this secondary plasma is excited by the shock wave, while the primary plasma acts as an initial explosion energy source.

We assume that laser induced shock wave plasma generation takes place even in the high pressure regions such as 1 atm. The purpose of this work is to prove that the excitation process in LIBS is essentially the same as that for LISPS. In this work we have demonstrated that at initial stage of the plasma expansion, the shock wave front coincides with the plasma emission front. This also becomes strong evidence to support our model.

Experimental procedure

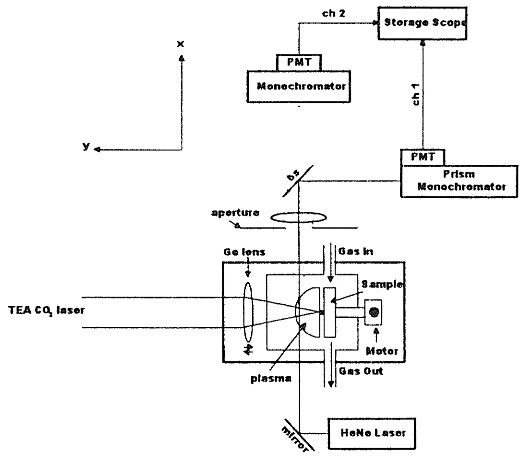

Fig. 1. Experimental Setup

Figure 1 shows the experimental set-up used in this work. A TEA CO_2 laser (400 mJ, 100 ns) was focused onto the surface of the target by a Ge lens (f = 100 mm) through a ZnSe windows. The sample were placed in vacuum tight metal chamber (12.5 cm x 10 cm x 10 cm), which could be evacuated with a vacuum pump and filled with the desired gas pressure. The chamber pressure was measured by a digital manometer (DM-760, Nishiyama Seisakusho). Some kinds of glass plates were used as targets in these experiments. The radiation of the laser-induced plasma was observed through an optical window at a right angle to the laser beam by means of an imaging quartz lens (f = 100 mm) with an aperture of 10 mm x 10 mm. The plasma was imaged with an enlargement (1:3) onto the entrance slit of a monochromator (Nikon P-250). The whole chamber, together with the sample and focussing lens could be moved in x-y direction by manual or by step motor.

In order to measure the arrival of the shock wave front, shadowgraph technique was employed by using He-Ne laser as a probe light to detect density jump. The signals of the plasma emission and probe light are detected simultaneously by using two-channel storage scop (HP-545616B).

Result and discussion

In order to make clear the relationship between the secondary plasma and the plasma produced at high pressure which is usually used for LIBS, dynamical process of the plasma generation has been studied in wide pressure range systematically. As a result it was shown that similar phenomena take place even in the high-pressure regions. For example, plasma shape is hemispherical, the plasma emission front moves with time following the shock wave equation and the spatially integrated total emission intensity increases with a certain rising time after the laser bombardment and then decays slowly. When we observe the plasma generated at 1 atm by naked eyes, we cannot see the structure inside the plasma due to the strong contiuous emission. But we confirmed with the aid of time resolve spectroscopic technique that this plasma also consists of two parts, primary plasma and secondary plasma.

It is naturally supposed that if the secondary plasma produced at high pressure is also excited by the shock wave, we can directly detect the existence of the shock wave front by optical method such as, shadowgraph or schlieren photograph techniques; so far in the secondary plasma produced at low pressure we could not detect the density jump due to the shock wave front.

Figure 2 shows the relationship between the appearance of the density jump and the emission of sodium line (588.9 nm) at various position from the taget when we focused the TEA CO_2 laser on glass sample in air at 100 torr. It is clearly observed that the rising of the emission takes place at the same time as that of the density jump. But above 4 mm, emission comes late to the density jump and at the distance above 6 mm only density jump can be detected until around 30 mm.

Based on this experimental result we can conclude about the mechanism of the plasma generation as follows: right after cessation of the primary plasma, atoms gush out from the primary plasma at supersonic speeds, pushing the surrounding gas like a piston. This expansion of the propelling atoms, being impeded by the surrounding gas, gives rise to compression process. As a result of this compression, a blast wave is generated in the surrounding gas.

The practical application of the laser induced shock wave plasma (LISPS) will also be presented.

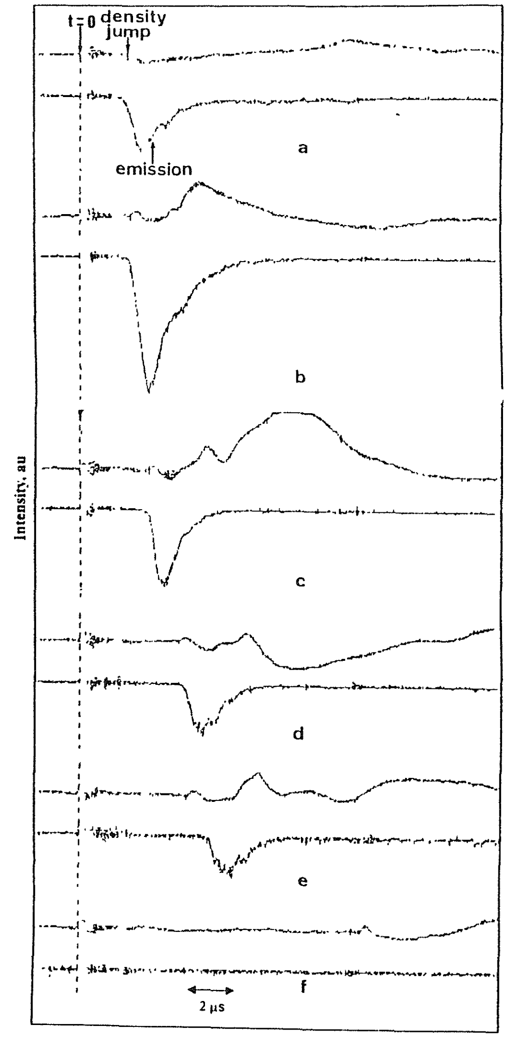

Fig. 2. Time history of the density jump and plasma emission taken at various position from the glass target in air at 100 torr. a) 1mm, b) 2mm, c) 3mm, d) 4 mm, e) 5 mm and f) 10 mm.

Refrences

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