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Dynamics of femtosecond pulsed laser induced Ti plasmas under different pressures

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Abstract. The femtosecond laser ablation process and induced breakdown spectroscopy of transition metal Ti in air background has been investigated systematically. The ablation process is simulated by means of a three-dimensional two temperature model (3D-TTM). The time-resolved spectroscopy is employed to determine the characteristics of plasma during its evolution. The time-of-flight spectroscopy (TOFS) is also used to characterize the plasma expansion. The evolution behaviors of the plasma and its spectral characteristics have been analyzed as a function of pressure. It is shown that the component, expansion behavior and characteristics of the plasma have strong pressure dependences. The results are discussed in terms of the interaction mechanisms between ambient air and plasma species.

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Key words: Femtosecond laser ablation; Two temperature model; Laser induced breakdown spectroscopy.

1 Introduction

Laser ablation is one of the basic physical phenomena when intense and ultrashort laser pulses interact with solid material. Meanwhile it is an important application of the laser-material interaction [1-2]. Due to the extremely high power density and ultrafast interaction with material, the femtosecond pulses are able to ablate the material without evident thermal effect and therefore act as a useful tool for micro-machining [3-4]. Meanwhile, the fs-laser ablation process is always companied by spectral emissions which was

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called fs-laser induced breakdown spectroscopy (FLIBS) [5-6]. The laser induced breakdown spectroscopy (LIBS) can act as a potentially useful tool for numerous applications in material surface microanalysis and provide the information about the component of the sample surface [5]. Moreover, the FLIBS improves the spatial resolution and spectral sensitivity of the traditional LIBS analysis and can be applied in more delicate and complicate works [7-9], such as chemical mapping and depth profiling of complex biological systems [10-13].

With the evolutions of fs-laser induced plasma being generally understood, a more detailed and comprehensive understanding of Ti particles in fs-laser plasma is desired [14-16]. A sufficient understanding should include the component and evolution of the plasma. Particularly, the ambient gas plays an indispensable role in the behavior of the plasma characteristics. The collisions of the plasma species with the ambient gas will seriously impact the kinetic and optical properties of the laser plasma. Until now the phenomena due to the existence of ambient gas have been investigated widely, such as shielding effect, expanding velocity and laser supported detonation wave (LSDW) [8, 16]. However, there are few reports about the pressure effect on the dynamics of the fs-laser induced Ti plasma as far as we know.

In addition, investigation on the fs-laser ablation can serve to evaluate the early stage of the plasma formation [17-19]. This non-equilibrium heating process is generally described by the two temperature heat-conduction model (TTM) [20-21]. The theoretical simulations based on TTM are able to provide the temporal temperature behavior of the target and therefore give the information about the timescale of material removal and the early formation of plasma.

In present work, the fs-laser ablation of Ti target and the induced plasma have been investigated systematically. The ablation process is simulated by a three-dimensional two temperature model (3D-TTM) and the onset point of the material removal from the Ti surface is evaluated. The particular attention has been paid on the pressure effect on plasma evolution. The detailed informations about the plume species and expanding velocities are achieved and analyzed by time-resolved spectra and time-of-flight profiles. The pressure dependences of these properties are discussed in detail. The theoretical and experimental studies shown in this article will contribute to an insight into the characteristics of fs-laser plasma.

2 Experimental method

The experimental investigation of the plasma emission spectrum is implemented in the systems as shown in Fig. 1. An optical amplifier system (Hidra 25) generating 1000 fs laser pulses is used as the excitation source. The wavelength of the laser pulse is 800nm. A titanium plate (20 mm $\times$ 20 mm $\times$ 2 mm) with the purity of 99.999% is adopted as the sample. The laser beam is focused on the sample surface with the diameter of $\sim$200 μm in a vacuum chamber. The pressure is changed from 10Pa to 1atm. The peak power