Interaction of laser ablated plasma plume with a downstream microwave plasma in a multicusp for synthesis of nanoparticles

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The interaction of laser ablated plasma plume from Al targets with downstream microwave plasma confined in a twelve pole multicusp (MC, surface magnetic field ~ 0.4 T) is investigated for the synthesis of nanoparticles. The downstream plasma temperature and density are varied in the range ~ 8 eV to ~ 14 eV and ~ 10^9 cm^{-3} to ~ 10^{10} cm^{-3} respectively by varying the neutral pressure (0.1 – 1 mTorr) and microwave power (200 – 300 W). The electron density (n_e) and electron temperature (T_e) are estimated from Langmuir probe measurements. The synthesis and distribution of the nanoparticles will be investigated at the surface of the targets and on a substrate kept below the plasma plume, including the interaction of the plume with the downstream plasma.

1. Introduction

Microwave plasmas have been actively researched for its applications in several areas such as material processing and plasma health care [1, 2]. The variation in the plasma properties like electron temperature (T_e) and electron density (n_e), by varying the background gas pressure and power of microwaves have been used in substrate cleaning, etching and also in the controlled generation of vacuum ultraviolet radiation [1, 3]. The interaction of laser with materials in the background microwave plasma for synthesis of nanoparticles has its own advantage. For example, during the ablation in the plasma ambient, particles get etched and hence it is expected that smaller size particles can be deposited.

The coupling of the laser beam to the target surface depends on the ambient as well as on the laser parameters (wavelength, pulse width) and thermo-physical properties (diffusivity, thermal conductivity, reflectivity etc.) of the irradiated material. Therefore it is interesting and important to investigate the interaction of lasers with various materials like metals and metal alloys in different ambient conditions. Laser ablation of such targets in different ambient (e.g. gases, liquids) have been studied thoroughly [4-6], however the material ablation in a background plasma confined in magnetic multicusp (MC) has not been investigated so far. In this abstract we report the particle deposition on the ablating target at different conditions of the background plasma.

2. Experiment

The basic experimental set-up consists of a microwave source (magnetron, operating at 2.45 GHz) whose output is launched into a cylindrical vacuum chamber (VC), as shown in Fig. 1. Plasma confinement is brought about by using a twelve pole MC (12 cm in diameter and 30 cm in length) [7] kept inside VC. Hydrogen gas is employed to generate the plasma and the discharge pressure is set in the range of 0.3 to 0.9 mTorr. Hydrogen plasma is generated with microwave powers of 200, 250 and 300 W. The plasma parameters (n_e, T_e) have been evaluated using Langmuir probe measurements. To synthesize the particles via laser ablation, the target is fixed at the centre of the MC in the VC. A Q-switched Nd-YAG laser (Solar TII LF 114) having maximum energy 300 mJ/pulse in fundamental wavelength 1064 nm and pulse width 15 ns at repetition rate 10 Hz is used for ablation of solid Al targets. The laser intensity used in this study is 5.7 J/cm^2. To produce the Al plasma in the background microwave plasma, the laser beam is focused onto the target (Al) using a lens having a focal length of 30 cm. The deposited particles are analysed using a FESEM (Model/Supplier: JSM-7100F; JEOL).

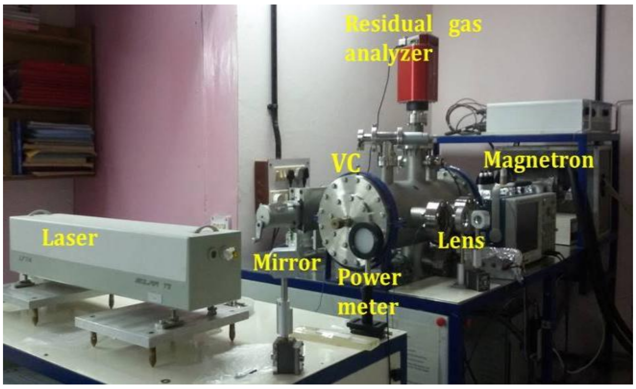

Fig. 1. Digital picture of the laser ablation setup in the background microwave plasma.

3. Results and Discussion

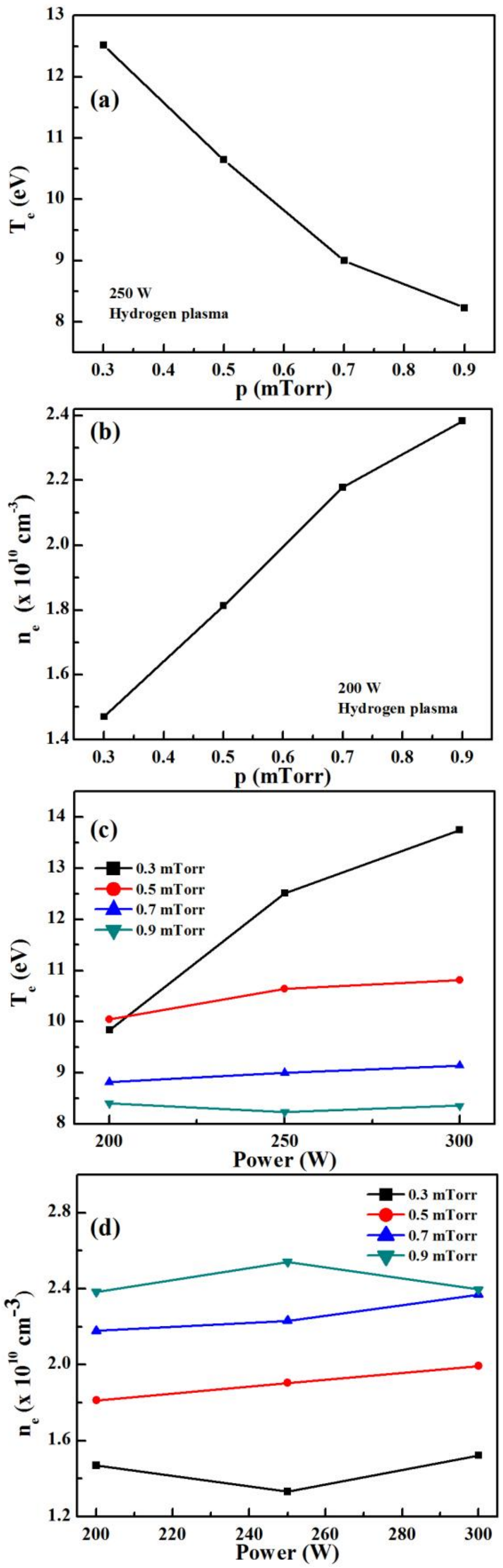

Fig.2. Variation of the plasma parameters (a) electron temperature (T_e) and (b) electron density (n_e), with respect to power at different pressures.

In order to understand the laser ablation in the background microwave plasma, we have first measured n_e and T_e of the hydrogen plasma generated at different combinations of microwave power and gas pressure. The measurements have been carried out at the centre of the MC where the target is fixed for particle generation by laser. The results are presented in Fig. 2.

Once the plasma parameters are known, the target is irradiated with the laser pulses to deposit the particles. Figure 3 (a) and (b) show the particle deposition on the target at 0.3 mTorr pressure in the absence of plasma and in the presence of plasma (T_e ~ 13.8 eV, n_e ~ 1.5×10^{10} cm^{-3}) respectively. It can be seen that the particles are mostly of micron size at the crater periphery. The characteristic shape of the particles formed in the ambient is elongated aggregates or filaments from the electrostatic aggregation of smaller particles [4].

The individual spherical particles are formed from a melted liquid. The smaller particles less than 100 nm are formed due to the vapour condensation and there is low probability of ejecting from the melted liquid due to the surface tension forces [8, 9]. The approximate size of the ejected droplet can be obtained from the following equation [8, 10]:

$$r = \left[\frac{6\sigma}{\rho_l} \frac{1}{\Delta L} (\Delta t)^2 \right]^{1/2} \quad (1)$$

$$\Delta L = 2r\alpha\Delta T + 2r(\rho_s - \rho_l)/3\rho_s \quad (2)$$

where r is the size of the droplet that can be ejected from the melted liquid, σ is the liquid surface tension, ρ_l, and ρ_s are the densities of liquid and solid phase respectively, α is the thermal expansion coefficient, ΔT is the temperature difference between the surface and melting point, Δt is the time difference between time to reach melting point and laser pulse duration. By putting the parameters in Eq. (1), the size of the particles that are ejected from the melted liquid is estimated to be greater than 500 nm. Figure 3(c) shows the particles deposited on the target that is biased at 15 V at same plasma conditions as of Fig 3 (b). The particles deposited on target with and without plasma do not show significant difference in their shape and size. The mean size of the particles increases (from ~1.3 µm to ~5 µm) with increase in plasma electron temperature (from 10 eV to 13.8 eV). The mean size of the particles in the case of biased target is ~ 0.5 µm. However, the size of the particles can be further controlled to the nanometre scale by controlling the velocity of the plasma particles falling on the target.

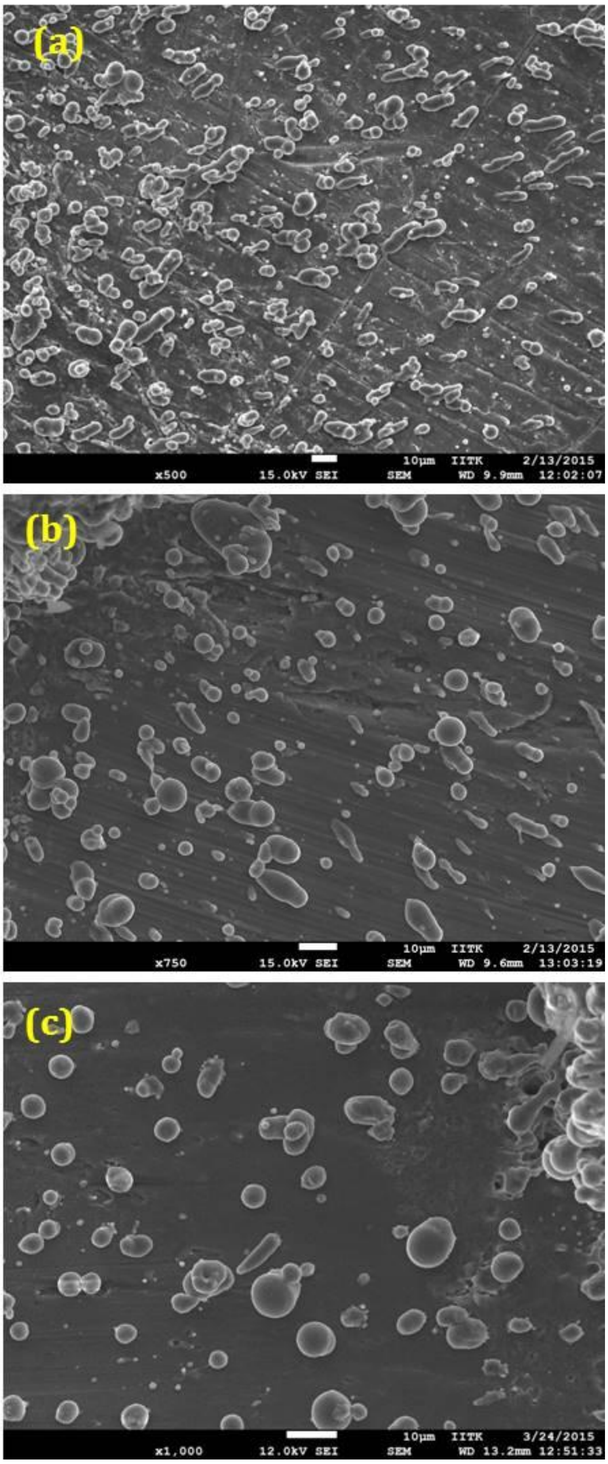

Fig. 3. Al particles deposited on the target at 0.3 mTorr pressure of (a): hydrogen ambient, (b): hydrogen plasma ambient and (c): hydrogen plasma ambient with target biased at 15 V.

This can be achieved by controlled biasing of the target. Further experiments in this direction are being carried out and will be presented in the conference. We are also investigating the effect of changing the atomic mass of the gas such as using Argon and Krypton instead of hydrogen. In another set of experiments, we plan to put a separate substrate with or without bias, below the plasma plume in the interaction region with the background plasma, and investigate the formation of nanoparticles on this substrate.

4. Summary

Laser ablated particles are deposited on the target with and without hydrogen plasma. Currently micron sized particles are reported whose size increases with increase in plasma (electron) temperature. Before carrying out the ablation of the target material, investigation of the background microwave plasma density and electron temperature have been carried out, which can be varied during the experiment by changing the gas pressure and the microwave power. Further experiments are being performed to deposit the nanoparticles on the target by biasing it with a suitable voltage. Particle deposition would also be investigated on a substrate located below the plasma plume interacting with the plasma, to validate the theoretical model of particle formation via vapour condensation and ejection from the melted liquid.

5. References

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