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DESIGN NOTE

A fibre optic evanescent wave sensor for monitoring the rate of pulsed laser deposition of metal thin films

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Abstract. A novel sensing technique for the *in situ* monitoring of the rate of pulsed laser deposition (PLD) of metal thin films has been developed. This optical fibre based sensor works on the principle of the evanescent wave penetration of waveguide modes into the uncladded portion of a multimode fibre. The utility of this optical fibre sensor is demonstrated in the case of PLD of silver thin films obtained by a Q-switched Nd:YAG laser which is used to irradiate a silver target at the required conditions for the preparation of thin films. This paper describes the performance and characteristics of the sensor and shows how the device can be used as an effective tool for the monitoring of the deposition rate of silver thin films. The fibre optic sensor is very simple, inexpensive and highly sensitive compared with existing techniques for thin film deposition rate measurements.

Keywords: pulsed laser deposition, fibre optic sensor, evanescent wave, silver thin films

1. Introduction

Pulsed laser deposition (PLD) is established as a technique for the preparation of thin films of various substances ranging from pure elements to multicomponent materials (Chrisey and Hubler 1994, Saenger 1993). PLD is a very convenient technique for thin film preparation and it offers superior film qualities compared to films deposited by other methods. Even though the laser–target interaction is a very complex process in terms of theoretical understanding, the interest in PLD is growing quickly due to the numerous advantages offered by this method. Unlike other deposition methods, PLD involves a number of controlling parameters such as laser fluence, repetition rate of laser, laser wavelength for the material deposition, etc (Kautek *et al* 1990, Venkatesan *et al* 1988, Hansen and Robitaille 1987). Smoother films with correct stoichiometry are usually obtained with PLD due to the congruent evaporation. Online measurement of the deposition rate of ablated material is essential to establish optimal film growth as well as for the continuous monitoring of the deposition process.

Currently, fibre optic sensors (FOSs), which form an essential part of photonics technology, play a major role in measurement and process control due to their many attractive advantages in sensing and measuring different physical and chemical variables. FOSs can also be utilized for the online measurements of different parameters with the added advantage of the possibility of taking remote measurements (Leonard 1995). Evanescent wave (EW) spectroscopy is one of the sensing methods used in a certain class of FOS for monitoring and measurement of a variety of physical and chemical variables (Radhakrishnan *et al* 1993, Ruddy *et al* 1990). An optical fibre based EW sensor to monitor the deposition rate of thin films of an organic material (polypyrrole) produced by AC plasma polymerization has been reported by us previously (Deepa *et al* 1998). Here we demonstrate the suitability of this technique for monitoring the rate of PLD of silver thin films. This sensor overcomes most of the demerits of other conventional techniques for deposition rate measurements. This EWFOS illustrates the effect of irradiation wavelength and laser energy on the deposition rate; deposition conditions can thus be optimized. To the best of our knowledge this is the first attempt in this direction. This technique can be applied, in principle, to PLD of a variety of materials.

2. Experimental details

A schematic diagram of the experimental set-up is shown in figure 1. PLD was achieved by focusing a Q-switched Nd:YAG laser (Quanta Ray DCR-11) with a convex lens of

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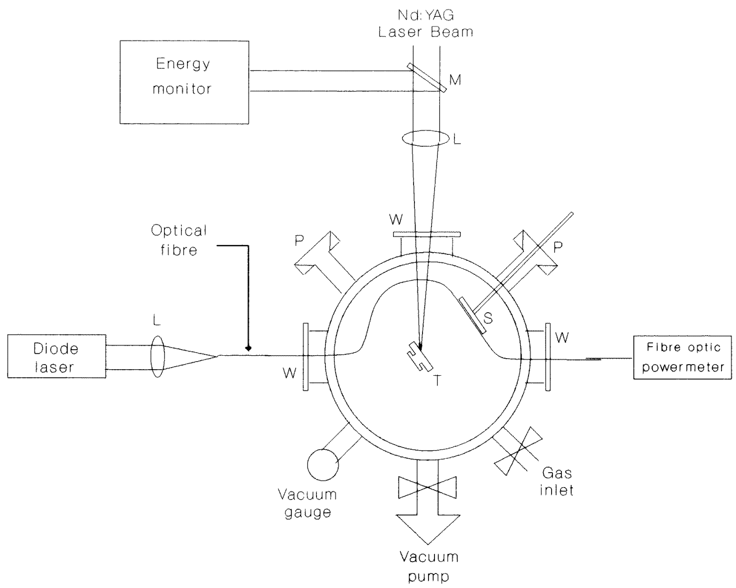

Figure 1. Block diagram of the experimental set-up. M, 10% reflector; L, lens; W, glass window; P, substrate insertion port; T, rotating target holder; S, glass substrate.

focal length 0.5 m onto a silver target (spot radius = 50 μm) at an angle of 45° with respect to the target normal. The spot radius was kept the same throughout the course of the investigation. The target was a silver disc of diameter 0.015 m and thickness 0.001 m, fixed to a target holder. The target was rotated using a DC motor in order to avoid multiple hits at the same location as well as to avoid splashing. Also, the laser was focussed at larger radial distance from target centre in order to remove the heavy mass particulates and to obtain congruent evaporation (Chrisey and Hubler 1994). A cleaned glass substrate was kept parallel to the target surface (perpendicular to the plasma plume) at a particular distance. Target and substrate holders were kept inside a plasma chamber which can be evacuated to a pressure of the order of 10^{-3} mbar.

A multimode optical fibre (200/380 μm) with polished end faces having an uncladded sensing region of length 0.01 m was placed close and parallel to the glass substrate so as to receive ablated material from the target. The two end faces of the fibre were taken through two sealed ports in the plasma chamber walls without breaking the vacuum. The beam from a diode laser (4.25 mW, 670 nm) was focused onto one end of the fibre and the other end was attached to a commercial fibre optic power meter (Meggar OTP 50).

Ablation of the target material and subsequent deposition were achieved for two laser fluences and at two different wavelengths, 1064 nm and 532 nm (second harmonic of the Nd:YAG laser). The repetition rate of the laser beam was 10 Hz and the vacuum in the chamber was kept the same throughout the course of the investigation. The experiment was also performed for various target–substrate distances.

3. Results and discussion

The laser–target interaction produces ablation and the ejected materials form a plasma plume which, on condensation, causes the deposition of thin films of target material on the substrate as well as on the sensor element.

As the deposition proceeds, silver is continually deposited on the substrate as well as on the uncladded portion of the fibre. In a typical case (100 mJ, 1064 nm) the thickness formed after irradiation by 1800 pulses was found to be 650 Å. The thickness of the films formed on the substrate as well as on the uncladded portion of the fibre is more or less the same, since the target–substrate distance (0.02 m) closely matches the extent of the plume from the target. The laser beam guided through this fibre encounters EW absorption in this region of the fibre and the output power decreases, subsequently resulting in saturation of output power (Deepa *et al* 1998). Here, the theory of light propagation in a conducting isotropic medium is applicable and absorption occurs due to the EW penetration into the stratified silver. In metals the refractive index is a complex quantity and the imaginary part is preponderant (Born and Wolf 1964) resulting in substantial reduction in output power.

Investigations were carried out at two different wavelengths of the laser, 1064 nm and 532 nm. For each of these wavelengths, studies were carried out with different energy densities of the laser beam. Figure 2 shows the variation of the fibre output with time for a substrate to target distance of 0.02 m corresponding to laser wavelengths 1064 nm and 532 nm. The estimated error was found to be less than 5% for these measurements. Comparison of the slopes of the plots at different energies clearly reveals that there is an increase in the deposition rate with an increase in energy density. The plots also reveal that the time interval within which saturation sets in is lowered as the energy fluence is increased. This observation also confirms the fact that the deposition rate increases with increasing energy density of the laser beam. The uncladded sensing region (length 0.01 m) of the fibre essentially receives the forward directed component rather than the evaporated component. The forward directed component has been shown to increase

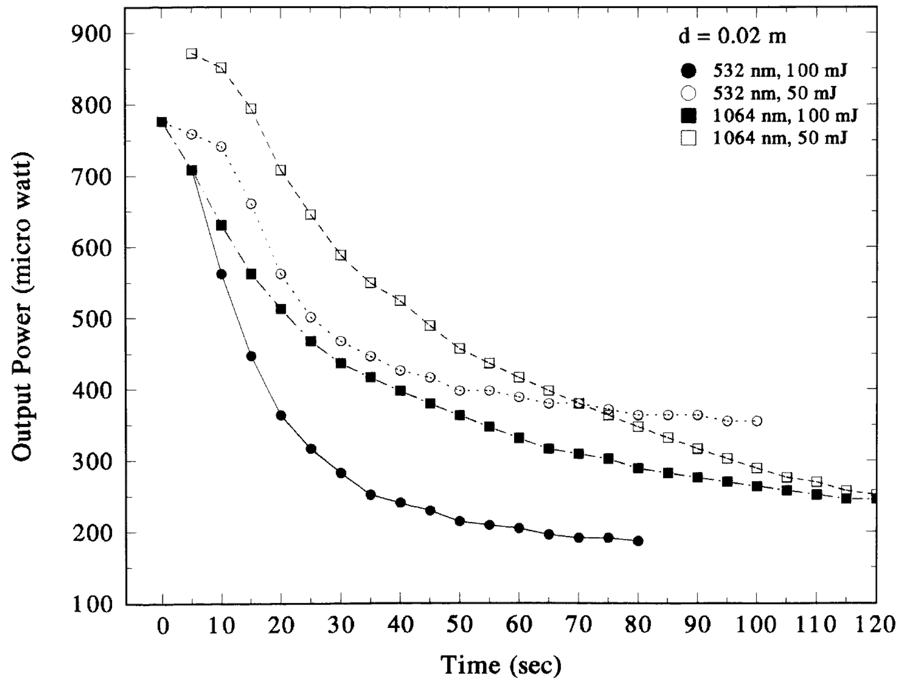

Figure 2. Variation of the fibre output with time. d is the substrate to target distance.

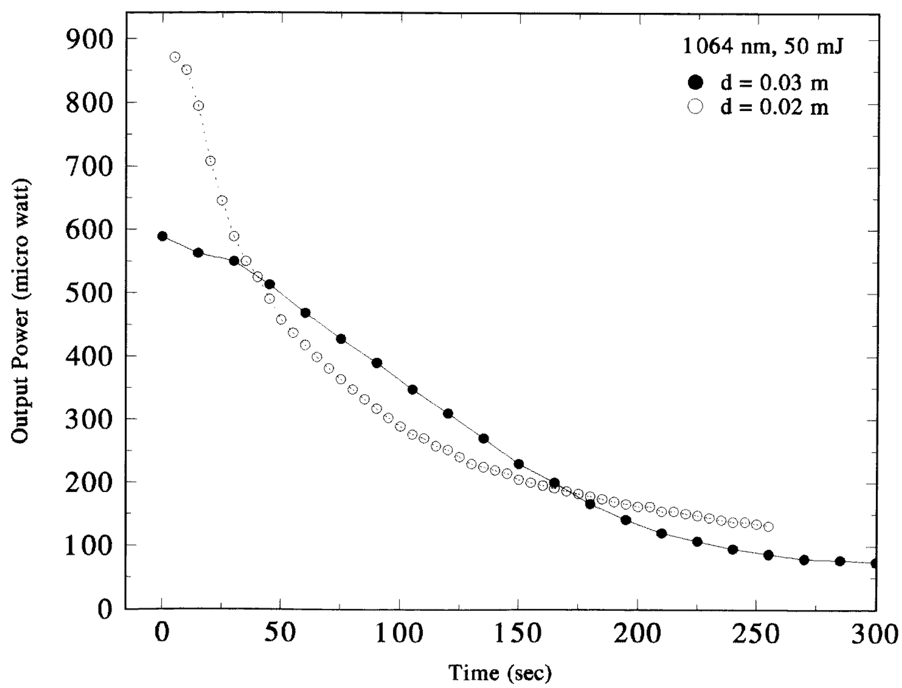

Figure 3. Variation of the fibre output with time for different substrate to target distances d.

with laser energy density and deviation from this behaviour occurs mainly at large angles with respect to the target normal (Venkatesan *et al* 1988). Our results also confirm these observations as we have selected a small exposed length of 0.01 m of the fibre.

The growth rate of Se films has been shown to increase with laser power and decrease with irradiation wavelength (Hansen and Robitaille 1987). 1064 nm light penetrates deeply into the target while 532 nm light is almost completely absorbed within the first 100 Å. This is also supported by the work of Kautek *et al* (1990) who described an increase in absorbance of deposited superconducting films with decreasing wavelength. Our plots also show that the deposition rate increases at lower wavelengths. Investigations were also carried out for two different target–substrate distances with 1064 nm laser wavelength and the results are given in figure 3. A significant decrease in deposition rate with increased distance was observed.

In conclusion, we have developed a simple and highly sensitive FOS to monitor the rate of PLD of metal thin films. The sensor was employed to establish the dependence of deposition rate on some of the control parameters of the irradiating laser beam. There is, however, a limitation on the thickness maximum range which can be measured with this set-up.

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