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Fast imaging of laser-induced plasma emission of vanadium dioxide (VO_2) target

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INTRODUCTION

- The main objective of this study is to fully optimise the synthesis of vanadium oxide nanostructures using pulsed laser deposition.
- We will attempt to realise this by studying the mechanism of the plasma formation and expansion during the pulsed laser deposition process of vanadium oxide, since the source of the films is a laser- generated plasma composed of neutrals and ionised atoms, molecules and other species.
- In this poster presentation, a spatio-temporal evolution study of different species such as VI (437.85 nm), VII (326.1 nm), VIII (237.1 nm) and VO (608.56 nm) are presented and compared.
- The plume expansion dynamics of an ablated target of VO_2 was also investigated using a fast-imaging technique.

MOTIVATION

- VO_2 is electrically conducted at a temperature higher than 68 °C and is electrically insulated at a temperature lower than 68 °C.
- Due to this behaviour, VO_2 has been presented as an attractive thin film material for electrical or optical storage, laser protection and solar energy control for windows in space satellites.
- It is important to understand the laser plasma interaction and plasma plume expansion during a pulsed laser deposition process of synthesising the VO_2 nanostructures, since it is difficult to synthesise a monoclinics VO_2 nanostructure with a well-defined size and morphology [1].

THEORY

It is important to understand the mechanism of the plasma formation and expansion, since the source of the films is a laser-generated plasma [2] composed of neutrals and ionised atoms, molecules and other species. The nature of the plume process requires detailed quantitative data on the composition and dynamics of the plume evolution as it propagates towards the substrate. Fast photography using an intensified charge-coupled device (ICCD) has been used to study the plume dynamics of expanding plasma in a vacuum and ambient atmosphere. Using the drag-force model [3], one can describe the expansion of the plasma plume. In this model, the ejected species are regarded as ensembles that experience a viscous force proportional to its velocity (V) through the background gas that is given as:

$$V = V_o(e^{-\beta t}) \text{ or analogously } R = R_o(1-\beta t). \quad (1)$$

Where R indicates the position of the front edge of the plasma, R_o the distance at which the plasma propagation ceases and generally indicated as the stopping distance. β is a slowing coefficient. Both R_o and β are phenomenological parameters whose values are necessary determined by fitting the experimental data using equation (1).

EXPERIMENTAL

During the experiments, the vacuum chamber was filled with oxygen gas after the vacuum chamber devoted to the PLD process was evacuated up to a residual pressure of 10^{-5} mbar. The substrate was positioned and faces parallel to the target, VO_2. The overall emission of the bright, expanding plasma was recorded by means of a fast ICCD camera with magnification of 1/3, from the target laser ablation event, up to the arrival of the ablated species onto the substrate. The plasma plume study and optical emission study of ablation plasma plume of targets were carried out at vacuum and a range of oxygen gas pressure. During the expansion, the number of accumulation, ICCD gain and gate were adjusted for each image to compensate for the reduction of the plume intensity. The entrance slit spectrometer was 100 μm wide and 2 mm high. The plasma emission is translated horizontally with a step of 0.3 mm on the spectrometer entrance slit to provide spatially resolved measurements.

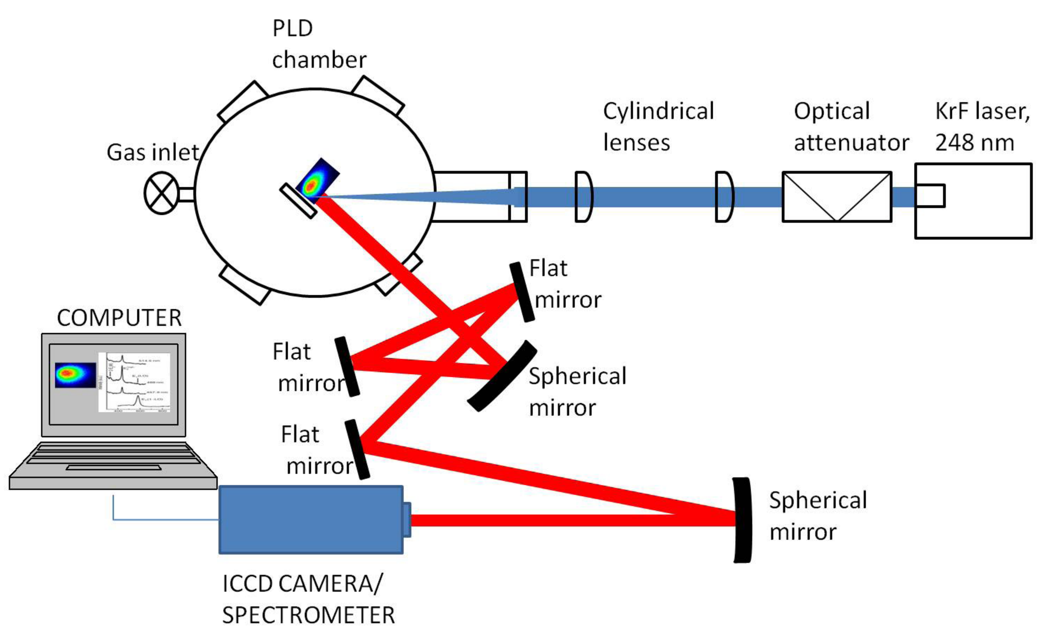

Figure 1: General schematic diagram of the experimental setup that was used in this study. This setup consists of a PLD chamber, KrF laser, optics, ICCD camera (Princeton Instruments PI-MAX, 1024 X 256 pixel size = 26 x 26 μm, spectral response is from 190 nm to 850 nm and temporal resolution is 5 ns), spectrometer and a computer.

PLASMA PLUME IMAGES

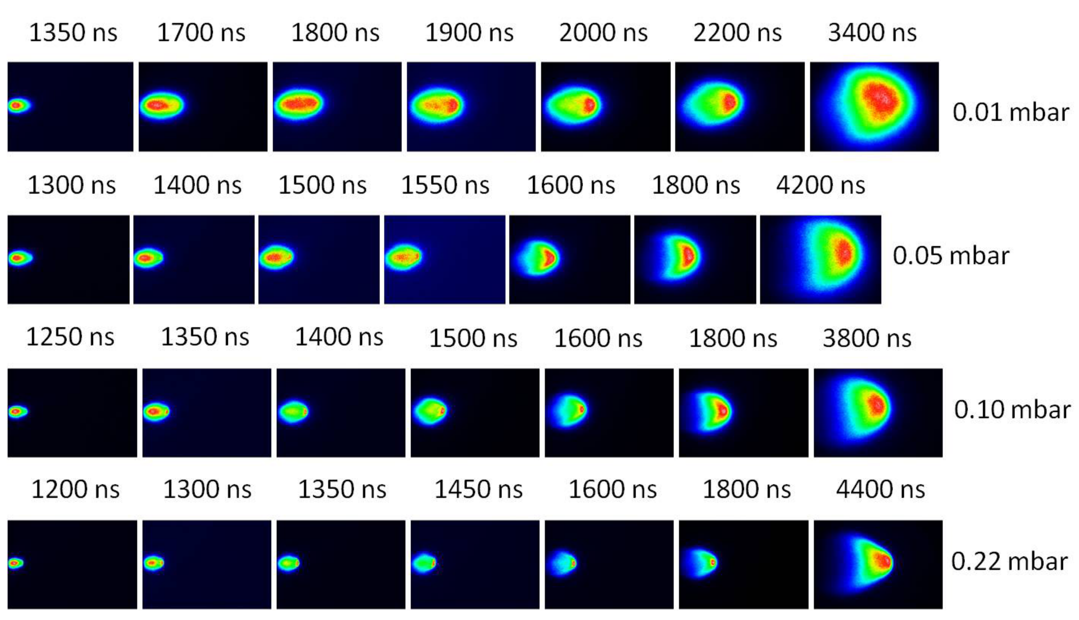

Figure 2: The temporal revolution of the visible plume for 0.01, 0.05, 0.10 and 0.22 mbar taken during laser ablation of the VO_2 target. The free expansion, splitting and stopping of the plume was observed during these oxygen pressures. The splitting took place at 1 900 to 2 000 ns for 0.01 mbar, 1 500 ns to 1 600 ns for 0.05 mbar, 1 400 ns to 1 500 ns for 0.10 mbar and 1 300 ns to 1 600 ns for 0.22 mbar.

		Oxygen Pressure (mbar)			
		0.2	0.1	0.05	0.01
VI	d_f (cm)	2.83	3.2	4.54	6.38
	β (μs^{-1})	2.6	2.8	3.9	4.7
	Vo (10^6 cm/s)	7.36	8.96	17.71	29.99
VII	d_f (cm)	2.7	2.8	4.2	5.9
	β (μs^{-1})	2.3	2.2	3.4	3.9
	Vo (10^6 cm/s)	6.21	6.16	14.28	23.01
VO	d_f (cm)	2.5	2.7	2.9	
	β (μs^{-1})	2.3	2.4	2.4	
	Vo (10^6 cm/s)	5.75	6.48	6.96	

Table 1: This table shows that values of the following parameters: d_f, β and v_o for the VI, VII and VO species at different oxygen pressures, which were determined using the drag model. The results show that the parameter's value decreases as the oxygen pressures get higher.

REFERENCES

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SPATIO-TEMPORAL EVOLUTION OF PLASMA SPECIES

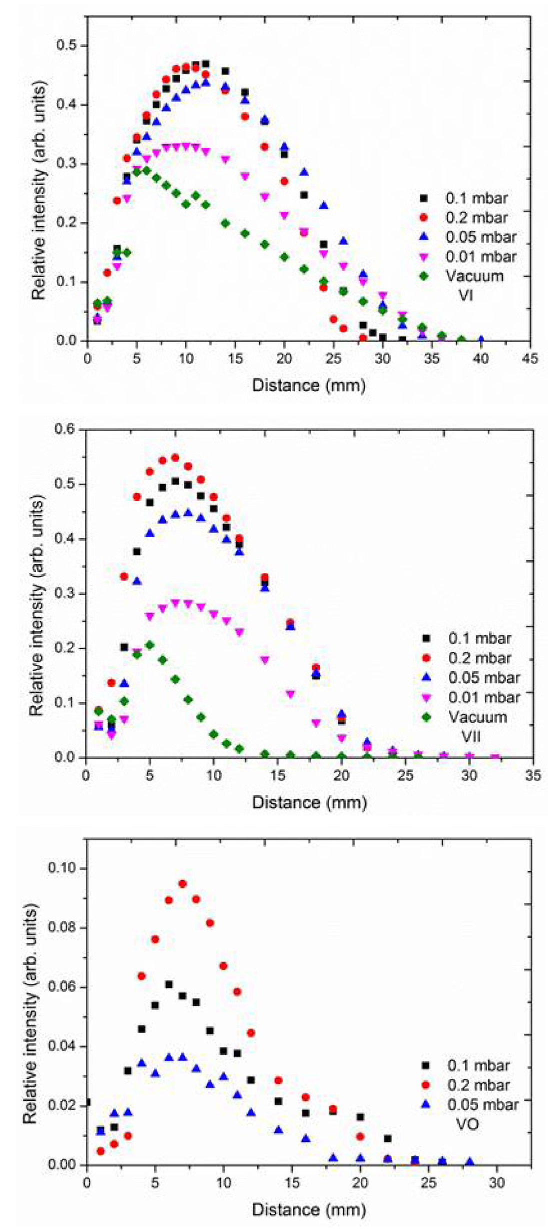

Figure 3: The maximum emission intensity of the species VI, VII and VO as a function of the distance from the target surface for different oxygen pressures. The emission intensity has a maximum at approximately 5 mm from the target surface and decreases as the target surface distance increases.

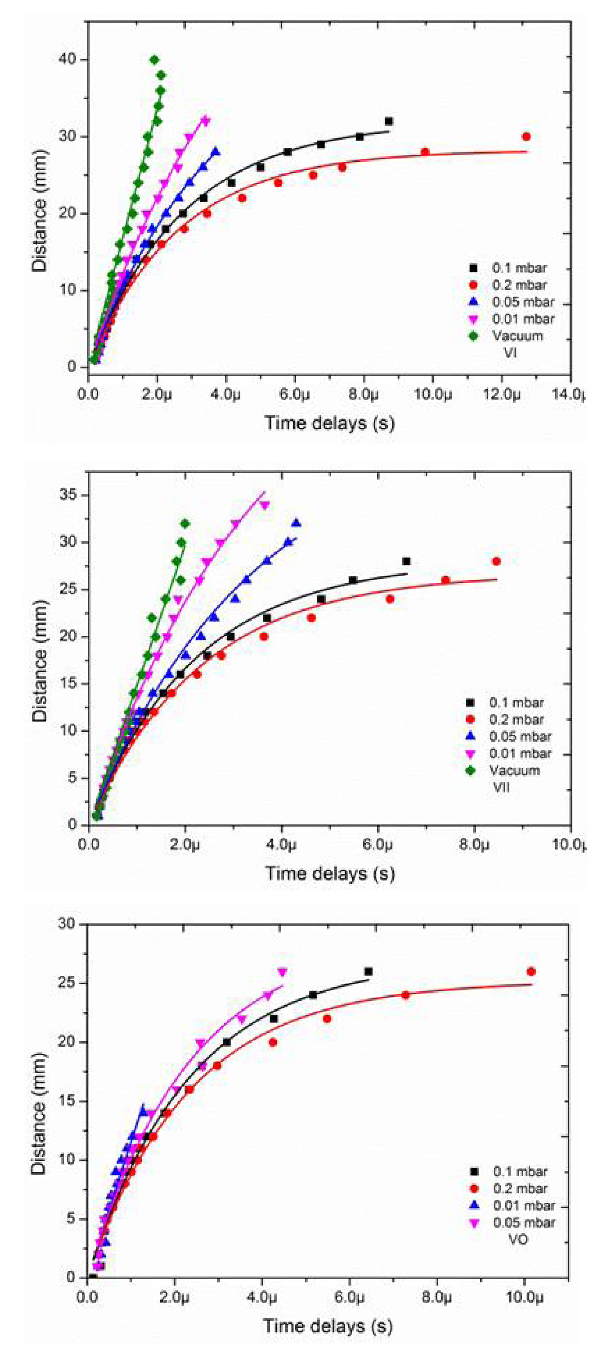

Figure 4: The distance against time delay graphs of the studied species of VI, VII and VO for the different oxygen pressures. The solid lines present the drag model fit. The graphs show the plasma plume expansion dynamics as it passes from free-like to shock-like and finally reaches a stopping time and distance for 0.1 and 0.2 mbar oxygen pressures. Another oxygen pressure shows the plasma plume-free expansion stage only. This is due to the limited area of the ICCD camera.