Multi-target Pulsed Laser Deposition (PLD) Technique for the growth of μm-to-nm scale Photo-active Thin-film Coatings

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Abstract. There has been an unprecedented increase in the growth of photonic components over the last 25 years based on different photonic materials; each having structural/functional limitation in integrated devices. The challenge is that the semiconductors are grown inside MBE chambers, whereas the polymeric waveguides are fabricated by spin-coating. By comparison, glass and crystal-based materials are processed via sputtering and sol-gel techniques. None of these materials processing techniques, therefore, are compatible for a single-step device fabrication, due to the incompatibilities of chemical and physical properties of individual materials. A solution for overcoming the materials limitation is to develop a multi-materials deposition chamber which allows sequential/heterostructure growth on a substrate, without compromising the structural, spectroscopic, and device performances. The rare-earth-ion doped glass- and crystal-based devices are pumped with semiconductor lasers, suggesting that the glass-semiconductor devices might perform better when structurally integrated which may also help in reducing the pump-power for achieving efficient population inversion. We explain the applications of PLD for controlling the structure of thin-films grown on inorganic and metallic substrates for photonic device and photo-active coatings for biological applications, respectively. Examples of materials deposited on dissimilar substrates are discussed with applications such as photonic devices and photo-bioactive surfaces for sensing.

1 INTRODUCTION

Over the last 25 years has been an unprecedented increase in the growth of photonic components based on semiconductor lasers, glass and polymer based optical fibres, organic LED, and solid-state lasers. Each of these components suffers from its intrinsic materials related limitations which then limit the performance in integrated devices. A solution for overcoming the materials limitation is to develop a device fabrication strategy which then allows multi-materials processing on a substrate, without compromising the structural, thermal, spectroscopic, and photonic device performances. The challenge is that the semiconductors are grown on an MBE machine, whereas the polymeric thin film materials are fabricated by traditional spin coating. By comparison, inorganic glass and crystal-based materials are processed via sputtering and sol-gel techniques. None of these materials processing techniques, therefore, are compatible for a single-step device fabrication, due to the incompatibilities of chemical and physical properties of individual materials. A vast majority of rare-earth ion doped glass- and crystal-based devices are pumped with semiconductor lasers, which then points out that the glass-semiconductor devices might perform better when structurally integrated, and that the integration engineering of dissimilar materials may help in reducing the pump power for achieving efficient inversion of excited states.

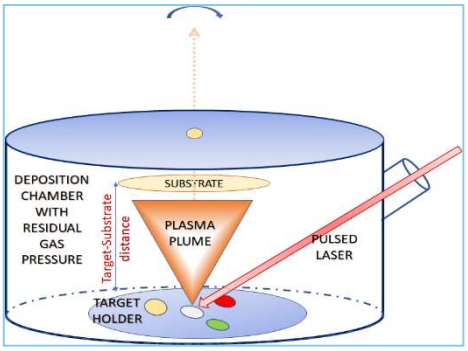

Figure 1: A schematic representation of PLD operation with process parameters needed for control of the quality of deposited thin films [1].

In this presentation, we explain the application of nano- and femto-second pulsed laser deposition (PLD) [1] for controlling the structure of thin-films grown on inorganic (silica-on-Si (SiO2-Si), silica, and semiconductor) and metallic surfaces for integrated photonic device and photo-active coatings for biological applications, respectively.

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2 MATERIALS AND METHODS

Figure 1 is a schematic representation of a multi-target PLD chamber in which we have access for both the excimer (193nm, 248nm) and an 800nm femto-second pulsed laser (100fs, 250-2kHz, 1mJ) sources. The maximum excimer laser energy per pulse was 5mJ and for a majority of PLD investigation sub-mJ energy was required. The repetition rates of both the excimer lasers (193nm and 248nm) were set at 20Hz with a pulse duration of 20ns [2,3].

3 RESULTS

Examples of materials deposition on dissimilar substrates for stress-matched waveguide fabrication are discussed and the photoluminescent emission properties of rare-earth ion-doped glass [4] (Figure 2) and inorganic biominerals, silicon [5,6] and polymer [3] films are explained. The deposition stress in thin films was analyzed (COMSEL) a priori for waveguide fabrication and biosensing applications so that the mismatch strain can be minimized during deposition by controlling thickness. The structure and spectroscopic properties of rare-earth ion doped thin films on silica, polymer, GaAs [4], and metallic titanium substrates were examined in detail and will be presented. We also demonstrate the fabrication of glass-polymer super lattice structures [2] (see Figure 3a), ion-implanted waveguide layers [7], nano-silicon waveguides [4] (see Figure 3b,c) for semiconductor integration, and photo-active minerals for biosensing.

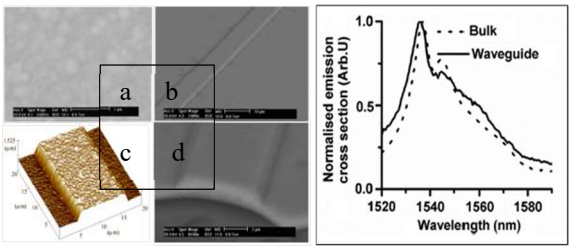

Figure 2: (**left**) collection of images (**a**) deposited oxyfluoride glass on silica, **b** to **d**) low magnification SEM image of the waveguide channel by laser machining, AFM image, and high magnification SEM, (right) Comparison of emission spectra in bulk glass and waveguide.

In the presentation, the laser machining and surface finishing properties of deposited structures using femto-second Ti-sapphire lasers is also described, which clearly shows that such complex structures from start-to-finish can be fabricated using different types of pulsed lasers. The amplified spontaneous emission and gain properties of coated thin films and waveguides are characterized for a range of device applications.

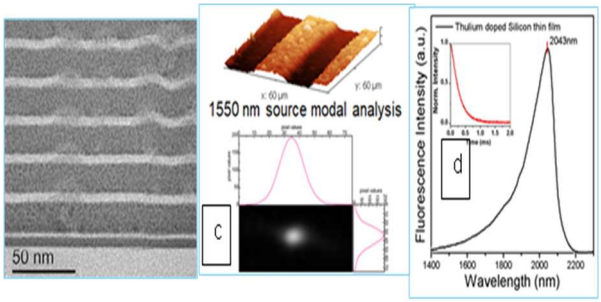

Figure 3: a) a TEM image of glass-polymer superlattice; b) fs-pulsed laser deposited and laser machined Si-doped with Tm3+ion waveguide; c) Waveguide modes; d) Room temperature photoluminescence spectrum of Tm3+ions in the Si-waveguide. Inset shows lifetime data.

Acknowledgments: The authors acknowledge the support for the EU funding for the ISMarD project (953128) under the EU-H2020-NMBP-20-2021 Grant agreement. AJ also acknowledges the support from the UKRI (EP/M015165/1; EP/M022854/1; EP/K020234/1, EP/D048672/1).

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