Pulsed Laser Deposition for Coating Applications

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Abstract Excimer lasers provide the shortest commercially available wavelengths and correspondingly, the highest commercially, available photon energies for laser material processing. Depending on the laser gas the emission of excimer lasers covers a range of wavelengths from 351 nm down to 157 nm with the respective photon energies between 3.5 eV up to 7.9 eV. In conjunction with the high ultraviolet output energies of up to 1200 mJ per pulse, excimer laser ablation offers maximum flexibility in terms of the target material spectrum and the ablation area. Process stability and thin film quality in Pulsed Laser Deposition (PLD) experiments largely benefit from the exceptional pulse-to-pulse stability of the excimer laser radiation which is of the order of 0.5 % (1 sigma). The top-hat beam profile which is imaged on the sample minimizes fractionation during the ablation process and supports stoichiometric transfer from target to substrate enabling controlled thin film growth.

1. Introduction
Pulsed Laser Deposition (PLD) as a physical vapour deposition technique for coating development and material screening opens up nearly unlimited pathways to functional coatings by means of rapid protocoating. Prerequisites for a successful rapid protocoating are well-conceived ablation systems and lasers enabling efficient, development of thin film coatings for medical device manufacturing, mechanical engineering, microsystems technology or optics on a short timescale. In the PLD technique a high pulse energy laser beam, preferably the rectangular profile of a short wavelength excimer laser at 248 or 193 nm, is demagnified on the target material which is to be deposited. Due to the short wavelength of the pulsed excimer light (20ns) and the resulting small penetration depth, the absorption takes place selectively in a limited volume near the surface leading to fast heating and explosive evaporation [1]. This non-thermal equilibration mechanism is the basis for depositing multi-component substrate materials controlling stoichiometry and crystal properties during thin film growth. The high energy photons of the excimer laser allow virtually all target materials to be deposited such as oxides, nitrides, and carbides for isolators, metals, complex ceramics, and polymers for semiconductors. The flexibility in view of the employed materials which can be varied during the deposition process allowing straightforward tailoring of multicoatings has rendered PLD an established and productive technology for coating and material development [2].
2. Pulsed Laser Deposition Requirements

2.1 Ablation Source
Uniform pulse energy, at both low repetition rates and in burst operation, is among the most critical laser output parameters for PLD. A constant, uniform pulse energy produces consistent deposition parameters, resulting in homogeneous films and a repeatable process. High laser pulse energy provides several benefits for PLD. First, it enhances the deposition rate of target materials. Depending on laser pulse energy several microns per minute are achievable [3]. Next, it enables a larger area on the target to be ablated at a given fluence. This area enlargement increases the deposition rate and reduces the plume angle, resulting in higher deposition efficiency. Finally, higher photon energies as provided by excimer lasers at wavelengths of 193 nm and 157 nm provide an even larger process window, allowing consistent, successful material ablation well above the ablation threshold also for transparent polymers and hard target samples [4].

Even compact excimer lasers provide high pulse energies between 200 and 500mJ with excellent pulse-to-pulse stability of typically 0.5%, 1 sigma as shown in figure 1.

![Figure 1](image.png)

**Figure 1.** Pulse energy and energy stability of a COMPexPro excimer laser as a function of operation voltage at a typically employed wavelength of 248 nm and a repetition rate of 10Hz.

2.2 Vacuum System
In order to generate smart material layers most effectively next to the ablation light source which is preferably a short wavelength excimer laser a sophisticated vacuum system is the key to success. Its essential components are the vacuum chamber containing heated substrate holder, target holder and UV optical elements for demagnifying the laser beam to the required on-target energy density of typically 1-5 J/cm². Both a constant deposition rate and homogeneous thin film properties over a large thin film area are provided by the exceptional pulse-to-pulse stability and beam homogeneity of advanced high-pulse energy lasers. Fully automated vacuum systems with up to 6 inch diameter substrates enable efficient and reproducible thin film
development for scientific as well as industrial research facilities. Rotatable revolvers, as shown in figure 2, allow to variably deposit up to 6 different target materials. The individual targets generally consist of small pellets offering high flexibility and reducing target costs to a minimum.

**Figure 2.** Target holder in an advanced PLD vacuum system, consisting of six rotatable targets enabling cost-efficient material screening (Source: Axyntec GmbH).

### 3. Coating Capabilities of Pulsed Laser Deposition

Of particular interest both in mechanical and optical engineering are coatings combining hydrophobic functionality with a high degree of transparency in a thin layer as provided by polytetrafluoroethylene (PTFE). This material cannot be deposited other than with pulsed laser deposition and demonstrates the flexibility of PLD. Thin PTFE layers of a thickness of above 100 nm significantly increase the contact angle on a given substrate to 110° as is shown in figure 3 for glass substrate and at the same time provide a transmission of >98 % as useful for e.g. self-cleaning eye glasses.

**Figure 3.** Water droplet on a glass surface before (left picture) and after (right picture) coating with a PTFE thin film (Source: Axyntec GmbH).

In medical device technology PLD deposited coatings lend the required biocompatibility to novel implants. As in the case of stents many devices cannot be made from biocompatible materials such as titanium directly but need to be chosen in view of their mechanical properties supporting high tensile stress during expansion in
the blood vessel. The appropriate layer material deposited with PLD exhibits high adherence also on the usually four times expanded stent material which is the prerequisite for its biocompatibility. In figure 4 a biocompatible metal oxide target has been used for pulsed laser deposition with excellent thin film homogeneity and strength. Deposition time for a 150 nm film on a 20 mm long stent is in the range of minutes [4].

![Figure 4](image)

**Figure 4.** Microscopic view of an expanded stent coated with a thin metal oxide layer (left). The enlarged view (right) gives evidence for the high thin film quality preserving its biocompatibility (Source: Axyntec GmbH).

4. Conclusion

Intelligent thin film development and rapid prototyping for various fields of applications is largely facilitated by means of pulsed laser deposition. Stable, high pulse energies of 248 nm excimer lasers provide controlled and reproducible target ablation characteristics. Combined with compact, automated vacuum systems for fast and convenient substrate handling stoichiometric multi-layer thin-films with good homogeneity and tailored physical characteristics are efficiently generated.

References

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