New excimer lasers advance coated conductor upscaling

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Abstract. High power excimer lasers designed for use in pulsed laser deposition (PLD) of thin films, including coated conductor layers allow faster deposition rates and eventually faster tape feed rates than before. Throughput increase depends on the individual PLD system design and can be driven mainly by excimer laser repetition rate or by pulse energy. Intelligent beam delivery as well as substrate-target scanning algorithms will leverage the full potential of the latest generation of high power excimer lasers.

1. Introduction
Coated conductor development has made significant performance leaps over the last decade as have output power and stability advances in excimer laser technology. Consequently, among the most promising fabrication routes aiming at breaking the commercialization barrier for second-generation high-temperature superconductive (2G HTS) coated conductors pulsed laser deposition (PLD) is found to be at the forefront with regard to achievable production quality and capacity. Sophisticated large-area deposition beam architecture unleashes the full production capability of ever more powerful UV excimer lasers paving the way towards cost-competitive 2G HTS wire to enter the marketplace.

2. Pulsed Laser Deposition – Market and technology drivers
Since the first pulsed excimer laser deposition of superconducting YBCO films in 1987, PLD has become one of the most popular techniques for depositing a variety of complex materials. Reproducing the ablation target’s cation stoichiometry is thereby regarded one of the greatest benefits of PLD for thin film deposition. In fact, the last decade has seen virtually every class of materials to be grown in one of the many hundred thin film deposition labs throughout the world. From metals and semiconductors to multi-stoichiometric ceramics, from carbon to organic polymers, and with certain premises even biological samples have successfully been deposited in thin layers [1]. As of today, major market demand for functional thin layers comes from (a) display industry requiring transparent conductive oxide films (e.g. ZnO, ITO), (b) the LED industry’s need for e.g. GaN films as blue emitter, (c) the automotive and medical industry benefitting from diverse protective coatings such as diamond-like carbon thin films, and (d) from the emerging superconductivity industry requesting oxide buffer layers and rare earth cuprate based superconducting films for coated conductors.

Ready-to-use PLD vacuum and handling solutions supporting 8 inch (200 mm) diameter substrate wafers as well as over 100 m length of substrate tape reel-to-reel coating are commercially available off-the-shelf from various PLD system suppliers [2]. PLD systems, components and monitoring

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equipment together with mature and reliable excimer lasers technologically drive PLD thin film industrialization on both wafer and tape substrate geometries.

3. Commercialization potential

Further establishing the PLD method on the coated conductor reel-to-reel production floor particularly demands upscaling both the lateral (area) and the vertical (thickness) deposition rate along many hundreds of meters. Novel excimer laser beam utilization schemes and sophisticated substrate-target geometries in conjunction with the evolving output power of excimer lasers such as the high power LAMBDA SX series (shown in the inset of figure 1) form the backbone of the superconductor industry’s high-rate PLD mass production systems constantly pushing the performance-cost-ratio of coated conductors toward commercial breakthrough. The industry-proven design of the LAMBDA SX series enables stable performance for three-shift, large-area UV ablation and illumination.

![High Power Excimer Lasers for PLD](image)

**Figure 1.** Power range provided by high power excimer laser models.

Steady advances of both the substrate, target and beam handling technique as well as of the excimer laser ablation sources have rendered PLD one of the most promising approaches en route to breaking the performance/price-barrier of coated conductors. PLD prevails among the most promising techniques and PLD based coated conductor manufacturing with an end-to-end current density of 176 kA-m over 500 m tape length has recently been reported by manufacturer Fujikura in Japan [3].

Alternative, chemical deposition technologies for buffer and superconducting layers of coated conductors are the Metal Organic Deposition (MOD) route and the Metal Oxide Chemical Vapor Deposition (MOCVD) route both involving wet chemistry processing steps.

As a matter of fact, for coated conductors to emerge and to gain market share over LTS and conventional copper based solutions much larger production capacities still representing a bottleneck are to be achieved. As of today, magnetic resonance imaging (MRI) is a 3 billion dollar market for superconductors and consumes half of the worldwide production capacity of low temperature superconducting material (LTS). Speaking in LTS wire demand more than 3000 MRI systems are annually shipped with every one system requiring ca. 200 km of wire.
Against this background, coated conductor manufacturing unit lengths need to evolve from the current hundreds of meters to a kilometer in length and beyond and this without sacrificing the overall end-to-end current density performance of the tape.

HTS market projections are that for 2G HTS tapes following the coated conductor performance-price-roadmap the global market will see a strong HTS growth rate from ~100 million USD in 2008 to ~500 million USD in 2013[4].

4. Increasing the deposition rate via the laser output energy

Novel beam delivery architectures based on excimer laser beam splitting and scanning enable the formation of several parallel material plumes [5]. With the premise that the required excimer laser fluence for each of the illumination spot sizes on the target is maintained, in a first approximation the deposited volume per unit time scales with the number of generated parallel beamlets and material plumes, respectively.

High power excimer lasers providing stabilized output energies which are as high as 1 Joule ideally suit fluences of the order of a few Joule per square centimeter required for high-rate multi-plume deposition architectures.

Moreover, the high per-pulse energies delivered by the excimer laser exhibit extreme pulse-to-pulse stability even at high repetition rates and hence provide high process repeatability in PLD.

Figure 2 visualizes the improvement in the typical long-term pulse energy stability and gas lifetime for 300 W high power excimer lasers operating in stabilized energy mode at a pulse energy of 1000 mJ and 300 Hz.

![Energy Stability & Gas Lifetime Comparison](image)

**Figure 2.** Evolution of long-term energy stability in high power excimer lasers.

In todays high power excimer laser models over the course of 50 million laser pulses translating into nearly two days and nights of continuous, hands-free operation with a single gas fill, an energy stability of typically better than 1 %, rms is obtained. The measurements shown in figure 2 have been recorded for a wavelength of 308 nm which together with the wavelength of 248 nm is most
frequently employed for high UV energy industrial applications, since these yield precise laser-material-interaction and at the same time optimum laser optics lifetime.

5. **Increasing the deposition rate via the laser pulse frequency**

Next to requiring sufficient output energy being intense enough to enable the combined fluence supporting multi-plume architectures, tape manufacturers have indicated excimer laser pulse frequency to be another driver of overall PLD processing speed [6]. The latest Coherent high power excimer laser series model LAMBDA SX 540 C has been designed to offer twice the laser pulse frequency in order to further boost throughput in industrial high-volume processing. The LAMBDA SX 540 C model provides stabilized energy operation at up to 900 mJ and repetition rates as high as 600 Hz for a wavelength of 308 nm. A non-stop 600 Hz long run over 75 million pulses with a preset stabilized pulse energy of 800 mJ corresponding to stabilized 480 W operation is shown in figure 3.

![Figure 3](image)

**Figure 3.** Stabilized run of a 308-nm LAMBDA SX 540 model operated at 600 Hz and 800 mJ with a single gas fill.

For the tape manufacturers to transfer the two times higher repetition rate into correspondingly higher deposition rates and eventually into faster tape feed rates novel beam delivery algorithms have to be employed which fully leverage the increased repetition rate potential. On the basis of sophisticated beam scanning designs which are capable to avoid local overlapping effects during target ablation and maintains laterally homogeneous, large-area superconducting and buffer layer growth, respectively, manufacturers can capitalize on the high laser pulse frequency without sacrificing coated conductor quality.

6. **Matching excimer laser parameters and deposition system design**

In table 1 a synopsis of latest performance specifications as provided by the LAMBDA SX high power excimer laser series for the wavelengths 248 nm and 308 nm is given.
Table 1. Performance specifications of LAMBDA SX 300 and 600 Hz excimer laser models at 248 and 308 nm.

| Laser Model | LSX 200K | LSX 300K | LSX 200C | LSX 300C | LSX 540C |
|-------------|----------|----------|----------|----------|----------|
| Wavelength: | 248 nm   | 308 nm   | 248 nm   | 308 nm   | 248 nm   |
| Max. Stab. Energy: | 670 mJ | 1000 mJ | 670 mJ | 1000 mJ | 900 mJ |
| Max. Stab. Power: | 200 W | 300 W | 200 W | 300 W | 540 W |
| Max. Rep. Rate: | 300 Hz | 300 Hz | 300 Hz | 300 Hz | 600 Hz |
| Energy Stab. (rms): | < 1.5 % | < 1.5 % | < 1 % | < 2 % | < 2 % |

Depending on the individual PLD system layout which in most industrial installations uses proprietary design for beam delivery and scanning as well as substrate-target geometry, either repetition rate or pulse energy might be the main throughput driver. Accordingly, the best match between excimer laser model and PLD system layout is to be made in order to unleash the entire UV ablation and deposition potential for an effective coated conductor capacity scale-up.

7. Conclusion
Intelligently capitalizing on multihundred watts of average UV power together with evolving setup designs will significantly expand PLD based coated conductor manufacturing speeds. Ultimately, highest tape feed rates will be accomodated via sophisticated multi-beam ablation and multi-plume deposition architectures, respectively, tapping the full UV power available from today’s state-of-the-art excimer lasers.

As a best case scenario for scale-up, the factor of two higher laser repetition rate translates into a factor of two higher material deposition rate whereas a split into a number of n beams will result in an n-fold increase of deposition speed for both PLD-grown superconducting and buffer layers.

The significant upscaling potential of coated conductor processing via the PLD route in conjunction with the inherently high PLD-grown superconductor thin film quality and performance renders excimer laser based PLD a leading technology to accelerate the looming market entry of coated conductors.

8. References
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