Efficient Manufacturing of Quantized Nanolaminate Multilayer Coatings

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1 INTRODUCTION

Quantized nanolaminates (QNL) consist of very thin layers of high and low refractive index. The nanolaminates exhibit a higher band gap energy than what would be expected from a homogeneous mixture of the high and low index material. This increased band gap leads to a shift of the absorption edge to shorter wavelengths as well as to a higher laser induced damage threshold (LIDT). QNL therefore recently gained increasing interest in the optical thin film community.

In this contribution we show how multilayer coatings that contain QNLs can efficiently be produced on the Evatec *CLUSTERLINE® 200 BPM* sputter deposition tool and present fs-LIDT results of mirrors for 1030nm showing increased laser damage resistance for the designs with QNL layers.

2 DEPOSITION METHOD

The Evatec *CLUSTERLINE® 200 BPM* is a magnetron sputter deposition tool equipped with automatic substrate loading from cassette to cassette. It can be configured with up to four sputter sources, a plasma source (PSC), plasma emission monitoring (PEM), and an in-situ optical monitoring system with broadband and monochromatic capability.

16 substrates of 200mm diameter are placed on a turn table. Each substrate is additionally rotating to achieve an excellent thickness uniformity without using shaper masks.

When depositing Ta_2O_5/SiO_2 QNL (figure 1b), both sources are running simultaneously. Both materials are sputtered from metallic targets and oxidized near the sputter target controlled by the PEM. During one rotation of the table, each substrate receives a thin Ta_2O_5 layer and a thin SiO_2 layer when passing below the respective sources. The thickness of such a layer pair can be adjusted by the table rotation speed, whereas the ratio between high index and low index material is defined by the sputter powers. Figure 1c shows a transmission electron microscopy (TEM) analysis of a nanolaminate consisting of Ta_2O_5 (black, ca. 1.35nm thick) and SiO_2 (white, ca. 2.18nm thick) layers. To deposit multilayer optical interference coatings with QNL layers, the process sequence simply consists of the standard high or low index material deposition steps and the QNL layer steps.

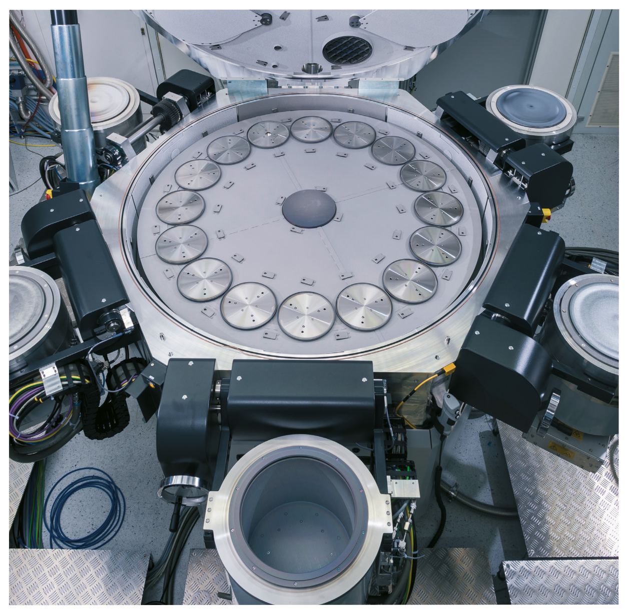

Figure 1a.
Evatec CLUSTERLINE® 200 BPM deposition tool opened for service

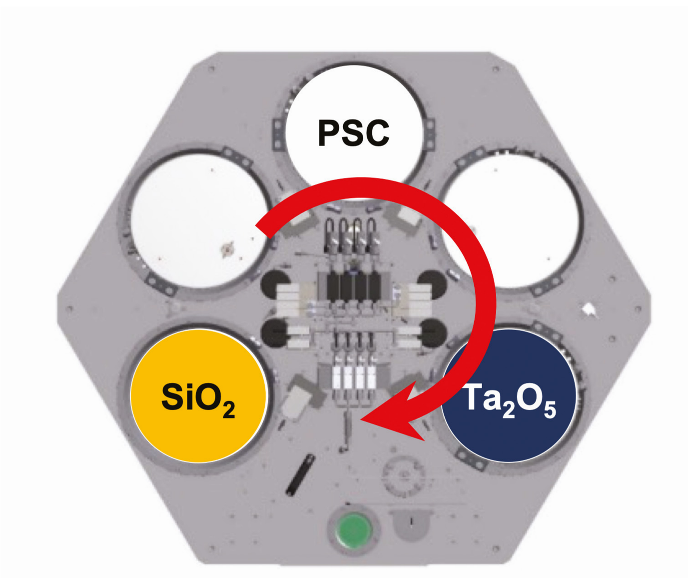

Figure 1b.
Schematic for deposition of Ta_2O_5/SiO_2 QNL

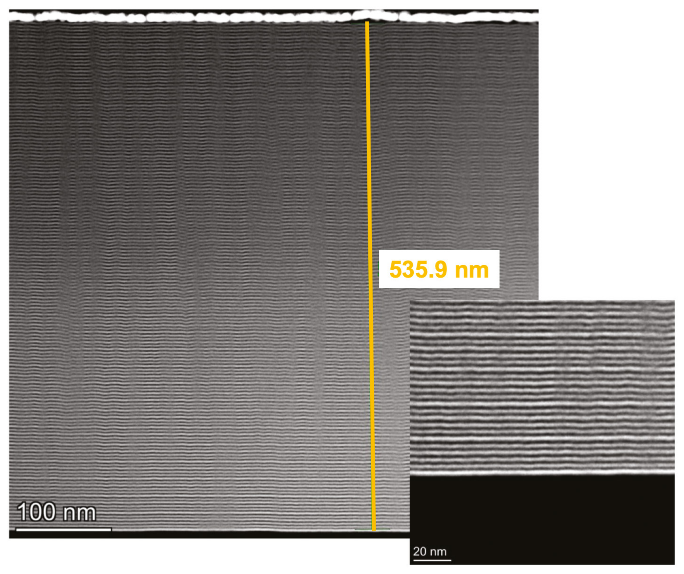

Figure 1c.
TEM analysis of a Ta_2O_5/SiO_2 QNL

3 MULTILAYER DESIGN AND MONITORING

Figure 2a shows the refractive index dispersions determined from spectrophotometric measurements of two different QNLs along with the SiO_2 and Ta_2O_5 refractive indices. These material properties can then be used like standard materials in multilayer designs.

As an example, figure 2b shows the layer thicknesses of a 30 layer mirror for 1030nm at 0° angle of incidence (AOI). For layers 1…18 Ta_2O_5 and SiO_2 are used to form the base mirror, whereas QNL and SiO_2 are used for the remaining layers to make use of the postulated higher laser damage threshold of the QNL material. This is justified because high electric field amplitudes are expected near the mirror surface. Additionally, thicknesses were adjusted to lower the E-field amplitudes in the QNL and Ta_2O_5 layers.

The in-situ optical monitoring Evatec GSM1102 measures reflection on a defined substrate at every rotation of the substrate table. Therefore, the monitoring "sees" an additional layer pair of the QNL with every measurement. The measured reflection spectra agree very well with the simulations based on the determined refractive index of the QNL. Figure 3a shows the spectra measured by the optical monitor at the start and end of the standard Ta_2O_5 layer 17, figure 3b shows the according spectra for the QNL layer 19. This illustrates that the changes in the reflection spectra from start to end of the layers are significant, which allows for precise optical monitoring.

3 MULTILAYER DESIGN AND MONITORING (CONT.)

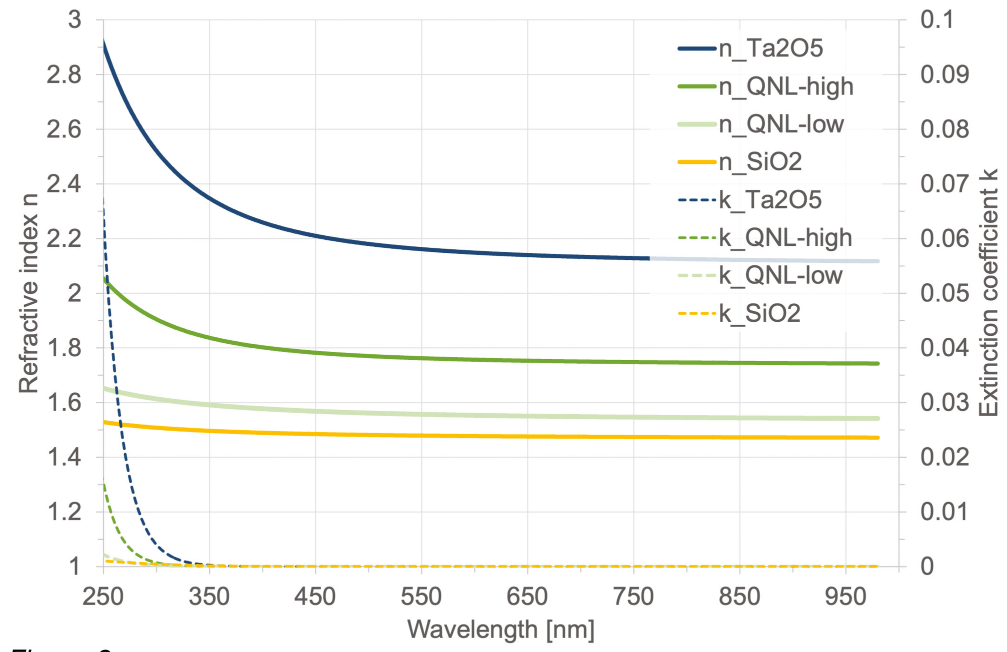

Figure 2a.
Refractive index dispersions SiO_2, Ta_2O_5, and of two Ta_2O_5/SiO_2 QNLs

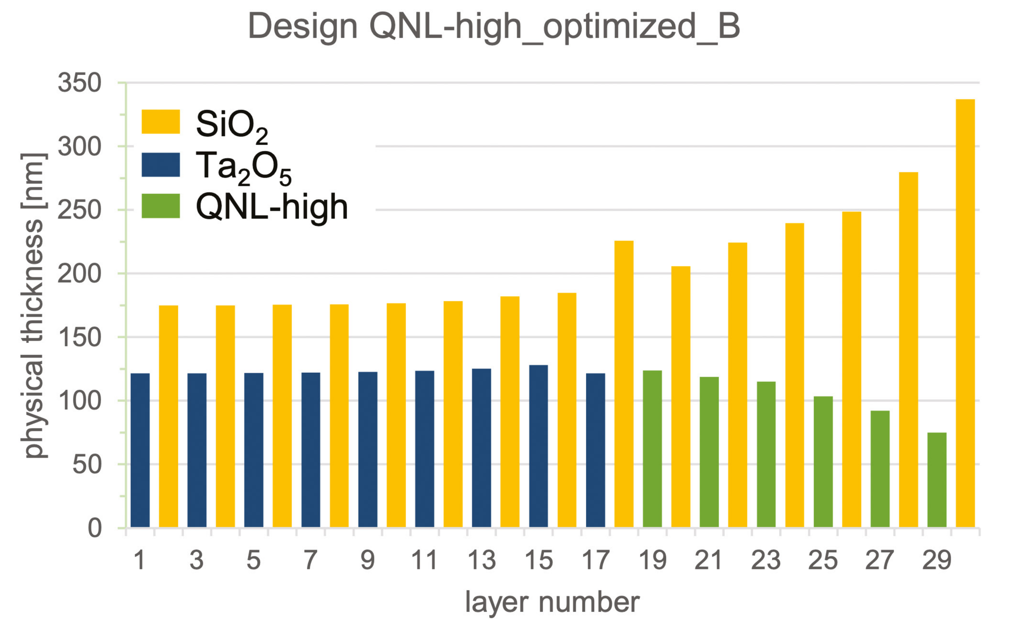

Figure 2b.
Design thicknesses of mirror for 1030nm consisting of Ta_2O_5, SiO_2 and a QNL material

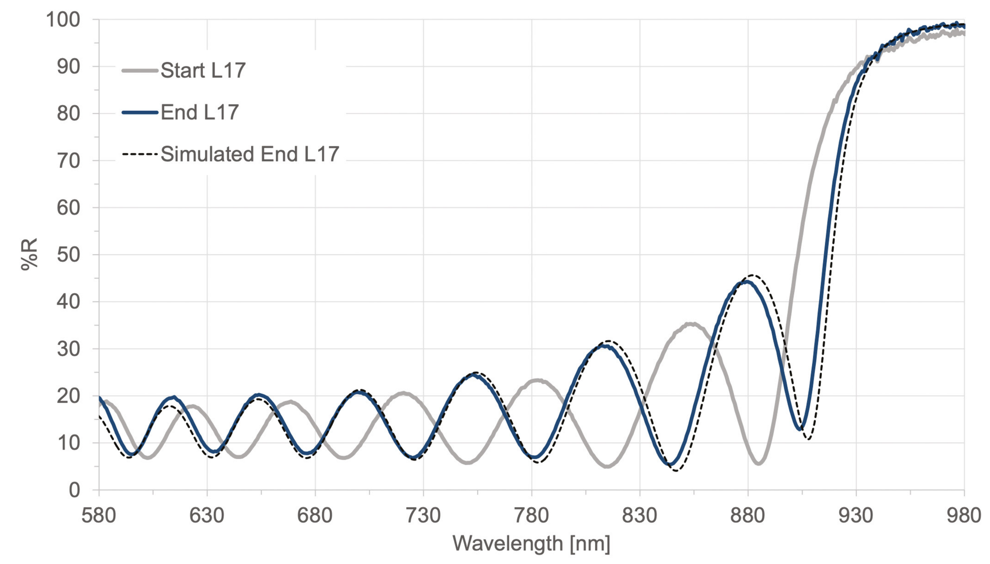

Figure 3a.
Optical monitoring spectra at start and end of the Ta_2O_5 layer 17

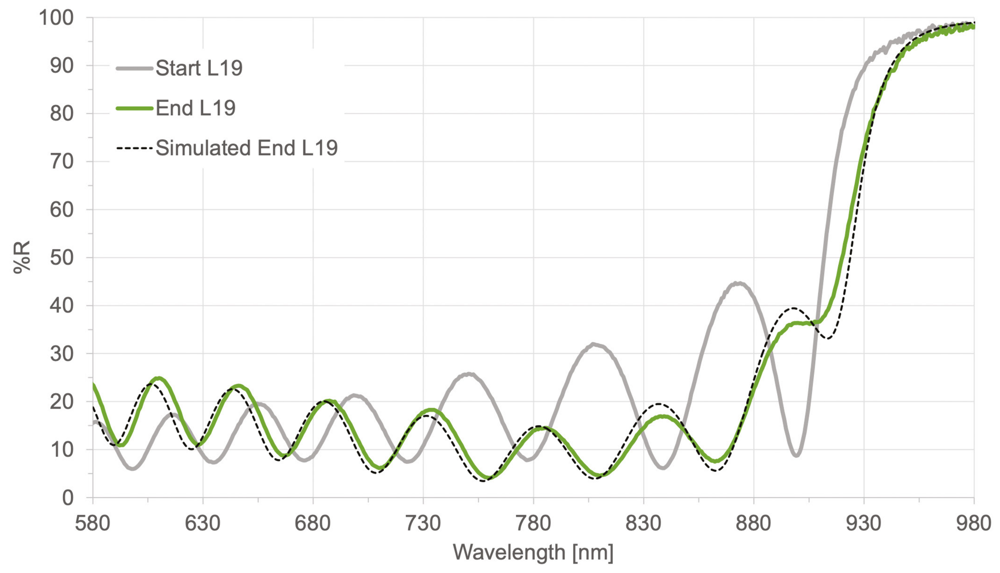

Figure 3b.
Start and end spectra of the QNL layer 19

4 MIRRORS FOR 1030NM AND FS-LIDT RESULTS

A series of mirrors for 1030nm at 0° AOI with and without QNL layers were designed, deposited, and characterized. For each material combination "std" designs composed of quarter-wave layer thicknesses were set up, as well as "optimized" designs, where the layer thicknesses were adjusted to reduce the electric field amplitudes in the higher index layers close to the mirror surface. The "HR" designs consist of Ta_2O_5 and SiO_2 layers only, whereas the "QNL-high" designs use Ta_2O_5 for the first part of the design and QNL with high index for the remaining part. Accordingly, "QNL-low" uses the lower index QNL material.

These multilayer designs were deposited and then submitted to femtosecond laser damage testing at the LIDT facility at RhySearch. The test conditions were 1030nm laser wavelength with 300fs pulse duration, 200kHz repetition rate, and an effective beam diameter of 32µm. LIDT was determined for 2×10^7 pulse repetitions.

Figure 4 summarizes the LIDT results. The fabricated mirrors achieved an LIDT in the range of 0.83…1.23 J/cm². For all material combinations, the "optimized" designs reach higher LIDT than the "std" quarter-wave designs. The two best results are the mirrors which contain QNL layers, whereas the Ta_2O_5 / SiO_2 mirror "HR" does not exceed 1.0 J/cm². For comparison, a commercially available ion-beam sputtered mirror for high power fs-laser applications was included in the test, it reached an LIDT of 0.66 J/cm², i.e. a significantly lower value than all other samples.

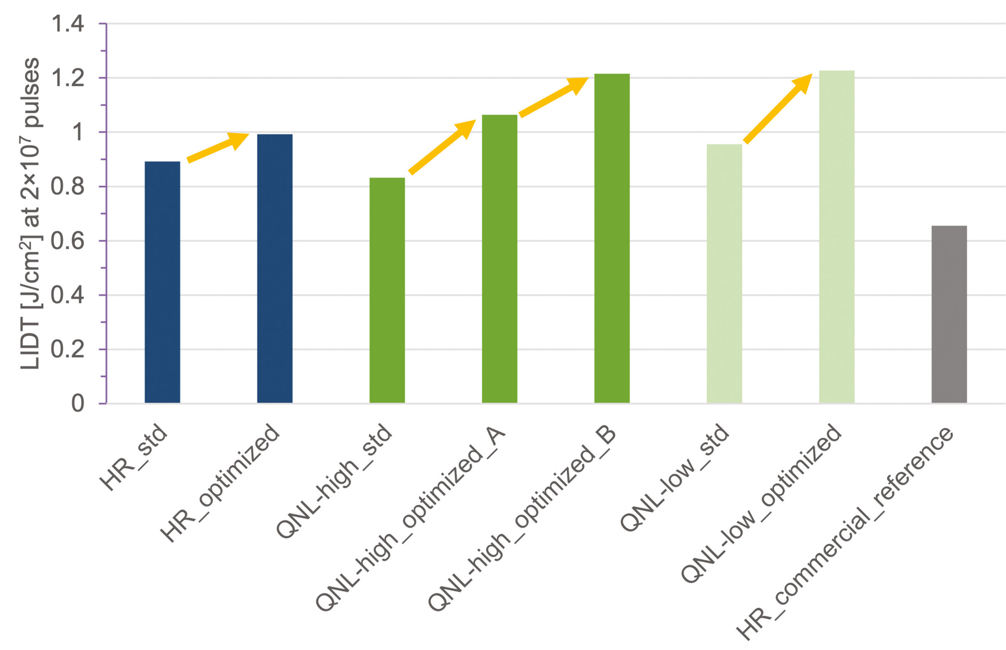

Figure 4. Femtosecond LIDT at 2×10^7 pulses for different mirrors for 1030nm. The arrows indicate the improvement due to the E-field optimization.

5 CONCLUSIONS

Quantized nanolaminate layers can efficiently be deposited using a magnetron sputtering production tool. Tuning the deposition parameters of the *Evatec CLUSTERLINE® 200 BPM* allows for adjusting the refractive index of the QNL and to optimize the bandgap shift. The QNL layers can be incorporated in multilayer designs using the standard tools for characterization, design, and optical monitoring. This is demonstrated using a series of mirror designs. LIDT testing of the mirrors shows an excellent performance of the designs containing QNL layers.