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UV coatings using Ta_2O_5-SiO_2 quantized nanolaminates

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Abstract. In the last few years, quantized nanolaminates (QNL) have become increasingly popular as a metamaterial in the development for optical coatings. Experiments were often performed using IBS or ALD coating techniques, which yield excellent accuracy but are very time consuming to coat. By using a magnetron sputter system with rotating substrate table, we are able to produce these layers at very high deposition rates and to use these nanolaminates as standalone high index material in optical designs. Due to the properties of QNL to increase the band energy and thus shift the absorption edge into lower wavelength ranges, it is possible to create designs in the UV range that would not be possible with simple Ta_2O_5-SiO_2 material combination in regular designs. In this work we show a selection of different designs such as anti-reflective coatings, mirrors and short pass filters at wavelengths from 266-355nm which covers an important range in laser applications.

1 Introduction

Quantized Nanolaminates (QNL) represent a material system in optical coatings that was first developed by Laserzentrum Hannover in 2017 [1]. Two optical materials with different refractive indices are coated alternately as very thin layers with typical thicknesses of 0.1-2nm on a substrate. If many of these layers are successively coated, they will result in a QNL material with new optical properties. The refractive index of this new material corresponds to the thickness ratio between the two individual layers. Due to the very thin thickness of the high index material, however, valence electron mobility is restricted, which leads to a shift of the absorption edge into the low wavelength range [1]. This effect has been demonstrated several times, mostly by IBS or ALD systems [1,2,3]. Unfortunately, the process change between two different materials requires a lot of time, so that it was only possible to use this new material system in complex layer designs with considerable effort. We were able to develop a process on a magnetron sputtering system in which we can produce such QNL systems from Ta_2O_5 and SiO_2 as a continuous material with sputtering rates of up to 0.8nm/s and 2400 laminate pairs per hour without interrupting the process [4]. This means that we have now succeeded for the first time in using QNL economically as an independent optical high index material for complex optical filter systems.

2 Experimental setup

For our experiments, we use a magnetron sputtering device Clusterline® 200 BPM from Evatec to produce the coating designs. The tool has a rotating substrate table with also rotating substrate holders. There are two sputter sources on the system, one for coating SiO_2 and one for Ta_2O_5. The sources are operated simultaneously and run constantly throughout the coating process for the nanolaminates. Due to the rotating table, the substrates are coated with only a thin layer of the respective medium as they pass under each source.

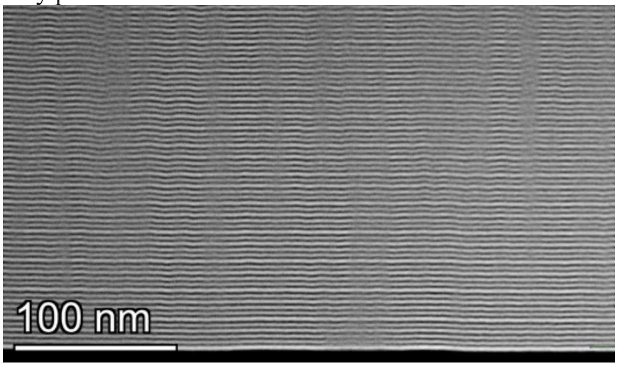

Fig. 1. The Graphic shows a cut out of a TEM measurement of a Ta_2O_5-SiO_2 QNL single layer stack.

The process is carried out until the nanolaminate structure reaches the desired total thickness (Fig. 1.). In-situ optical broadband monitoring is used for layer termination, assuming a constant refractive index dispersion for the QNL material. Simple SiO_2 is used as the low index material for multilayer systems. This enables us to produce complex filter systems in which QNL is the high refractive index material and is coated at a rate of up to 0.8nm/s on 15 8-inch wafers simultaneously.

3 Properties of QNL

For the experiments, we first created processes with different Ta_2O_5-SiO_2 ratios and determined their mixed refractive indices. We then coated selected combinations with different table rotation speed (Fig. 2.).

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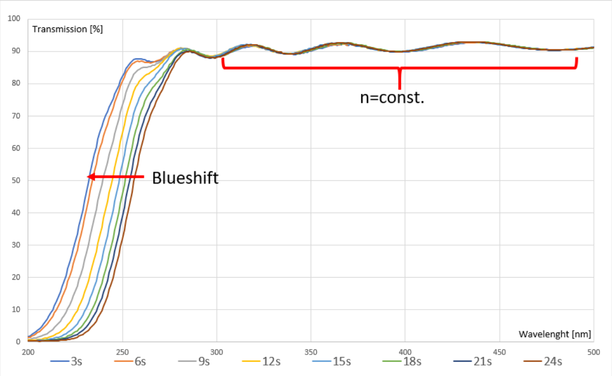

Fig. 2. The diagram shows the transmission spectrum of several QNLs with identical refractive indices, but different table rotation speed (s/rotation) and therefore laminates of different individual thicknesses. The blueshift is clearly recognizable.

Within a set of combinations, the coated refractive indices remain constant, as the proportions of Ta_2O_5 and SiO_2 remain the same, but the thicknesses of the individual laminates vary, resulting in different band gaps. This leads to a shift of the absorption edge to shorter wavelengths for higher rotation speeds, i.e. a blueshift of up to 25 nm. We then calculated the refractive indices at 550nm and the bandgaps for these sets (Fig. 3.).

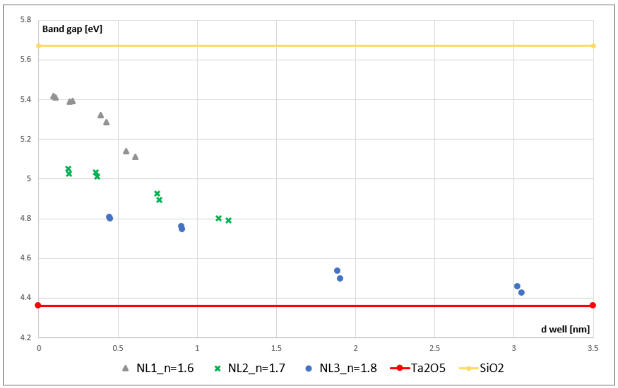

Fig. 3. The calculated band gap compared to the well (individual Ta_2O_5 laminate) thickness for three different QNL combination sets is shown in this graph with the band gaps of single Ta_2O_5 and SiO_2 layers.

4 QNL Designs

With the knowledge gained at the single layer stacks of the QNL we created several designs for the UV range, using the QNL as high- and SiO_2 as the low refractive index material. Two 355nm HR mirrors with a short pass range to the UV have been coated, one with QNL (NL3) and one with Ta_2O_5 as comparison (Fig. 4.). The transmission of the QNL design covers a wide useable range down to 280nm, whereas the short pass using standard Ta_2O_5 gets strongly absorbing below 310nm. It should also be noted, that the back-side reflection of the substrate (Herasil) has not been deducted. Furthermore, a double-side anti-reflective coating for 266nm using a different parameter set (NL1) for the QNL layers and a lower refractive index has been coated. The spectral measurement (Fig. 5.) shows the low reflection and low loss of the QNL design at 266nm.

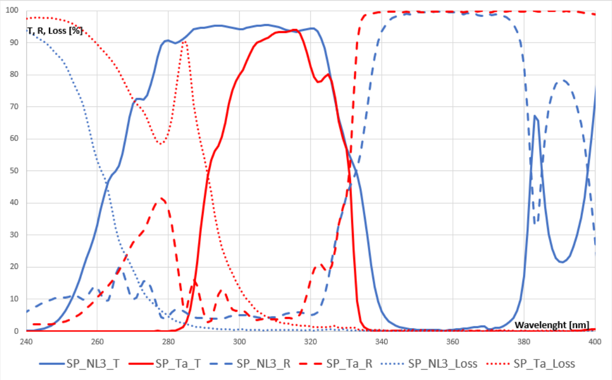

Fig. 4. The diagram shows two short pass filter, each 40-layer designs with a high reflectance mirror at 355nm. One with QNL (blue) and one with Ta_2O_5 (red) as high refractive index material. Solid lines represent the transmission, dashed reflection and dotted the loss.

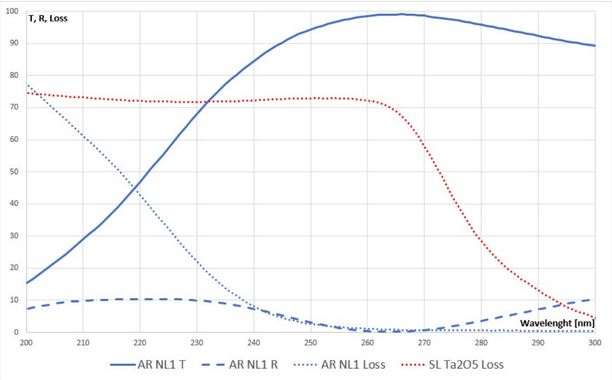

Fig. 5. A double-side 6-layer anti-reflective coating at 266nm is shown (blue). The solid line represents the transmission, dashed reflection and dotted the loss. As comparison also, the loss-curve of a single 177nm thick Ta_2O_5 layer (red) is added.

To compare, the loss of a Ta_2O_5 single layer lays at ≈ 70% at 266nm which makes it not usable in a design in this wavelength range.

5 Conclusion

During the experiments, we successfully produced quantized nanolaminates with varying Ta_2O_5-SiO_2 ratios, resulting in different refractive indices. By adjusting the rotation speed of the substrate table, we controlled the thickness of the individual layers and effectively tuned the bandgap. These newly developed optical materials were then applied to different QNL-SiO_2 multi-layer designs in the UV range to show the benefit compared to classic Ta_2O_5-SiO_2 designs, including short-pass filters and anti-reflective coatings.

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