Comparison of gradient index and classical designs of a narrow band notch filter

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INTRODUCTION

Rugate structures, as well as gradient refractive index films in general, attract a lot of interest. The gradient index systems may provide advantages in both, optical performance and mechanical properties of the optical coatings. Rugates have shown to be specially interesting for design of notch filters. Notch filters, also known as minus or band stop filters, are optical components having very low transmittance in a narrow spectral range but a high transmittance elsewhere. They are mainly used in Raman and fluorescence spectroscopy, laser systems and as laser protective coatings. The ideal notch filter would have one hundred percent of reflectance in the required rejection band and zero reflectance outside of this region.

A lot of theoretical work on design of rugate filters has been done in the last decades. However, only few of the designs could be deposited, which is often caused by practical problems, e.g. preparing materials with the desired refractive index values. In this paper three designs of a narrow notch filter are presented. Special care was taken to make them as simple for production as possible. It means that thickness of individual layers or periods, total thickness, refractive index range and gradients of refractive indices applied in these designs are feasible. One of the designs is a classical HL system. The second is a rugate system synthesized by an apodized sinusoidal structure that is approximated by homogeneous sublayers. The last presented design is a combination of the two first mentioned. It is also based on an apodized sinusoidal shape, but is approximated by a hybrid structure, i.e. a combination of linear gradient index ramps between the lowest and the highest refractive index applicable and homogeneous layers of high index values.

SPECIFICATIONS

The performance of the required notch filter should satisfy the following demands under normal incidence: reflectance (no back side reflections included) should be lower than 10% in the wavelength range 400-515 nm and 550-700 nm, transmittance in the range 530-534 nm should be lower then 0.01% and the total physical thickness of the design should not exceed 10 ìm significantly. Three different approaches have been applied to model the filter and three different designs were obtained. As substrate material BK7 glass was taken in all three cases. For the sake of clarity in the comparison of the designs, it is assumed that all the materials and the substrate are free of absorption. However, dispersion of the materials is taken into account.

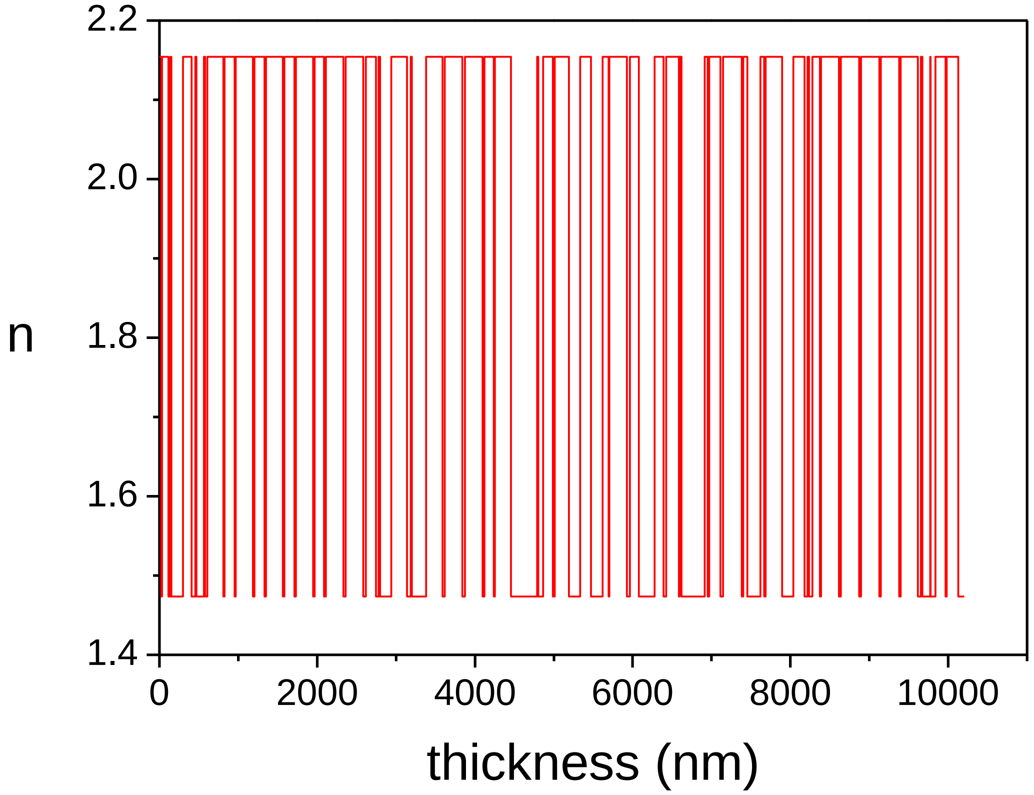

Figure 1. Refractive index profile of HL design.

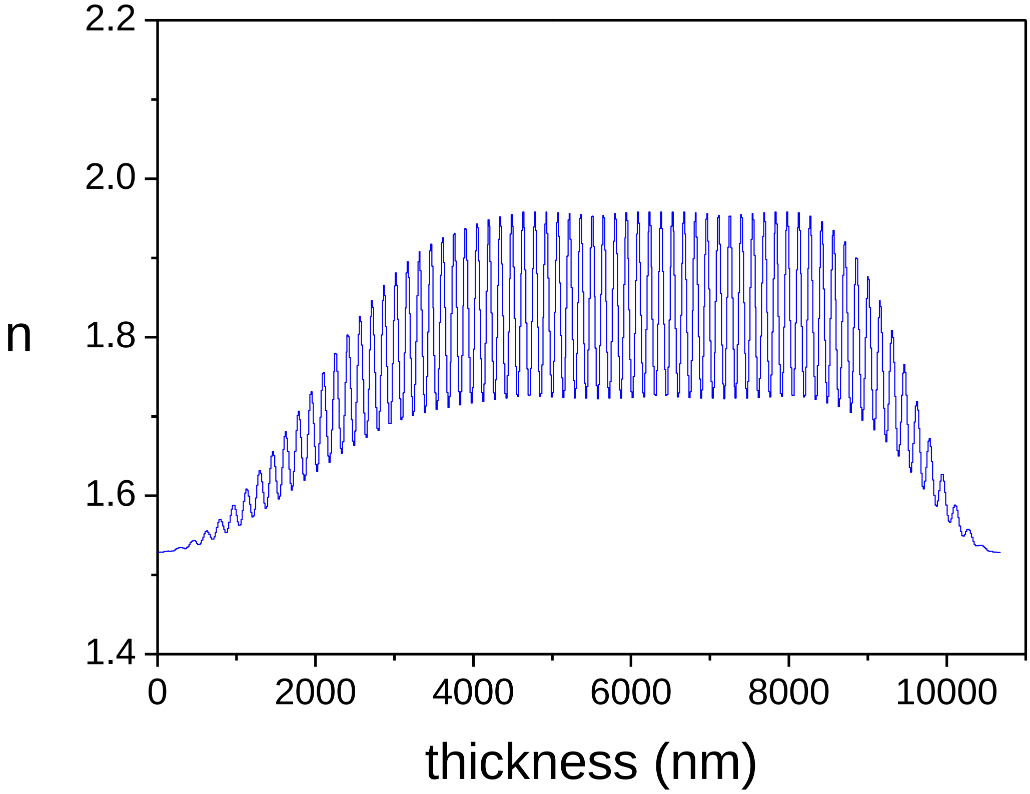

Figure 2. Refractive index profile of the rugate design. In the other two designs the target reflectance out of the rejection band was defined as 0%, so this is why the rugate has higher reflectance in the mentioned region.

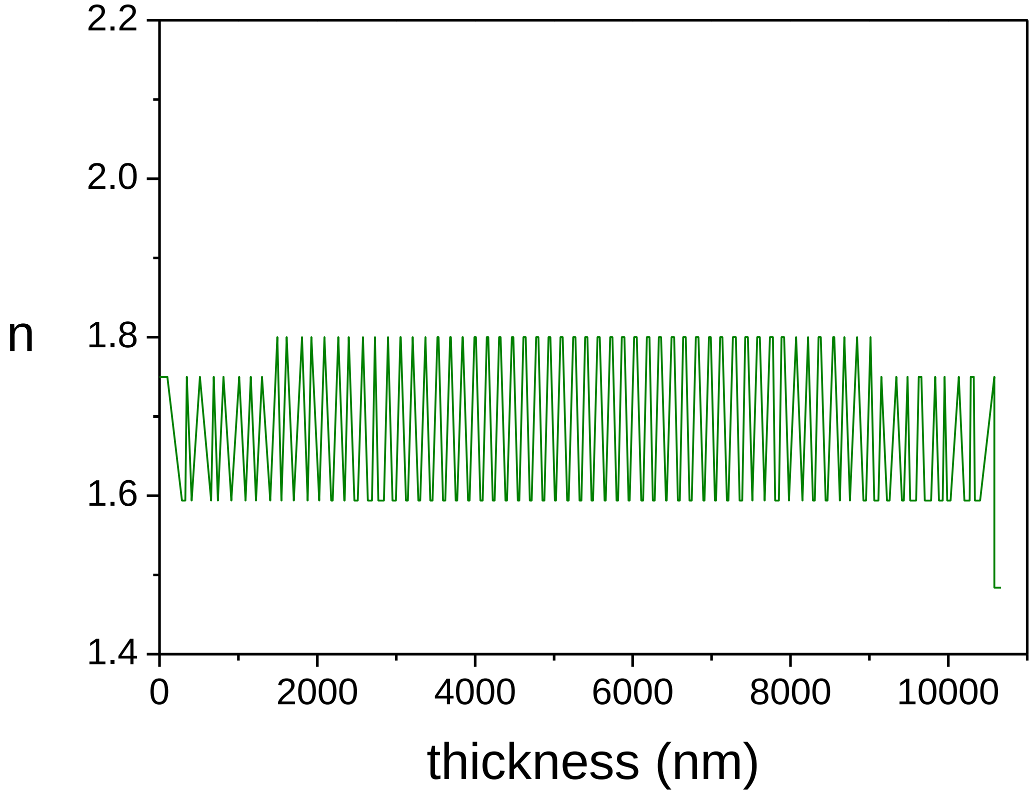

Figure 3. Refractive index profile of hybrid design.

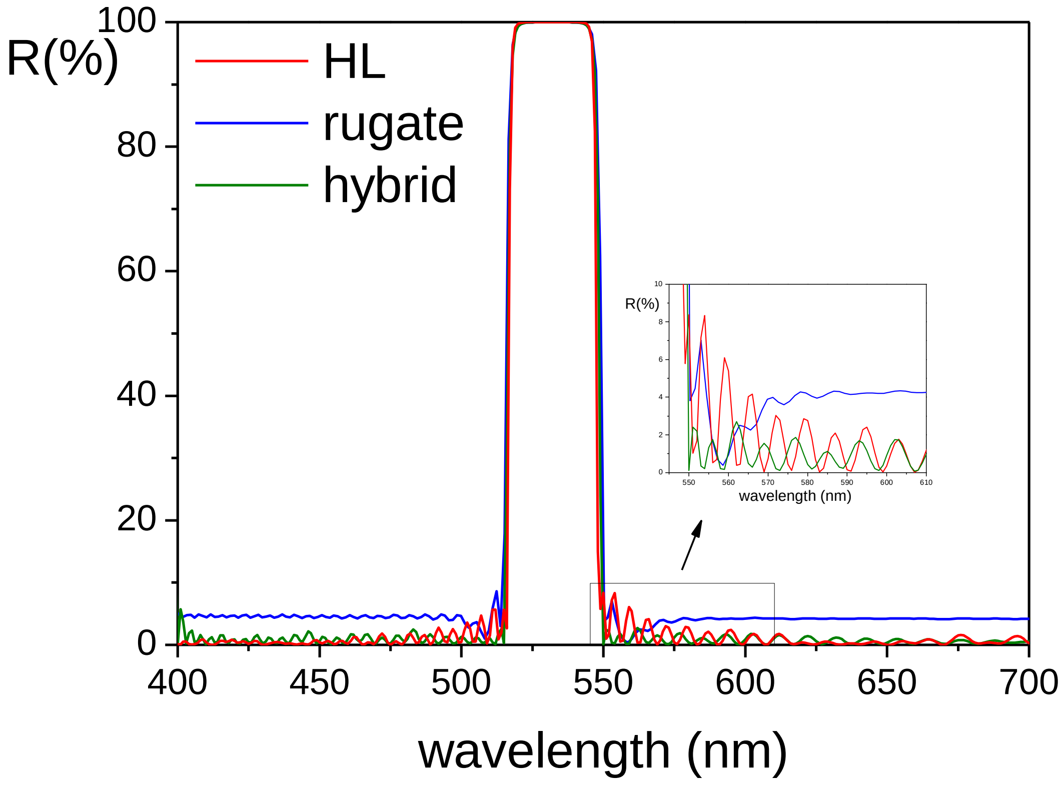

Figure 4. Comparison of the calculated reflectance spectra of the three notch designs.

	HL	rugate	hybrid
materials (high/low)	Ta_2O_5 / SiO_2	TiO_2 / SiO_2	Nb_2O_5 / SiO_2
contrast of n (n_{max} - n_{min}) in the rejection region	0.681	0.236	0.156
n_{max} / n_{min} @ 532 nm	2.153 / 1.473	1.958 / 1.582	1.800 / 1.594
T / R @ 532 nm	0.0016 / 99.9984	0.0118 / 99.9882	0.0093 / 99.9907
FWHM (nm)	31	33	32
OD	4.76	3.92	4.01
number of periods	53	70	66
d_{total} / d_{min}	10205 / 7.6	10680.46 / -	10666.67 / 8.78
$n_{average}$ @ 532 nm	1.939	1.739	1.685

Table 1. Comparison of the notch designs and their performances.

CONCLUSIONS

- graded index designs need more thickness for the same optical density then the HL stack
- gradient index approach gives better sidelobes and ripple suppression, specially in the case of the rugate design
- the hybrid design has simpler refractive index profile compared to the rugate and is easier to adapt to different deposition systems according to the maximum principle[13], in the case of normal incidence, optimum design will be the one using only two materials, having maximal possible refractive index contrast, that is HL design. In the case of oblique incidence gradient index designs may show similar or even better optical properties than their HL-counterparts. This was recently demonstrated for the case of omnidirectional broadband antireflective coatings[2]

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