Wide-angle broadband AR coating by combining interference layers with a plasma-etched gradient layer

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The realization of broadband antireflective (BBAR) properties for optical lenses is a challenging topic of optics. The performance of conventional interference stacks composed of alternating layers of high- and low- refractive-index materials is normally limited to the bandwidth of visible light and a small range of incidence angles [1]. For the requirement of a broader spectral range and an enlarged light incidence angle range up to 60°, limitations for the residual reflectance attainable are evident. A multilayer-based AR coating consisting of silica (n=1.46) and tantala (n=2.1) and optimized for bandwidth 400-800 nm and incidence angles from 0° to 60° will necessarily show a residual reflectance of about 4% at 60° incidence angle more or less independent on the number of layers and the total coating thickness. A design example is shown in Fig. 1.

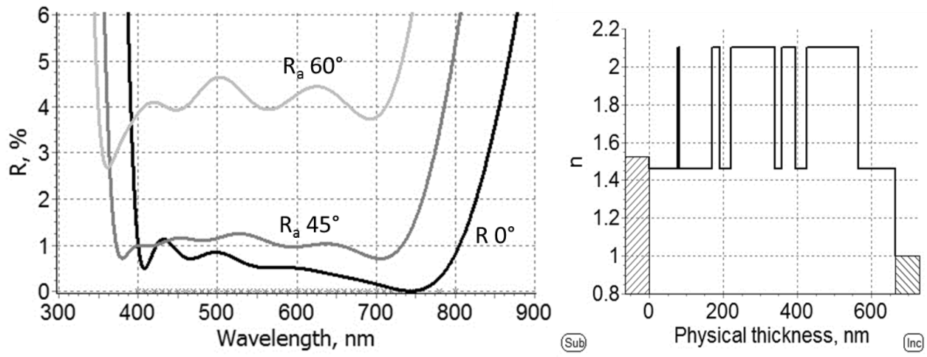

Fig. 1: Refractive index profile and calculated reflectance for a BBAR design on glass (n=1.52), optimized for incidence angles 0° to 60°.

As an alternative to multilayer coatings, a single layer with gradual decreasing effective index from the substrate surface to the ambient medium and with thickness of about 400 nm would act much better for omnidirectional antireflection [2]. However gradient layers with continuously decreasing index and sufficient thickness are hard to realize practically on glass.

An alternative method to get along with a thinner low-index top-layer is its combination with an interference stack, where high index layers are also incorporated into the multilayer. A suitable design solution for a wide range of incidence angles comprises at first a gradient layer with rising effective index starting from the substrate surface (Fig. 2). After a certain maximum a gradual layer with decreasing refractive index follows. For practical reasons the rising gradient was be replaced by discrete layers of available materials like Ta_2O_5 (n=2.1), Al_2O_3 (1.67), SiO_2 (1.46) and MgF_2 (1.38)(see Fig. 3). For this coating a low-index top-layer with a thickness of about 200 nm is needed only. This new design principle was patented by Fraunhofer IOF in 2009 [3]. Initial designs have been evaluated and implemented recently by applying plasma-etched PMMA as a top-layer [4].

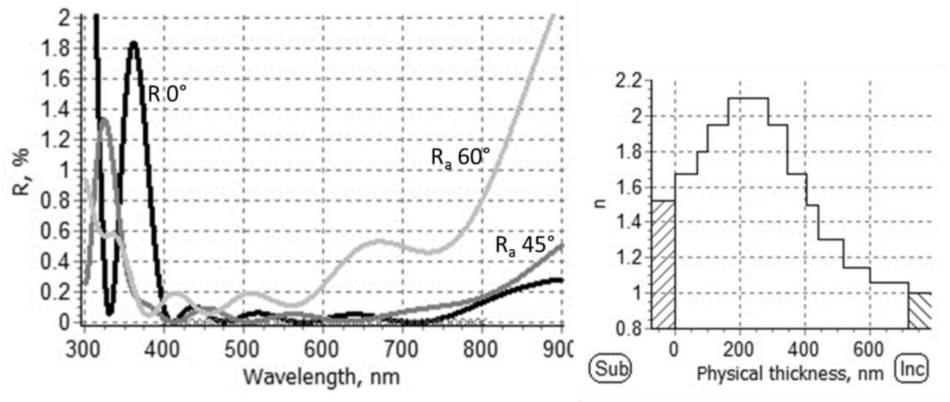

Fig. 2: Refractive index profile and calculated reflectance of BBAR design for incidence angles 0° to 60°. The design consists of a gradient with rising effective index starting from the substrate surface. After a certain maximum a graded layer with decreasing refractive index follows.

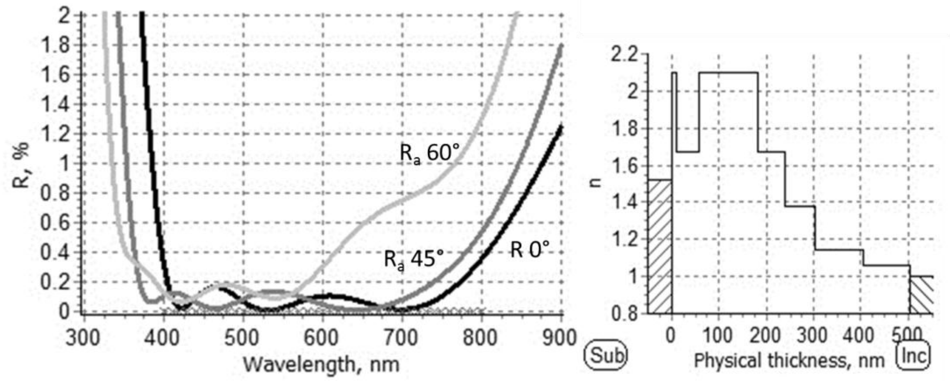

Fig. 3: Refractive index profile and reflectance of BBAR design of Fig. 2 after replacement of parts of the gradients by discrete layers of available compact materials (Al_2O_3, SiO_2, MgF_2).

Gradient layers exhibiting a low effective refractive index can be produced by plasma-etching of organic layers. The organic small-molecule materials were evaporated thermally and etched in low-pressure plasma using an Advanced Plasma Source [5]. For example, Fig. 4 shows SEM images of nanostructured layers achieved from 1,3,5-Triazine-2,4,6-triamine (melamine), N,N´-di(naphth-1-yl)-N,N´-diphenyl-benzidine (NPB) and Tris(4-carbazoyl-9-ylphenyl)amine (TCTA) thin films.

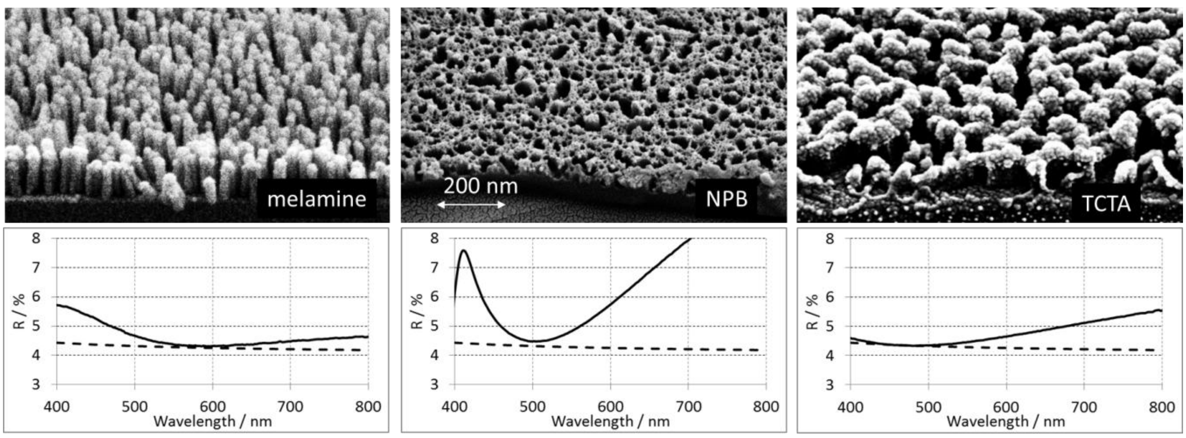

Fig. 4 SEM images and reflectance spectra of plasma-etched organic layers on glass BK7 (including backside reflectance, dotted line)

Produced as single layers on glass, all these layers exhibit an effective refractive index in the range 1.35 to 1.25. An improved antireflective performance can be expected by combining these layers with interference stacks. However, design calculations and experiments show that the optical properties of the top-layer have to be described with high accuracy because of the high error sensitivity of all the subsequent multilayers.

New broadband antireflection coatings based on this principle will be developed during the next years within in the scope of the recently started BMBF-project “FIONA” which is coordinated by the Carl Zeiss Jena GmbH [6]. Further project partners are the companies Agfa-Gevaert HealthCare GmbH, asphericon GmbH, Leica Microsystems CMS GmbH, Qioptiq Photonics GmbH & Co. KG, Leica Camera GmbH and the Fraunhofer IOF.

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