Effective medium approximation for deeply subwavelength all-dielectric multilayers: when does it break down?

We report on theoretical analysis and experimental validation of the applicability of the effective medium approximation to deeply subwavelength (period $\lambda/30$) all-dielectric multilayer structures. Following the theoretical prediction of the anomalous breakdown of the effective medium approximation [H. H. Sheinfux et al., Phys. Rev. Lett. 113, 243901 (2014)] we thoroughly elaborate on regimes, when an actual multilayer stack exhibits significantly different properties compared to its homogenized model. Our findings are fully confirmed in the first direct experimental demonstration of the breakdown effect. Multilayer stacks are composed of alternating alumina and titania layers fabricated using atomic layer deposition. For light incident on such multilayers at angles near the total internal reflection, we observe pronounced differences in the reflectance spectra (up to 0.5) for structures with different layers ordering and different but still deeply subwavelength thicknesses. Such big reflectance difference values resulted from the special geometrical configuration with an additional resonator layer underneath the multilayers employed for the enhancement of the effect. Our results are important for the development of new homogenization approaches for metamaterials, high-precision multilayer ellipsometry methods and in a broad range of sensing applications.