Semiclassical Coupled Wave Theory for Bandgap Calculations in Periodically Stratified Dielectric Media

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Abstract — Photonic crystals are artificial low-loss either two-dimensional (2D) or three-dimensional (3D) dielectric structures with a periodic modulation of the refractive index. Due to Bragg reflection, electromagnetic (optical) waves cannot propagate through such structures in certain directions, at certain frequencies. Hence, photonic crystals can exhibit bandgaps (even omnidirectional bandgaps in certain cases) and, as a result, control the propagation of electromagnetic waves in novel ways, with obvious application to dielectric mirrors, dielectric waveguides, and dielectric laser cavities.

A conventional one-dimensional (1D) periodically stratified dielectric structure retains most of useful properties of 2D and 3D photonic crystals for incident light. However, it is much more attractive from a technological point of view. The usual theoretical methods for calculation of bandgaps and reflection/transmission characteristics in periodically stratified media include the Floquet-Bloch formalism, the transfer matrix method, and the coupled wave theory. Among these three, the coupled wave theory offers superior physical insight and gives simple analytical results in limiting cases. Unfortunately, the conventional coupled wave theory of Kogelnik fails in the case of high refractive index contrast, which is essential for a functional 1D crystal.

In this paper, we apply the recently developed semiclassical coupled wave theory to calculate the bandgaps in bilayer, rugate, and exponential rugate periodic stratifications. Comparison with the exact numerical results obtained from the transfer matrix method is given. It turns out that being analytically almost as simple as the conventional coupled wave theory, the semiclassical version is essentially exact for any achievable modulation of the refractive index in those structures.