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Reflectance and transmittance of Metallo-dielectric one-dimensional photonic band-gap structures

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Traditional one-dimensional photonic band gap (1-D PBG) material is composed of alternating high and low index dielectric layers (HL structure). This dielectric quarter-wave stack forms a high reflective mirror. On the other hand, using 1-D metal-dielectric (MD) PBG, Ward et al[1] found a series of thin Al metal plans is a better reflective mirror than a bulk Al surface. A few methods to obtain a high reflective mirror have been developed so far. Scalora et al[2] focused an attention on the transmissive properties of MD-PBG structures and demonstrate a highly transmissive pass band in MD-PBG crystal containing ~10 optical skin depths of a metal. In this paper we discuss the MD-PBG structures that is the combination of high index dielectric material, low index dielectric material and a metal. One structure has the high reflectivity accompanied with relative high transmissivity even though the total metal thickness is thicker than optical skin depth by a few times. The other structure has higher reflectivity. In periodic structures, the layered, MD-PBG structures that we discuss are composed of a high index dielectric material, a low index dielectric material and a metal. We presently assume the high index material as Si_3N_4, the low index material as SiO_2 and the metal as aluminum. And we use the reference wavelength λ_o=400nm. At l_o=400nm, the refractive index of Si_3N_4 n_h, the refractive index of SiO_2 n_l, the refractive index of Al nm are n_h=2.074, n_l=1.47 and n_m=0.49-4.86i, respectively.[3] The refractive index of incident and substrate material, n_i and n_s are n_i=1 and n_s=1.65, respectively. One-quarter wave (QW) $\lambda_o/4n$ is 48.2nm at Si_3N_4 and 68.0nm at SiO_2. We consider a stack of layers, which is composed of a consecutive 3-layers of the high and the low index dielectric material and the metal (HLM structure). We call this stack one unit. First, we add 1QW thickness of the high index layer to the substrate that is low-index material with n_s=1.65 (HS structure). Then we add n units to this HS structure (n×(HLM)HS structure). Each thickness of the metal in each unit, therefore, is same in every unit. Similarly that of the high is same and that of the low is same in every unit. The optimum thickness for this structure can be found by letting the optical thickness of the high index dielectric material range over the value 0 to 2 QWs, the optical thickness of the low index dielectric material range over the value 0 to 2 QWs, the thickness of the metal the value 0 to 40nm independently. The optimum structure of layers is defined as having the combination of thicknesses resulting in the highest reflectance R_{max}. This approach to the problem of finding the optimum unit involves maximizing a function of three variables. In non-periodic structures, we add the high-index 1QW on the substrate as before. In non-periodic MD-PBG, the procedure is to add one unit of layers to a given substrate or multilayer system at one time. After adding n-th unit to the multilayer system which is composed of (n-1) units, the whole optimum structure can be founded, first by letting the optical thickness of the high index layer in this n-th unit range over the values 0 to 2 QW, the low-index layer range over the values 0 to 2 QW, the thickness of the metal the value 0 to 40nm independently, with other layers' thicknesses in (n-1) units being fixed and, second by finding the highest reflectance structure. The R and P.T. are given by the dots in Fig.1 with the number of unit, n. It can be seen that the optimum periodic structures provide enhanced reflectivity with just a few units. It can perhaps be thought that the metal layers incorporated into the dielectric layers give enhanced dielectric contrast. Each optimized n×(MLH)HS has metal layers about 40nm in total thickness, that is, n × (thickness of M) ≈ 40nm, which are about four skin depths of that metal. Nevertheless, P.T. of structure is a relative high magnitude. This high P.T. is a result from the fact each metal layer forms a Fabry-Perot cavity. In traditional Fabry-Perot cavity, a transmission resonance occurs whenever layer is about a multiple of the half-wavelength. It can be seen that the optimum non-periodic structures provide enhanced reflectivity compared with the periodic structures. We perhaps think this is the ultimate reflectance for a high reflector made with a given set of metal and dielectric materials. Fig.2 shows the reflectance and transmittance for four-unit structure with wavelength. It can be shown that the reflectance is >0.99 over about 35nm.

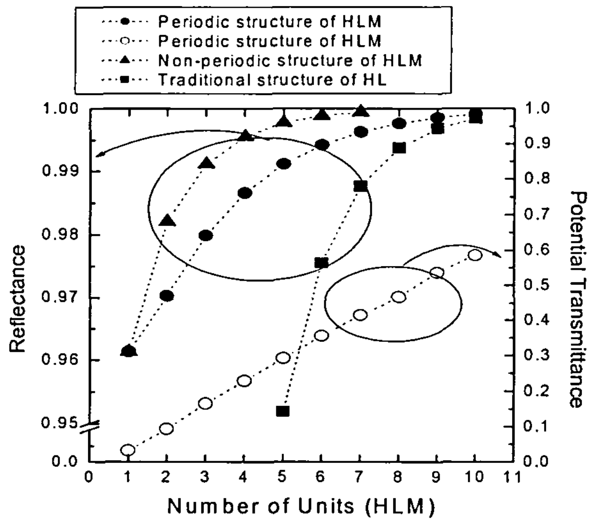

Fig. 1 Reflectance and Potential Transmittance verse number of units for optimum structures, periodic structures of HLM structure and non-periodic structures of HLM structure

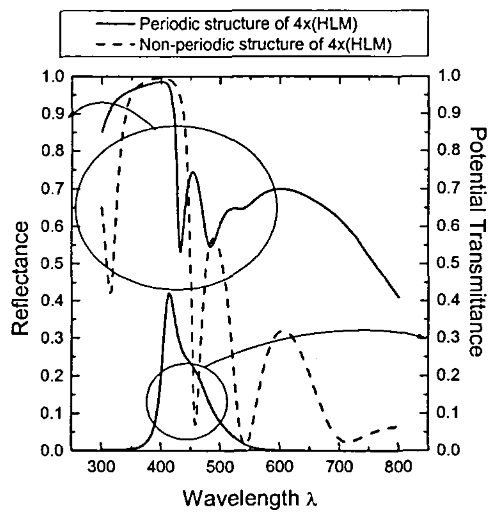

Fig. 2 Reflectance and Potential Transmittance verse wavelength for optimum structures with four units.

References

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