# Bragg-reflector-related surface states: surface plasmon polaritons above the bulk plasma frequency in indium tin oxide

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Surface plasmon-related excitations have most often been investigated at interfaces involving silver or gold but Rhodes et al have experimentally demonstrated the presence of both bulk and surface plasmon polaritons (SPPs) in indium tin oxide on a glass substrate [1,2]. Recently we have demonstrated theoretically [3] that both TM- and TE-polarized SPPs should be observable above the plasma frequency in a system in which the conducting film is on the surface of a Bragg relector, and further, that such states can be revealed without the use of prism coupling, the standard experimental configuration employed for such work. In that study, however, we considered only an idealised conductor. Here we consider a system employing a permittivity consistent with the experimental work on ITO of Rhodes et al and demonstrate that distinct features associated with the existence of these surface states above the (screened) bulk plasma frequency should be observable in the case of ITO surface layers.

[See J. Phys. D: Appl. Phys. Vol 43 45104 (2010) for more details of this work.]

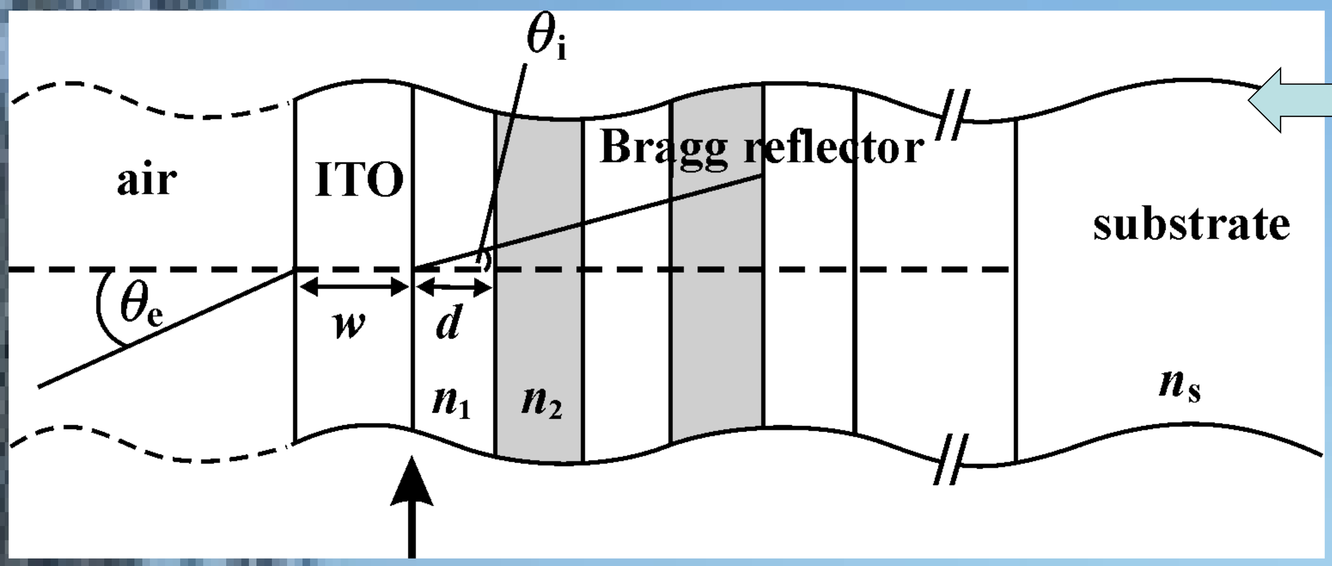



**FIG. 1** The basic structure considered, consisting of an ITO layer of thickness $w$ on top of a 20 layer pair Bragg reflector on a $SiO_2$ substrate. The refractive indices of the Bragg reflector layers are $n_1$ and $n_2$ and the top layer in the stack has width $d$. The refractive index of the substrate is $n_s$. The external angle of incidence for incoming light and the corresponding internal angle within the first Bragg reflector layer are indicated. The layer thicknesses employed were: $SiO_2$ ($n$ = 1.47) – 211 nm, $TiO_2$ ($n$ = 2.37) - 131 nm.

The permittivity of the ITO is taken to be of the form

$$\varepsilon(\omega) = \varepsilon_\infty\left(1 - \frac{\omega_p^2}{\omega(\omega + i\omega_c)}\right)$$

$\varepsilon_\infty = 3.8$, $\hbar\omega_p = 2.19/\sqrt{\varepsilon_\infty} = 1.123$ eV, $\hbar\omega_c = 0.111$ eV.

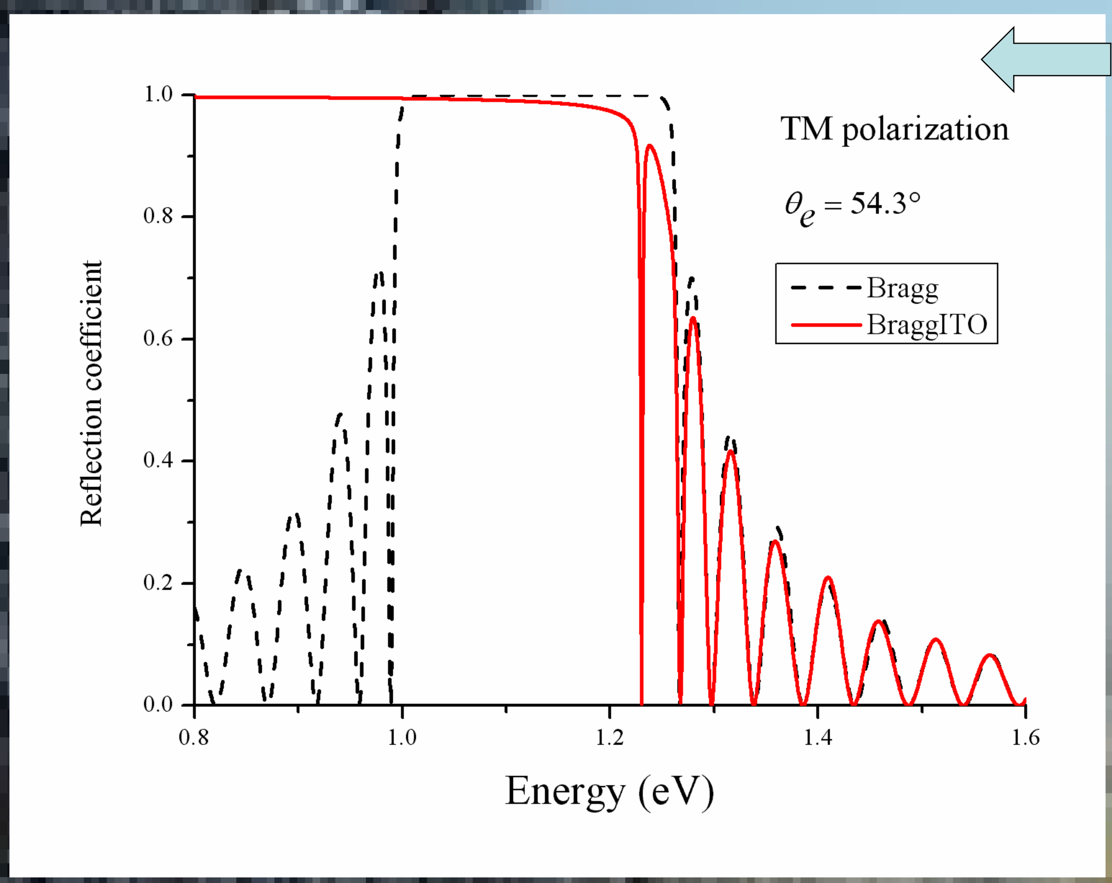
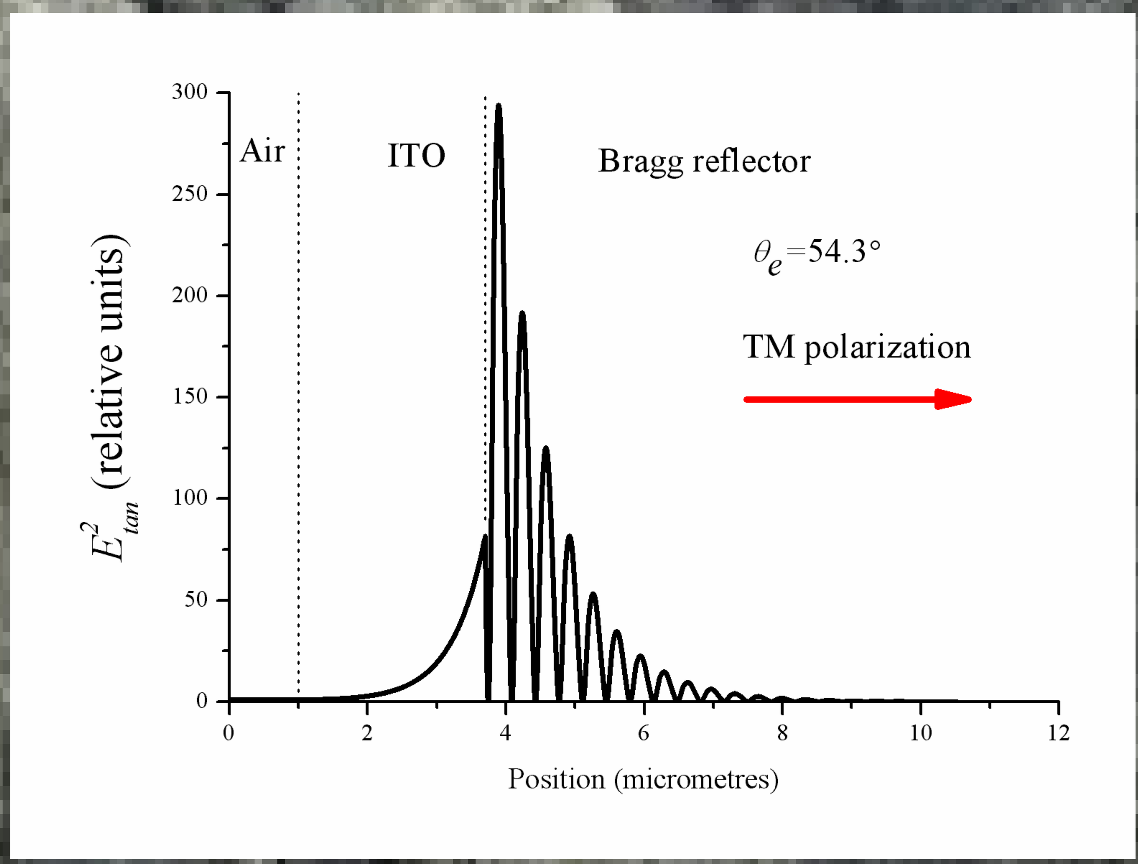



**FIG. 2 TM polarization.** The reflection coefficient as a function of energy at an external air/interface angle of 54.3°. Results for the air/Bragg reflector/glass substrate (Bragg) and air/ITO(1650 nm)/Bragg reflector/glass substrate (BraggITO) structures are shown. A distinct feature associated with an SPP at the ITO/Bragg reflector interface is present at 1.230 eV. A nominal collision term was employed in these calculations. The tangential component of $E^2$ for the associated SPP state is shown in **FIG. 3** (TiO₂ layer adjacent to the ITO.)



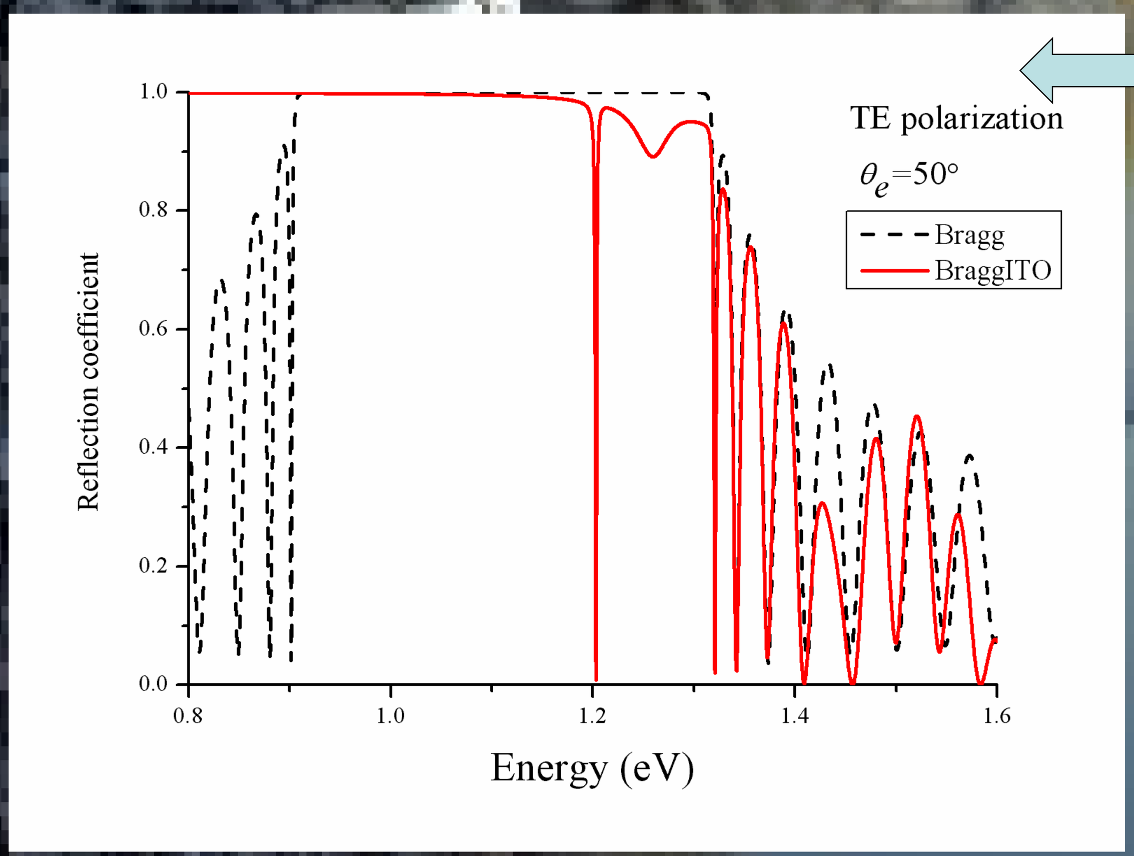
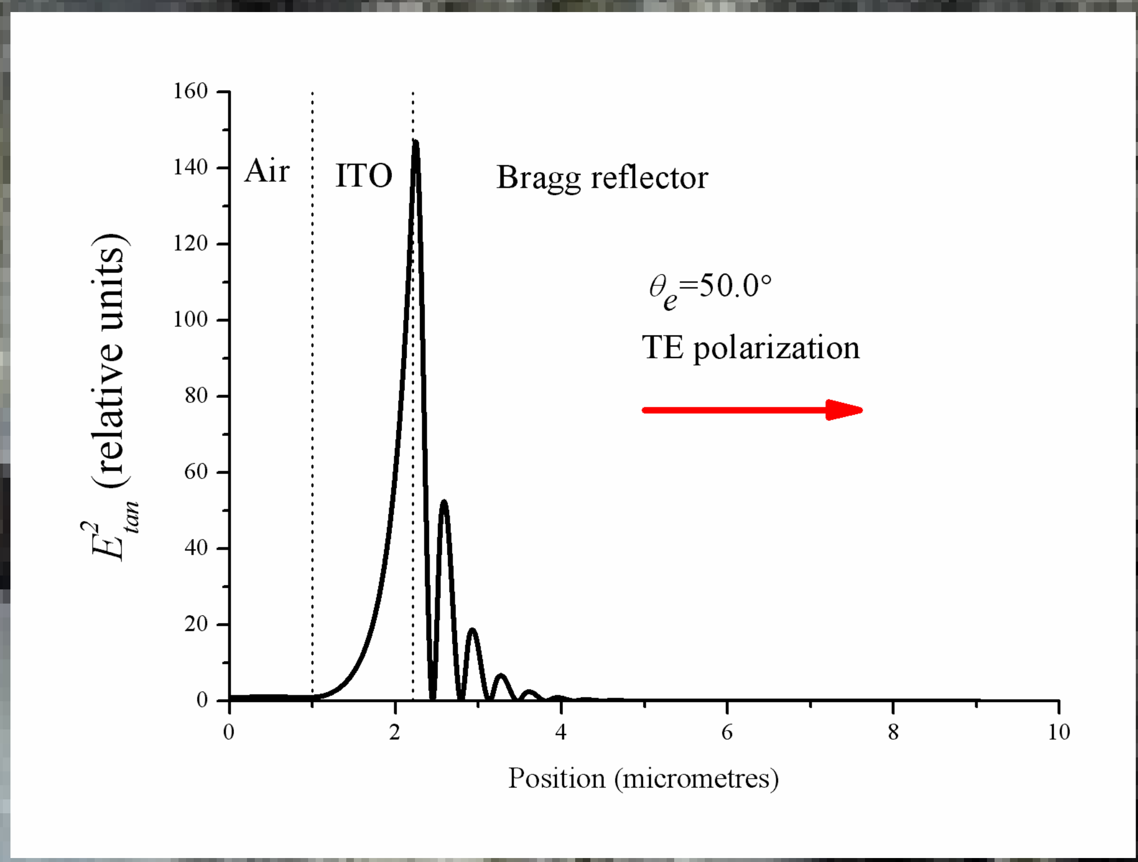




**FIG. 4 TE polarization.** The reflection coefficient as a function of energy at an external air/interface angle of 50.0°. Results for the air/Bragg reflector/glass substrate (Bragg) and air/ITO(1210 nm)/Bragg reflector/glass substrate (BraggITO) structures are shown. A distinct feature associated with an SPP at the ITO/Bragg reflector interface is present at 1.203 eV. A nominal loss term was employed in the calculations. The tangential component of $E^2$ for the associated SPP state is shown in **FIG. 5.** ($SiO_2$ layer adjacent to the ITO.)



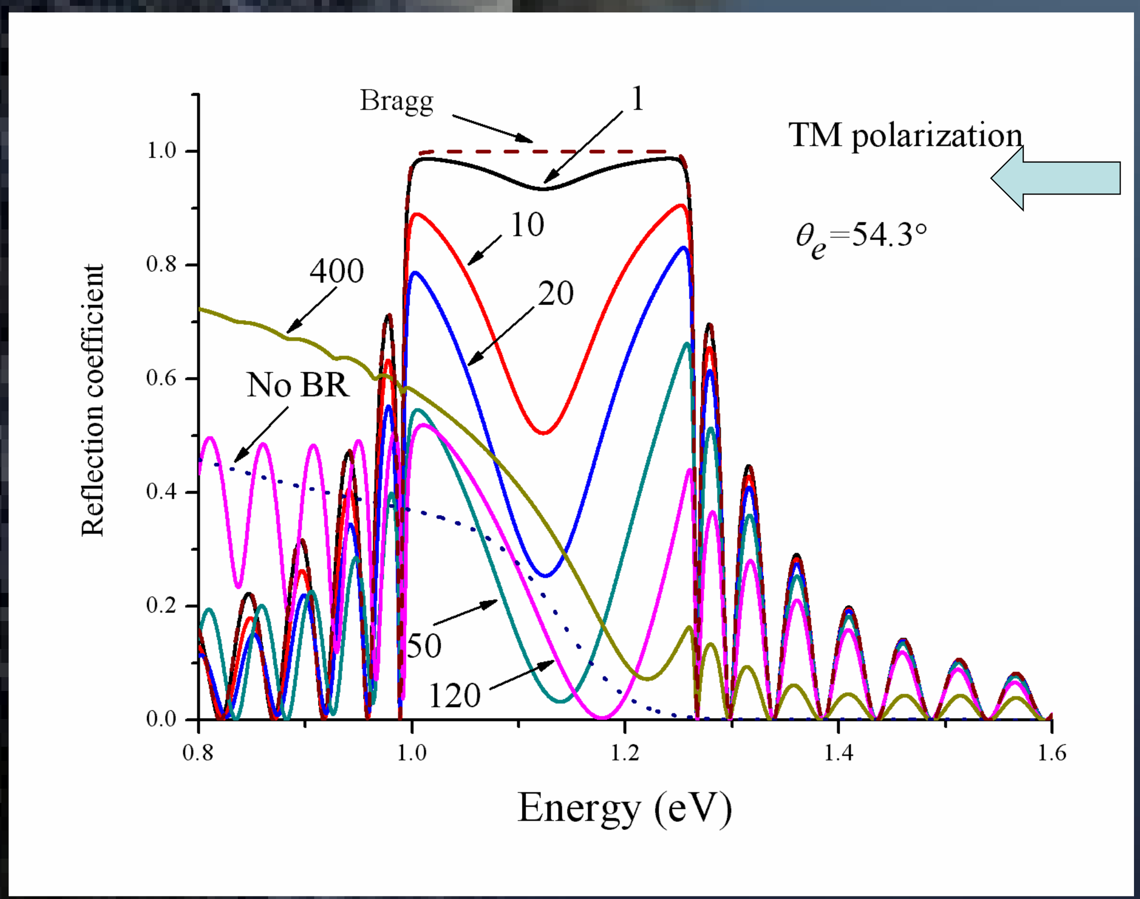
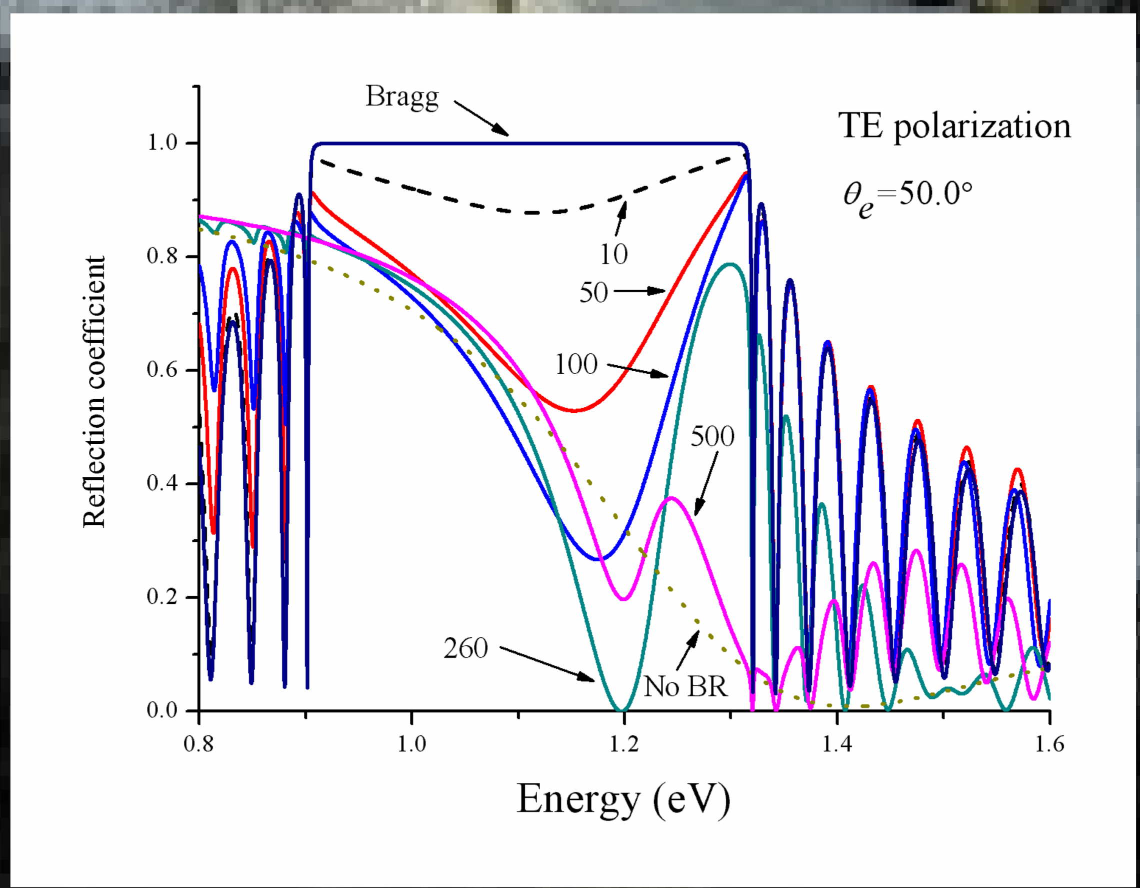




**FIG. 6** The TM reflection coefficient, and the TE reflection coefficient, **FIG 7** for a series of $w$ (nm) values at angles of 54.3° (TM) and 50.0° (TE) showing that distinctive features associated with SPPs above the bulk (screened) plasma frequency of 1.123 eV should be observable. The full loss term was included in these calculations.




[1] Rhodes C, Franzen S, Maria J-P, Losego M, Leonard D N, Laughlin B, Duscher G and Weibel S, 2006 J. Appl. Phys. 100 054905
[2] Rhodes C, Cerruti M, Efremenko A, Losego M, Aspnes D E, Maria J-P and Franzen S, 2008 J. Appl. Phys. 103 093108
[3] Brand S, Kaliteevski M A and Abram R A, 2009 Phys. Rev. B79 085416

TM – H polarised parallel to interfaces.

TE – E polarised parallel to interfaces.

The Bragg reflector is designed such that the centre of the photonic band gap is at 1 eV at normal incidence.

Calculations are performed using the transfer matrix method.