Ultra-wide Band, Polarization-Independent, Omnidirectional Absorbers.

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Abstract: Based on the effective medium theory for multilayers, we present the design of several all-angle, polarization-insensitive absorbers spanning the visible, near-IR and part of the mid-IR (from 400nm to 3500nm) using periodic, one-dimensional, metallo-dielectric structures.
OCIS codes (310.4165) Multilayer design; (310.3915) Metallic, opaque, and absorbing coatings.

Visible and IR absorbing materials are crucial in many applications such as thermo-photovoltaic energy conversion devices [1] and light harvesting for solar cells [2]. Many venues have been proposed during recent years to achieve broadband, polarization-insensitive, omni-directional absorbers. In [3] the authors experimentally demonstrate an ultrathin plasmonic absorber over the entire visible spectrum (400nm-700nm), in [4] the authors numerically study a broadband, 1-D metal grating with almost perfect absorption at λ~600nm, in [5] an absorber based on light propagation in a metamaterial forming an effective "black-hole" is discussed, and in [6] it is proposed a negative-index based, wide angle absorber for IR radiation. In this work we propose a viable, yet effective, alternative to achieve an efficient absorber for visible and near IR radiation. The generic structure under consideration is depicted in Fig.1. It consists of an *N*-period multilayer made of two different, generic, non-magnetic, materials with thickness respectively *a* and $b=\Lambda-a$ and electric permittivity ε_a and ε_b respectively.

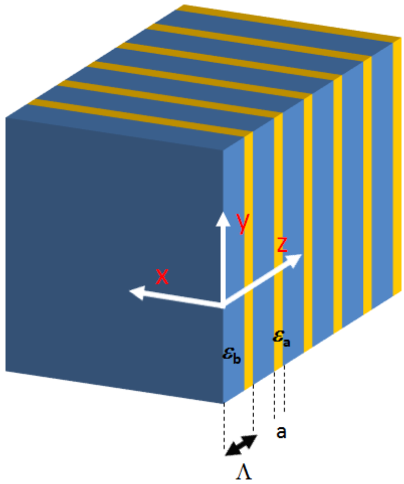

Figure 1: Generic multilayer structure with period Λ made of two different materials.

It is well known [7] that when the wavelength λ of the incident radiation is much longer than the thickness of the elementary cell (λ>>Λ) the multilayer behaves as an effective, uniaxial crystal with effective ordinary (o) and extraordinary (e) permittivity given by:

$$\varepsilon_{eff,e}=\varepsilon_{eff}^{(z)}=\frac{\Lambda}{a/\varepsilon_a+(\Lambda-a)/\varepsilon_b}, \qquad \varepsilon_{eff,o}=\varepsilon_{eff}^{(x)}=\varepsilon_{eff}^{(y)}=\frac{a\varepsilon_a+(\Lambda-a)\varepsilon_b}{\Lambda}. \tag{1}$$

Our idea is to use extremely thin metallic layers (*a*~10nm) in conjunction with much thicker dielectric layers (*b*~100nm) in order to create, according to (1), an "artificial" dielectric with a consistent imaginary part of the refractive index, but nevertheless weaker than the real part. In Fig.2 (upper panel) we show the real and imaginary part of the effective permittivities calculated according to (1) respectively for a Ta_2O_5(122nm)/Cu(6nm)/Ta_2O_5(122nm) elementary cell, for Ta_2O_5(122nm)/Mo(6nm)/Ta_2O_5(122nm) and for a Ta_2O_5(122nm)/W(6nm)/Ta_2O_5(122nm). As expected, according to the effective medium theory (1), we note that the ordinary permittivity in all the cases shows the overall properties of an absorbing dielectric material in the range 400nm-2500nm for the first two cases and in the range 400nm-3500nm for the last case, while the metallic behavior reasserts itself above 2500nm/3500nm. The extraordinary permittivity, on the other hand, maintains a dielectric behavior over the entire spectrum, with a less pronounced imaginary part, but still enough to guarantee high level of absorption when an adequate number of periods is considered. The middle and low panel of Fig.2 show the results of a rigorous transfer matrix calculation where the absorption of N=50 period structures has been calculated in the (λ,ϑ) plane, ϑ is the incident angle calculated with respect to the z-axis and λ the incident wavelength, for TM and TE polarized light respectively. As expected, and in complete agreement with the effective medium theory, we find for the 50 period structures a large spectral range of high absorption spanning the entire visible, the near-IR and part of the mid-IR. This ultra-wide band of absorption remains in place from normal to almost grazing incidence and, moreover, it is quite insensitive to the incident polarization.

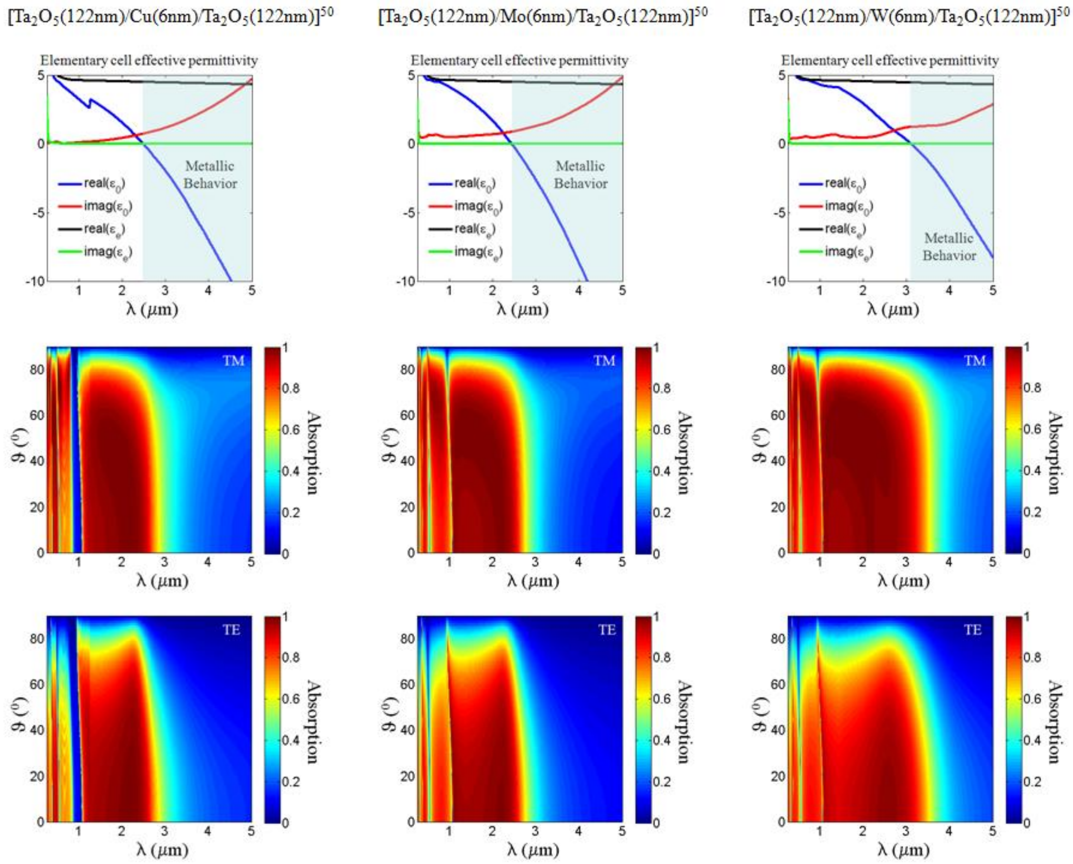

Figure 2: (Upper panel) Effective permittivities calculated according to the effective medium theory (1) for a symmetric dielectric/metal/dielectric elementary cell as specified on the top of the panel. (Middle panel) Absorption of the N=50 period structure in the (λ,ϑ) plane for TM-polarized incident light calculated using the transfer matrix technique. (Lower panel) Absorption for TE-polarized incident light.

In conclusion, we have reported a practical way to achieve broadband, omnidirectional, polarization-insensitive absorption in one-dimensional, periodic, metallo-dielectric structures. These structures can be easily fabricated using standard sputtering or thermal evaporation techniques, moreover, they can be applied over large areas with relative low cost which is a desirable characteristic for many applications.

References

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