

DEVELOPMENT OF “SMART” OPTO-ELECTRO-MECHANICAL SYSTEMS BASED ON “TRANSPARENT METALS”

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Abstract: This paper deals with the the investigation of novel application for an optical material based on a photonic band gap structure realized by using several periods of suitable metals and dielectric couples. The optical properties of these new materials, have been largely studied by the authors showing the possibility of obtaining high trasmittance levels in given wavelength windows even with large thickness of metals.

In this paper these new material, named “transparent metals”, are used in smart opto-electro-mechanical structures such to obtain both novel devices with electrically controllable optical properties and sensors with optical output signals for hostile environments.

Theoretical models of this novel devices have been developed together with experimental prototypes and experimental verification of the expected results have been performed.

Keywords: Opto-Electro-Mechanical Systems, Photonic Band-Gap Materials, Transparent Metals.

1 INTRODUCTION

In recent years, advances in photonics technology have generated a trend toward the integration of electronic and photonic devices. Photonic devices offer an array of advantages over conventional electronic devices. For example they can provide enhanced speed of operation, reduced size, robustness to temperature fluctuation and other environmental changes, increased lifetime and high repetition rates. These structures can be made of semiconductor materials, ordinary dielectrics or a combination of both.

In particular great efforts have been devoted to theoretical and experimental investigations of photonic-band-gap (PBG) structures [1,2]. These are structures made by an ordered sequence of high and low index materials, each layer can be chosen such that its width is a fraction of the size of the reference wavelength. This form a quarter-wave stack. As a consequence of this arrangement interference effects cause some wavelengths to be transmitted while a range of wavelengths centered about the reference one, often referred as “band-gap”, are completely reflected.

The materials traditionally adopted in the fabrication of PBG strucutres are traditionally either dielectric or semiconductor substances, while metallic substances are almost exclusively used to enhance the reflective properties of the structures.

In a previous work [3] some of the authors have theoretically demonstrated the possibility of making a metallic structure transparent to visible light while, at the same time, maintaining its reflective properties for low frequency radiation, i.e. those of metal shield. These metallo-dielectric PBG structures have been named “transparent metals”.

The leading idea of this work consists in realizing novel PBG structures with electrically controllable optical properties by using transparent metals. This can be obtained if the thickness of one or more of the layers can be varied. The strategy adopted consists in considering an “air gap” as a layer of the PBG structure. The mechanical positioning of the two side of the resulting structure allows to control the air gap thickness and then the optical properties of the whole structure. Piezo-electric actuators have been used for the positioning and suitable control and signal conditioning circuitry has been developed.

These smart opto-electro-mechanical structure are adopted here in order to obtain optical filters and sensors with optical output for application to harsh environments.

Analytical models of the structures have been developed in order to demonstrate the existence of the desired system behaviors while experimental measurements have been performed onto the realized prototypes. Different technologies have been experienced for obtaining the the desired structures on a given substrate.

2 REALIZATION OF OPTO-ELECTRO-MECHANICAL SYSTEMS WITH TRANSPARENT METALS

From a theoretical point of view let us consider some numerical results obtained by using the matrix transfer method [4] and the beam propagation method. The transmissive properties of a given structure is computed as a function of a number of parameters such as incident wavelength, the number of layers and the layer thickness. Data regarding the refractive index and the absorption of these material have been gathered from the book of Palik [5], while the substrate has been modeled as a generic glass with refraction index 1.5 for a wide range of incident wavelengths.

As an example of “transparent metals” a PBG structure made up of seven period of Ag (20 nm) and MgF₂ (140 nm) is compared in terms of transmittance with the equivalent thickness of pure silver. As it can be observed in Fig. 1 the PBG structure shows transmittance in the visible range, that is not of the pure silver layer, together with reflectance in the high frequency range.

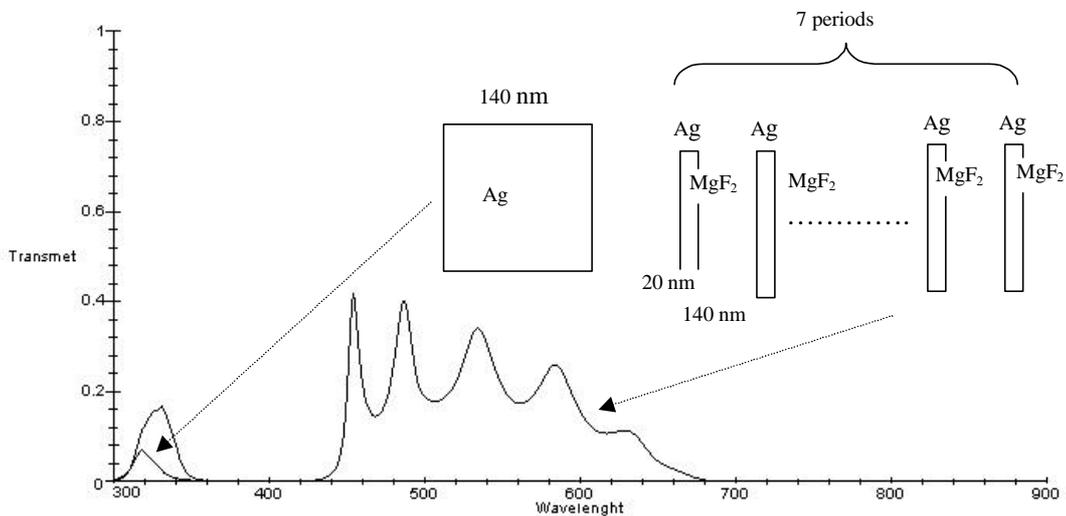


Figure 1. Transmittance of a single silver layer compared with a stratified PBG structure with the equivalent thickness of silver.

The controllable structure proposed here must contain at least one air-gap. In particular in the following Fig. 3 some calculation are reported for the PBG structure with a single air gap of width “d” reported in Fig. 2.

Glass	LiF	Ag	LiF	Ag	LiF	Ag	Air Gap	Ag	LiF	Ag	LiF	Ag	LiF	Glass	Glas	1 mm
							d								LiF	75 nm
															Ag	10 nm
															LiF	150 nm
															Ag	20 nm
															LiF	150 nm
															Ag	50 nm
															Air Gap	“d”

Figure 2. The PBG structure investigated with “transparent metals” and controllable air gap.

As it can be observed transmittance of the whole structure strongly depends on the value of “d”. If this value can be controlled it is possible to realize, for example, an “optical modulator” or an “optical limiter”.

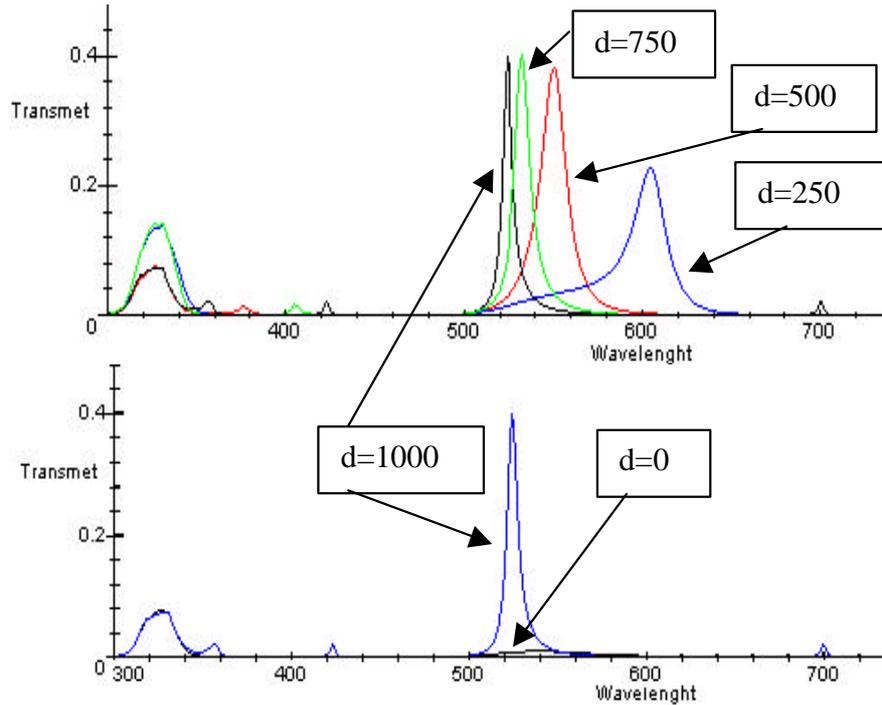


Figure 3. By varying the air gap width it is possible to obtain an “optical modulator” behavior (above graph) or an optical limiter behavior (below graph).

The electro-mechanical structure is shown in Fig. 4. Actuation is devoted to piezo-electric bimorph transducers and a suitable control circuit has been realized. By controlling the voltage applied to the piezo actuators the air gap width is changed resulting in a modulation of the light transmitted through the structure.

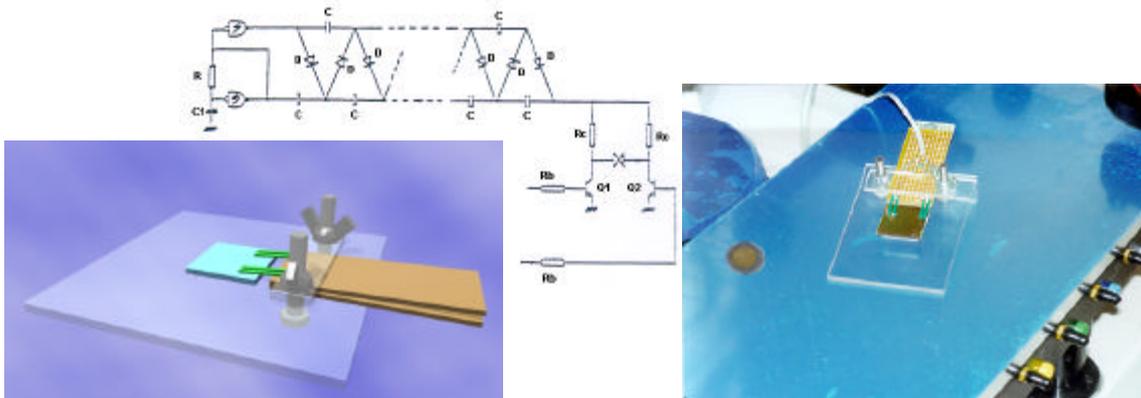


Figure 4. The opto-electro-mechanical structure realized. The design is reported together with a schematic of the control circuit and a photograph of the prototype.

Experimental investigations have been performed onto the realized prototypes in order to characterize both the air gap width and the optical behavior with respect to the voltage applied to the piezo actuator control circuit. In the next Fig. 5 the transmittance of the structure, obtained with a Perkin-Elmer spectrophotometer, is reported.

Even if somehow different from the theoretical expectations, these results are strongly encouraging. In fact it can be observed as the spectral content significantly changes with the air gap width. The absence of more evident resonance peaks can be related, in this release of the prototypes, to the surface roughness which induces scattering and then deviation from the theoretical calculations.

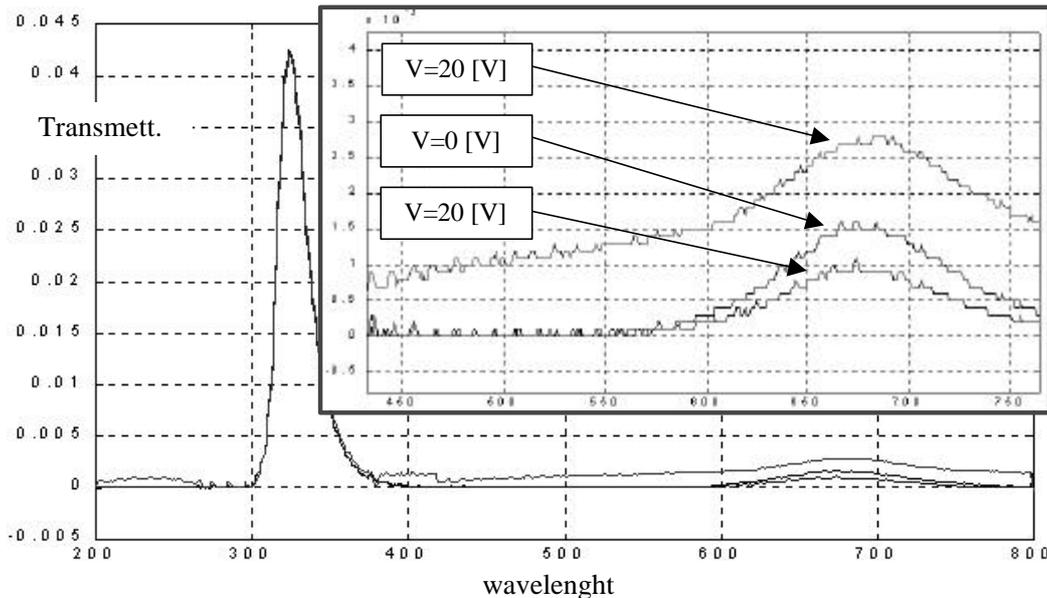


Figure 5. Experimental results showing the changes in the transmittance spectrum of the composite structure as a function of the voltage V applied to the actuators control circuit.

3 CONCLUSIONS

A novel opto-electro-mechanical system has been introduced in this work. It is based on the use of a novel material, named transparent metal, which allows for obtaining highly selective transmittance windows joint with the properties of metals such as shielding for low frequencies and conductivity.

The base idea was to control the thickness of one of the dielectric layer of the PBG structure in a continuous way instead of having static systems with given optical properties. One "air gap" has been considered as one of the layers of the PBG structure. The mechanical positioning of the two parts facing the "air layer" allows to control the air gap thickness and then the optical properties of the whole structure. Piezo-electric actuators have been used for the positioning and suitable control and signal conditioning circuitry has been developed.

These smart opto-electro-mechanical structure are adopted here in order to develop optical filters and sensors with optical output for application to harsh environments. In fact if, instead of actuating the system, the measurand acts on the system this change in the air gap can be detected through the change in the optical transmission spectrum. Electrical signal are not required and this make the system useful for sensor application to harsh environments even with fiber optic systems.

Analytical models of the structures have been developed in order to demonstrate the existence of the desired system behaviors while experimental measurements have been performed onto the realized prototypes. Different technologies have been experienced for obtaining the desired structures on a given substrate.

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