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SHORT COMMUNICATION

BROADBAND OMNIDIRECTIONAL IR FLEXIBLE WAVEGUIDES

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Electroless fabrication of waveguides has been extended to multilayer deposition. The theoretical calculations and experimental results have shown that the method shows great potential to produce broadband omnidirectional waveguides.

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The Mid IR spectral range between 2 and 12 μm consists of some lasers wavelengths, which are of great interest in the medical field (i.e. 2.1, 2.94, 6.45 and 10.6 μm). There is also a lot of spectral information on biological tissues, transitions and processes, which lies in this segment of the spectrum. Some solutions exist to transmit these spectral signals from source to tissue or from tissue to detectors or spectral analysis systems. There is a host of fibers and waveguides for this spectral range [1], however each of them has its own drawbacks. Among these are: limited spectral ranges, low energy transmission, poisonous, non-biocompatibility, sensitivity to bending and non-transmission for a certain spectral range. All these triggered researchers to try to find broader solutions to the transmission of this spectral range. A possible solution to overcome the above-mentioned drawbacks is the use of photonic crystals to guide the laser radiation.

Photonic crystals are materials patterned with a periodicity in dielectric constant, which can create a range of “forbidden” frequencies called photonic bandgaps. Photons with energies lying in the bandgap cannot propagate, by incidence, through the medium. This provides a way to construct materials with high reflectivity (R=1), such as a “perfect mirror”, laser cavities and waveguides.

These multilayer mirrors with high reflectance for a large interval of wavelengths and for omnidirectional incident angles exist for sometime now. However these mirrors are fabricated in techniques that cannot be applied for tubing inner coating in order to make optical waveguides out of them. Results in this field, obtained by a few groups, were published in [2-7]. There, the terminology of “photonic crystal”, based on energy gap [4] or reflectance band [7], was introduced. High reflectance in large interval of wavelengths and incidence angles was achieved using a big number of layers with alternating low and high refraction indices. Fink at al. group [5,6] has published some papers on a possible waveguide fabrication however it is not clear how long is the waveguide which will be created with their method.

We have expanded our method of electroless fabrication of waveguides [8] to multilayer deposition. The multilayer structure was made by alternate silver (Ag) and zinc sulfide (ZnS) layers of variable thickness prepared from chemical baths on glass.

Ag films were deposited from $AgNO_3$ solution. ZnS layer was plated above each silver film. The layers thickness was at the range of 10 nanometers.

Fig. 1 represent measurements of reflectance (R) from a 2 pairs (4 layers) mirror, in a window interval of 1000 to 2500 nm, where values of $92 \leq R \leq 100\%$ were obtained. This is an encouraging result, that lead us to continue to work on this method. In parallel to the experimental procedures we have also expanded our ray-tracing program to include multi-layer structures. The calculation is based on Fresnel analysis done on each boundary between layers. It creates a characteristic matrix for the whole set of boundaries [9]. This representation allows us to design the set of layers and the thickness in order to optimize the waveguide to the desired spectral window. A design of 5-8 μm transmission window is shown in Fig. 2. The improvement with the number of pairs of layers is very well shown when we move from 2 to 6 pairs of layers.

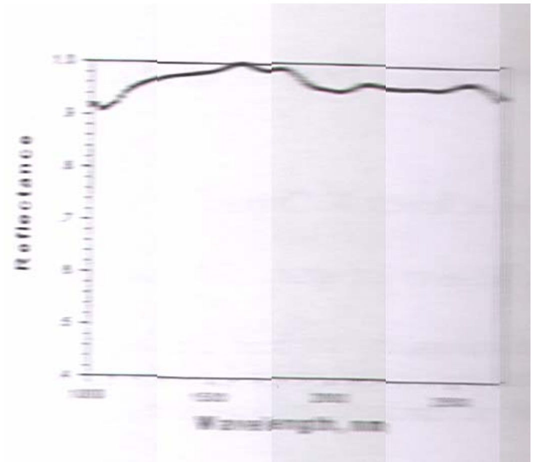

Fig. 1. Reflectance for a 2 pairs (4 layers) Ag/ZnS structure as a function of wavelength.

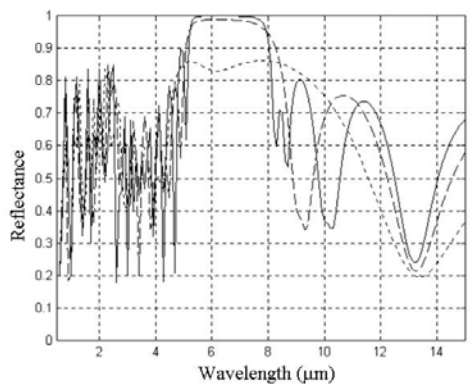

Fig. 2. Reflectance vs. wavelength (dotted line – 2 pairs, dashed line – 4 pairs, solid line – 6 pairs)

This result has enabled us to extend our theoretical calculations for multiple reflections in a flexible cylindrical waveguide and to obtain the value of the ratio between the delivered and coupled IR (10 μm) radiation, using the model of multilayer mirrors. As may be seen in Fig. 3, unlike the regular waveguide [8], where strong dependence on curvature was observed, no losses of reflectance appear during propagation through the waveguide (window of reflection) for all the values of radii of curvature from 1 to 500 cm.

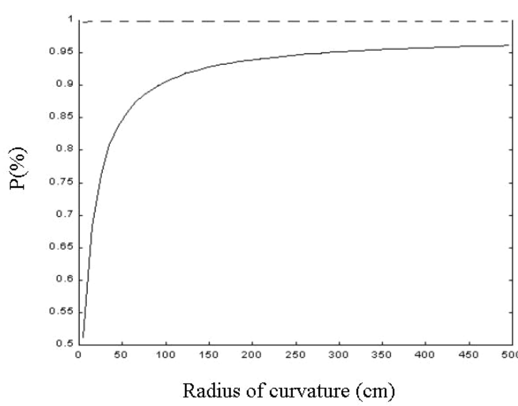

Fig. 3. Ratio of delivered to coupled IR radiation P(%) vs. radius of curvature: Regular (solid line) and Multilayer (dashed line) Hollow Waveguide.

The theoretical calculations and the experimental work suggest that there is great potential in this method to create these broadband omnidirectional waveguides.

Our main aim was to create waveguides in the mid-IR spectral range. This range of wavelengths is very important in the medical field (diagnostic and surgical). The obtained data from theoretical calculations and the experimental results suggest that the multilayer mirror system may be used for developing broadband omnidirectional low loss flexible hollow waveguides.

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