Study of Optical Nature of Fish Scale

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Abstract

Optical behavior of Fish scale, a bio-material, is studied in this work with the experimental probes like Fourier Transform Infra Red spectroscopy (FTIR) and a specially designed optical spectrometer. Analysis shows an existence of Photonic band in infra red (IR) region of electromagnetic waves as a consequence of layer structure present in it. Optical reflectance study of this material shows complete different nature to that of ordinary material. The effect much more resembles with type II or III Left Handed Maxwellian (LHM) materials.

1. Introduction

Many times manmade materials find its significant inspiration from nature or natural materials. The natural materials which serve as the model for the recent developments includes sea shell, pearl, mica, fish scale and many other bio materials with remarkable micro structure. The hierarchical structures of these materials are responsible for their functional nature. In earlier works authors investigated the optical aspects of the different material namely sea shell, mica [1] and pearl. Present paper deals with some novel optical properties like photonic and LHM nature of fish scale.

1.1. Photonic Nature

Multiple circular layers of the fish scale results photonic band gap in IR region of the spectra. In general Photonic crystals are the materials having a special kind of periodicity in their dielectric constants [2]. This periodicity generates the photonic band gap that is a frequency window through which the propagation of EM wave is inhibited. Bragg scattering of electromagnetic waves in certain directions from the different annuli layers gives rise to photonic behavior in the fish scale.

1.2. Aspect of Left Handed Maxwellian System

The optical behavior of this material is also different from the ordinary materials. Experimentally found reflectance measured over the surface of the fish scale shows completely opposite nature from that measured over ordinary dielectrics like glass. The nature is rather analogues to that of the optical behavior found from LHMS of type II or type III materials. The materials for which both real part of permittivity ε and permeability μ are negative for a given frequency range follow LHMS [3]. According to Kramers-Kronig relation frequency dependence of permittivity ε, permeability μ and refractive index n indicates that these quantities are complex. Depending upon the choice of phase factor ϕ_ε and ϕ_μ, n becomes positive or negative which categorize LHMS in four different types. $\varepsilon_2<0$, $\mu_2<0$, $n>0$ are the characteristics of LHMS type II or III material [4]. The experimental results and discussions are follows in the subsequent sections.

1.3. Fish Scale Morphology

Fish Scales are the hard, translucent and generally colorless. Its hydrodynamic property helps the movement of the fishes. The fish scales are produced from the mesoderm layer of the dermis. Its morphology provides the four taxonomic divisions of the fishes which are Placoidei, Ganoidei, Ctenoidei and Cycloidei [5]. Fish scales are mainly composed of calcium compound along with collagen fibers. The surface of scale can be divided into anterior, lateral and posterior regions. Its centre is known as focus, around which the circuli are oriented in a regular manner. SEM study [6] shows that the circuli are composed of upper osseous layer (3-4 μm in width) and lower fibrillary plate (1-2 μm in width). The circuli increases layer by layer depicting the age of the fish. Besides these biological aspects there are some excellent structural properties and physical behavior of this bio material for physicist's and engineer's interest.

2. Sample

The scale of the fish used for different experiments was collected from the side of the body between the dorsal fin and lateral line of *Katla katla*, a fresh water fish. After removing, the scales are rinsed with distilled water and ethyl alcohol and experimental specimens were developed. The scales of this fishes are of Cycloidei type.

3. Experiments

IR transmittance spectra of the sample were studied with Fourier transforms infrared spectrophotometer (Shimadzu, Japan, model IR Affinity-1) at a resolution 0.5 cm^{-1}. The optical reflectance measurement was carried out using specially designed optical spectrometer, an indigenous set up in which a monochromatic green LASER (wave length 532 nm) was used as a source and a polarizer was used at the collimator end of the spectrometer to get plane polarized light. The cross-wire of the spectrometer was replaced by a photo transistor to produce equivalent current proportional to the light intensity. The electric current equivalent of reflected light intensity for different angle of incidence (at angular resolution of $20''$) of the plane polarized light was recorded by Keithley 2400 (USA) source meter. Experiment was carried out for two sets of plane polarized light namely polarization parallel to the plane of incidence and polarization perpendicular to the plane of incidence. All measurements were done at room temperature, 300 K.

4. Results And Discussion

Aut FTIR transmittance spectrum has depicted in Fig. 1 showing the range 350 cm^{-1} to 7800 cm^{-1}.

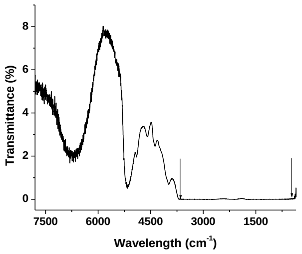

Fig. 1. FTIR transmittance spectra of fish scale

The sample consists of nano composites containing carbonate, phosphate and amide I, II, III groups. The figure shows an inhibition of propagation of EM wave between the marked wave number 482 cm^{-1} to 3630 cm^{-1}. This inhibition is due to the formation of photonic band gap in the material. Layer wise deposition with variation of dielectric constant gives rise to Bragg reflected ray which after recombination and destruction form this band gap. Figure 2 and 3 shows the plot of optical reflectance for parallel and perpendicular field of polarization of incident light. Graph A in both the figures show an investigation of Fresnel's equation on fish scale surface. Graph B in the figures, whereas, are standard electro-magnetic theoretical results on ordinary dielectric surface, refractive index 1.62, representing Fresnel equations.

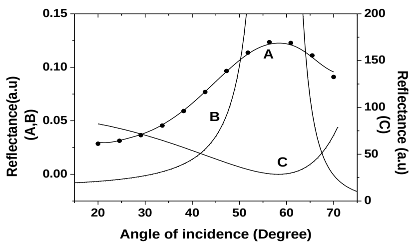

Fig. 2. Optical reflectance with angle of incidence (parallel polarization).

The overall nature of the graph A is complementary to that of the graph B in both the figures. Graph 2A points to the Brewster's angle of the dielectric at 58.31^0 showing zero reflectance of parallel component of E vector. The experimental result on the fish scale, on the other hand, in graph 2B shows a peak of reflectance of light at the same angle which can be designated as 'anti Brewster's angle'. Perpendicular component, Fig. 3, of E vector for fish scale shows very low reflectance near the grazing angle whereas for the dielectric it is very high. Graph C in both the figures are the representation of theoretical results found from the LHMS type II or III material using $\varepsilon_2 = -1.5\varepsilon_1$, $\mu_2 = -\mu_1$, $n_1=1$ and $n_2=1.62$.

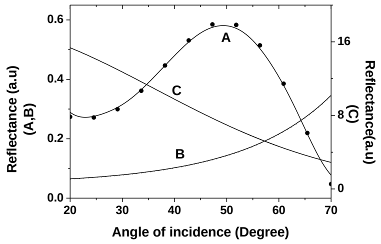

Fig. 3. Optical reflectance with angle of incidence (perpendicular polarization)

The nature of the experimental results (shown by graph A) found from fish scale surface are almost analogous to that of the theoretical results of LHMS type II or III [4] material for parallel polarization saving from the infinite intensity at anti Brewster's angle. Perpendicular polarization graph shows the fall of intensity with angle of incidence like LHMS theoretical graph though the nature of fall is not same for both of the cases.

5. Conclusion

The scale, hard cover of the fish, is a layer structure and it exhibits photonic band gap in the IR region. The manifestation of the layer structure is also responsible for unusual optical properties. The optical nature is like that of the nature found from the LHMS type II or III material. It would be the potential candidate for the future material science applications.

6. Acknowledgment

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10. References

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