Retroreflection from Nanoporous InP

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***Abstract* — Pronounced retroreflection behavior is reported for a fishnet nanoporous strongly absorbing semiconductor material. Retroreflection appears with diffusive specular reflection for all angles of incidence. Retroreflection is apparent by the naked eye with day light illumination and exhibits no selectivity with respect to wavelength and polarization of incident light featuring minor depolarization of retroreflected light. The phenomenon can be classified neither as coherent backscattering nor as Anderson localization of light. The primary model includes light scattering from strongly absorptive and refractive super-wavelength clusters existing within the porous fishnet structure. We found that retroreflection vanishes for wavelength where absorption becomes negligible.**

***Index Terms* — nanoporous semiconductors, retroreflection, backscattering**

I. INTRODUCTION

Scattering of the light in complex nanostructured media is the subject of extensive research. Non-trivial phenomena in this field include coherent backscattering [1,2], Anderson localization of light [3,4], the photonic glass concept [5], propagation of waves in quasiperiodic [6] and fractal [7] structures, anisotropic scattering in aligned nanoporous dielectrics [8], and Letokhov's (random) lasers [9]. But all of the above phenomena necessarily imply nonabsorptive material forming desirable nanostructured media since multiple scattering and interference of scattered light waves are of principal importance.

In this paper, we continue (see [10]) investigation of the reflection and scattering properties of fishnet nanoporous semiconductor InP not only in the spectral range of interband optical transitions where multiple scattering is inhibited by strong absorption, but in infrared spectral region where this material is transparent.

II. SAMPLE PREPARATION

Nanoporous InP samples were fabricated from (100)- and (111)-oriented n-type InP:Si wafers with variable free carrier concentration from 1.9×10^{16} cm^{-3} to 2×10^{19} cm^{-3}. The etching was carried out in an electrochemical double cell (Fig. 1) using a configuration of four platinum electrodes: reference electrode in the electrolyte (REE), reference electrode on the sample (RES), counter electrode (CE), and working electrode (WE), all of them connected to a Keithley 236 source measure unit. A 5% aqueous solution of HCl at different galvanostatic conditions was used as the electrolyte. Its temperature was kept constant at T = 23°C by means of a Julabo F25 thermostat on one side of the double cell (where pores were expected to grow). The electrolyte was continuously pumped through both cells with peristaltic pumps. The area of the sample exposed to the electrolyte was 0.12 cm^2. The experiments were performed in the dark, and the holes necessary for the dissolution of the material were created by the breakdown of the depletion layer.

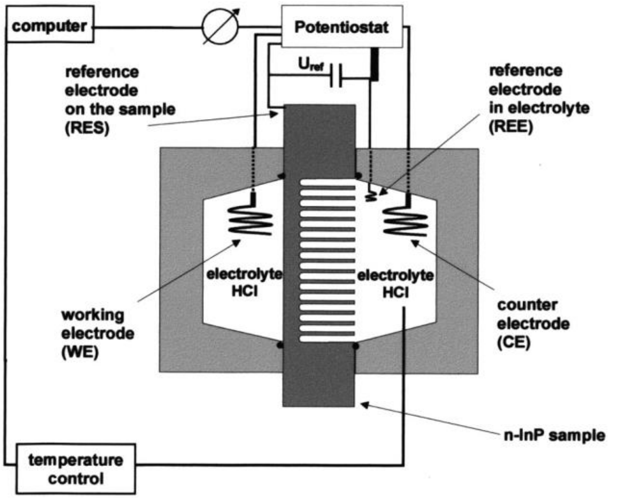

Fig. 1. Electrochemical etching set-up

The morphology of the etched samples was examined using a VEGA TESCAN TS 5130MM scanning electron microscope (SEM) equipped with an Oxford Instruments INCA energy dispersive x-ray (EDX) system. Fig. 2 shows the SEM micrographs for some of the fabricated samples.

Scattering/reflectance indicatrices were measured in an experiment sketched in Fig. 3. The samples were illuminated by a beam from a cw Nd:LSB microchip solid state laser (LEMT, Belarus) with λ = 531 nm and from Nd:YAG solid state laser (Solar LS, Belarus) with λ = 1064 nm. The beam was directed at incident angle α, and the spot size from the beam at the sample was approximately 2 mm. The scattered light was collected at varying angle β and guided to a spectrograph (Solar TII) followed by a detector (LN/CCD-1152-E 16-bit CCD array, Princeton Instruments).

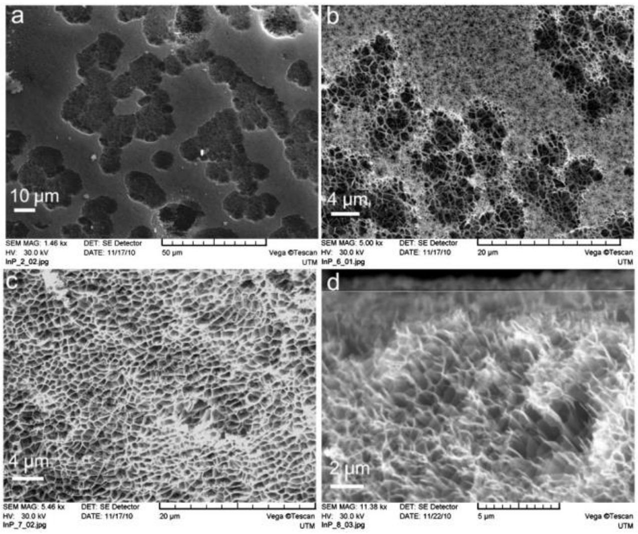

Fig. 2. SEM images of four InP samples.

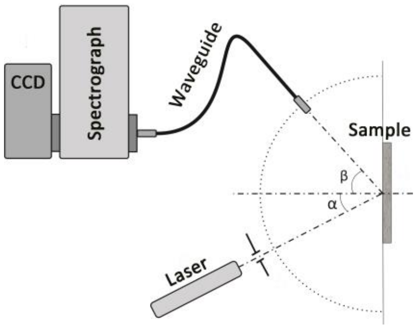

Fig.3. Experimental set-up.

At a wavelength of 531 nm a real n and imaginary κ parts of the complex refraction index of InP are n = 3.8 and κ = 0.5 [11]. The latter corresponds to the absorption coefficient 1.3×10^5 cm^{-1}. At 1064 nm wavelength the refractive index is 3.3 whereas the absorption coefficient can be treated as negligible [11].

III. RESULTS

Pronounced retroreflection behavior was found for most of samples of nanoporous InP for laser wavelength where absorption coefficient is very high because of interband optical transitions (Fig. 4, data for 531 nm). Therefore we believe that the observed effect is inherent in a strongly absorbing nanoporous semiconductor material. Retroreflection appears along with diffusive specular reflection for all angles of incidence. Retroreflection is apparent by the naked eye with day light illumination and exhibits no selectivity with respect to wavelength and polarization of incident light featuring minor depolarization of retroreflected light.

The observed phenomenon can be classified neither as coherent backscattering nor as Anderson localization of light. The primary model [10] includes light scattering from strongly absorptive and refractive super-wavelength clusters existing within the porous fishnet structure**.** The typical diffusive reflection inherent in low-absorptive porous structures becomes inhibited owing to low mean free path resulting from high dissipative losses.

To verify this primary model, the additional experiments for laser wavelength corresponding to low intrinsic absorption by InP have been performed (Fig. 4, data for 1064 nm). One can see that retroreflection vanishes for wavelength where absorption becomes negligible. The diffuse reflection gains angular dependence close to that typically observed in low-absorptive nanoporous materials. Notably, in a few cases (sample #1, sample #8) mirror-like reflection develops. The latter is believed to arise from the length scale properties, namely, for longer wavelengths not only absorption becomes lower but also scattering cross-section goes down since a portion of scattering units becomes smaller than the wavelength**.**

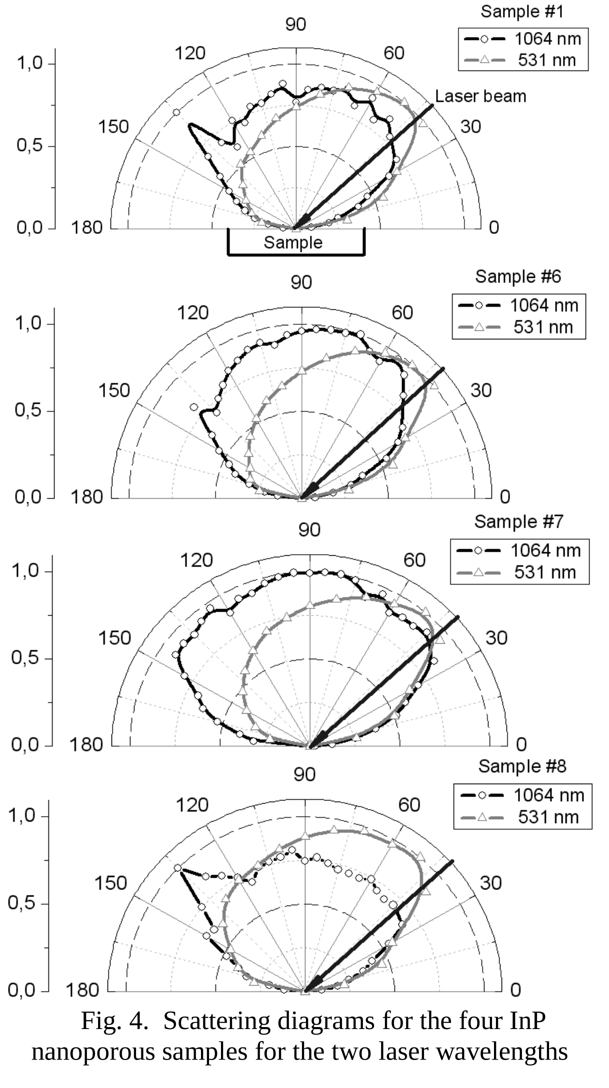

Fig. 4. Scattering diagrams for the four InP nanoporous samples for the two laser wavelengths

IV. CONCLUSION

The retroreflection phenomenon for certain nanoporous semiconductor structures is reported and examined. The retroreflection is believed to arise from scattering of light under condition of the mean free path being defined mainly by dissipative losses. For spectral range corresponding to intense interband optical absorption the effect is pronounced in day light illumination. The effect was found to vanish for laser wavelength where optical absorption of InP can be neglected.

ACKNOWLEDGMENTS

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