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EFFECT OF λ IN THE EM VISIBLE REGION ON THE REFLECTIVE PROPERTIES OF NICKEL NANOWIRES

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ABSTRACT

Nickel nanowires with vertical alignment on the copper substrate were synthesized by direct current electrodeposition method using polycarbonate template. The pore diameter of the template was 100 nm. The morphological study of Ni nanowires was carried out by using scanning electron microscopy (SEM). The reflective properties of the nanowires have been studied for the wavelength range of 380 to 700 nm of visible light. The measurement of the incident and reflected light was carried out by using a high resolution camera and a fiber. The analysis of the results showed that the reflection of incident light is low for lower and upper region of wavelength. The peaks in the reflective spectrum are observed at 470 nm and 540 nm.

KEYWORDS

Polycarbonate membrane template, Electrodeposition, nanowires wavelength, light intensity.

1. INTRODUCTION

Nanophotonics is emerging field in novel sensing and imaging applications, also in the areas of advanced information technology, cryptography, and signal processing. One-dimensional nanostructured metals have attracted much attention in this regard because of their potential applications in ultrahigh density magnetic recording, ultrafast optical switching, and microwave devices [1].

Materials exhibiting optical limiting properties are necessary for the production of photonic devices that control amplitude gain or extinction, polarization, phase, reflection and refraction of light [2]. Semiconductor-doped glasses [3,4], inorganic and hybrid nanostructures [5], organic molecules like dyes and fullerenes [6], colloidal metals and metal nanoparticles [7,8], silicon nanowires [9] and cadmium oxide nanowires [10] are some of the materials known to show good optical limiting.

When a light wave strikes a metal surface, it can excite a surface plasmon polarization, a surface electromagnetic wave coupled to plasma oscillations. Recently, the concept of plasmonics, in analogy to photonics, has received much attention since surface plasmons reveal strong analogies to light propagation in conventional dielectric components [11-13]. For example, it is now possible to confine them to sub-wavelength dimensions leading to novel approaches for wave guiding below the diffraction limit [14,15]. The combination of sub-wavelength confinement, single-mode operation, and the relatively low-power propagation loss of surface plasmon polarizations could be used to miniaturize existing photonic circuits [16]. Furthermore, the strong coupling between SP and emitters can be utilized to enhance infrared photodetectors, the fluorescence of quantum dots, and light transmission through metal nanoarrays [17-20]. High-field surface plasmon confinement was also used to demonstrate an all-optical modulator, to provide an extra degree of freedom for information storage, and to estimate the reflectivity of structures or surface roughness [21,22].

A great effort has been devoted to the study of metallic nanoparticles due to their distinct optical properties with respect to that of the bulk material [23]. The ability of nanoparticles to uphold charge density oscillation known as localized surface plasmons is the main factor behind distinct optical properties from their bulk counterpart. These spatially localized modes may appear at a metal/dielectric interface, manifesting themselves as optical resonances in the transmission and reflection spectra, being their most significant feature the local enhancement of the electromagnetic field at the metal/dielectric interface [24]. Size, shape, particle inter-distance, embedded environment, or material components of the nanoparticles are the parameter on which the spectral position, width, and intensity of the optical resonance depends. The influence of such parameters has been thoroughly studied in number of works putting forward the possibility of tailoring their optical response through the morphology of the particles [25-29].

2. NANOWIRES SYNTHESIS BY ELECTRODEPOSITION

A porous membrane with cylindrical pore geometry can be used as a template for the synthesis of 1D nanostructure. Two types of porous membranes are commonly used: anodic aluminum oxide (AAO) and track-etched polymer membranes. AAO films can be produced upon aluminum metal when aluminum is made the anode in an electrolyte, typically sulfuric, phosphoric, chromic, or oxalic acids at almost any concentration [30,31]. The pore densities as high as 10^{11} pores cm^{-2} can be achieved and the pores in these membranes have little or no tilt with respect to the surface normal resulting in an isolating, non-connecting pore structure. Microporous and nanoporous polymer membranes are commercially available filters, with a broad range of pore diameters (down to 10 nm) and pore densities approaching 10^9 pores cm^{-2}. However, due to the random nature of the pore-production process, the pores in polymer membranes are tilted with respect to the surface normal, and a number of pores may actually intersect within the membrane [32].

Among various chemical strategies, electrochemical synthesis in a template is one of the most efficient methods to controlling the growth of a variety of metal, conducting polymer, oxide and compound semiconductor nanowire arrays. As the nanowires grow, the nanopores of the template are filled. Because the nanopores, perpendicular to the polycarbonate membrane surface, are uniform in diameter, and hexagonally packed, the nanowires embedded in the template form highly ordered and vertically aligned nanowire arrays [33-35].

In this paper we investigated the effect of incident wavelength of visible light on the absorption spectra of electrodeposited Ni nanowires. Experiment demonstrates the absorption dependency of nanowires on the wavelength of light.

3. METHODOLOGY

Ni nanowires have been fabricated using template assisted electrodeposition process. Electrodeposition process was carried out in two electrode system shown in Figure.1. The cell system consists of a metallic base in circular shape on which substrate is placed and four small orifices are made to insert bolts to hold the upper system tightly so that electrolyte cannot leak out from the cell.

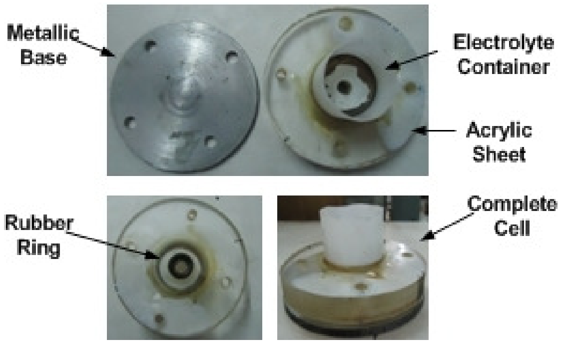

Figure 1. Cell system for electrodeposition of nanowires.

The container of the system is made up of plastic cylindrical shaped tube which is attached to acrylic sheet having a small orifice with diameter of 0.8 cm with strong adhesion. Platinum (Pt) electrode acts as anode and metallic base of the system acts as cathode. Commercially available 100 nm polycarbonate template has been obtained. The membrane is placed over the substrate and the system is tightly closed. Also it is ensured that no air bubble exits between membrane and substrate. Electrodeposition of Ni is done on Cu substrate through nano-porous polycarbonate membrane. The electrolyte for the deposition is prepared in 20ml double distilled water with 0.2M $NiSO_4.6H_2O$, 0.2M $NiCl_2.6H_2O$, and 0.1M H_3BO_3. The electrolyte is poured in the cylindrical container of cell and voltage of 2.7V is applied to the solution. As current passes through the solution electrolysis process takes place and Ni atom dissociates into Ni^{2+}, these ions moves towards the cathode through the membrane pour and deposits on the Cu substrate in the nano-porous space. Current density during the electrodeposition process was carefully monitored shown in Figure. 2.

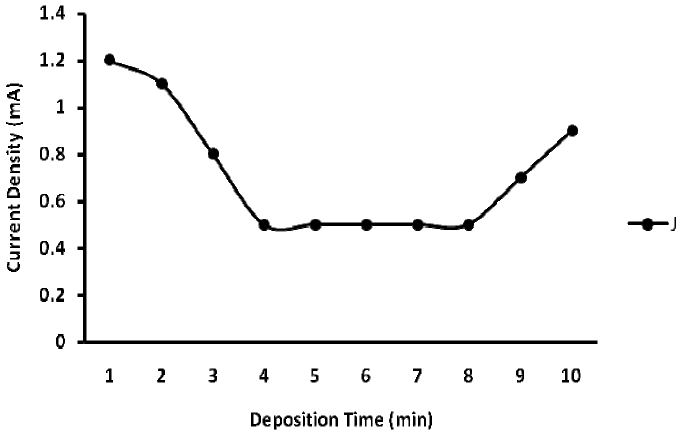

Figure 2. Current density (J) during electrodeposition process.

After the deposition process was completed, the sample containing template and deposited material was put in the dichloromethane (Cl_2CH_2) solution to dissolve the polycarbonate membrane. The prepared sample containing Ni nanowires were then characterized for morphological studies using SEM from national laboratory.

In order to study the reflective properties of Ni nanowires a setup is created to carry out the experiment. Light is focused to the input slit of a monochromator from the light source generator which consists of a movable lens to adjust the focal length. At the output slit of monochromator an optical fibre is attached to incident the light on sample containing nanowires. Angle of incidence of light is 30° w.r.t. plane of the sample. The reflected light from the sample is collected using a high resolution camera. Figure.3 shows the schematic of complete setup.

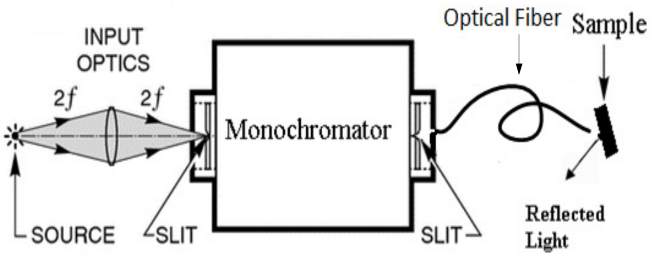

Figure 3. Schmetic of setup for collection of reflect light.

4. RESULTS AND DISCUSSION

After the successful deposition of Ni nanowires, the morphological studies of the sample containing nanowires were carried out. Figure.4 shows the SEM image of Ni nanowires. As Ni belongs to the family of magnetic material, it is expected that the nanowires fabricated will attract each other to form a bundle, which is evident from the SEM image.

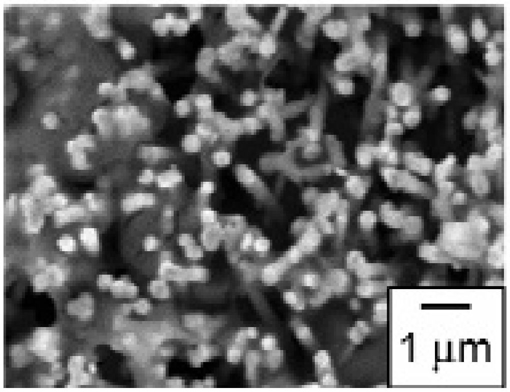

Figure 4. SEM of Nickel nanowires fabricate using electrodeposition.

Average intensity of incident and reflected light from the substrate containing Ni nanowires was calculated for visible spectrum of light. Variation in average intensity of incident and reflected light w.r.t. wavelength for 100 nm Ni nanowires is shown in Figure.5. From the graph it can be interpreted that the average reflected light from the nanowires is minimum for lower and upper ends of the visible spectrum. In the graph for wavelength ranging from 470 to 540 nm the average intensity of reflected light is constant. Peaks points in the average reflected light is observed at 570-580 nm wavelengths. In Figure.6 the peaks in the ratio of average reflected and incident light are observed at wavelength of 470 and 560 nm. Graph shows almost flat region for wavelength ranging from 470 to 540 nm. The investigations carried out for reflective properties show that these types of structures may be very useful for designing optical sensors.

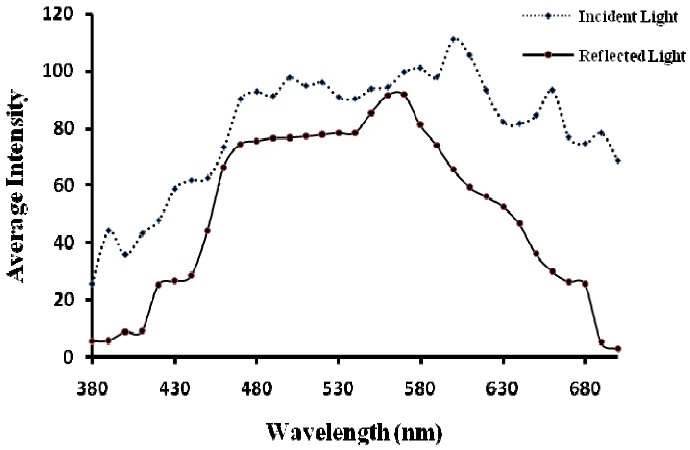

Figure 5. Average intensity of incident & reflected light from Cu substrate containing Ni nanowires from 380-700nm wavelength

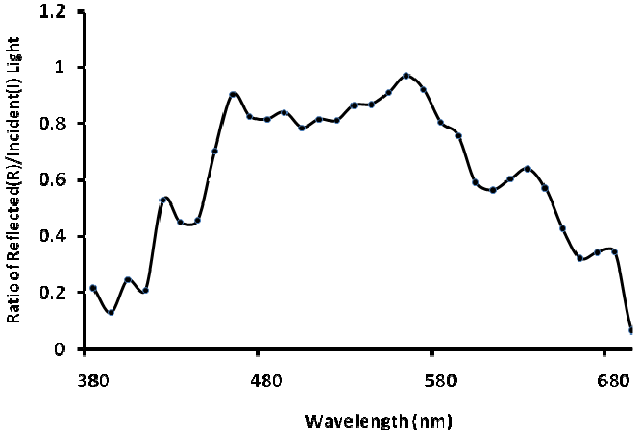

Figure 6. Ratio of average reflected and incident light w.r.t. wavelength.

5. CONCLUSION

Syntheses of Ni nanowires were done using direct electrodeposition in polycarbonate membrane. The pore diameter of the template was 100 nm. Morphological study of Ni nanowires was carried out by using scanning electron microscopy (SEM). The effect of wavelength on reflection of incident light was studied for visible region (380-700 nm). The analysis of the results showed that the reflection of incident light is low for extreme lower and upper wavelength of the spectrum. At wavelengths 470 nm and 540 nm a peak in the reflection spectra is observed. The reflection of light is constant for green visible light spectrum. The investigations showed that these types of structures may be very useful for designing optical sensors.

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REFERENCES

[1] C. S. Suchand S., A. K. Samal, T. Pradeep, Reji Philip (2010), "Optical limiting properties of Te and Ag2Te nanowires," *Chemical Physics Letters*, Vol.485, pp. 326–330.

[2] S. A. O'Flaherty, R. Murphy, S.V. Hold, M. Cadek, J.N. Coleman, W.J. Blau (2003), "Material Investigation and Optical Limiting Properties of Carbon Nanotube and Nanoparticle Dispersions," *J. Opt. Soc. Am. B*, Vol. 107, pp. 958–964.

[3] G.P. Banfi, V. Degiorgio, A. Fortusini, H.M. Tan (1995), "Third-order nonlinearity of semiconductor doped glasses at frequencies below band gap," *Appl. Phys. Lett.*, Vol. 67, pp.13-15.

[4] D. Cotter, M.G. Burt, R.J. Manning (1992), "Below-band-gap third-order optical nonlinearity of nanometer-size semiconductor crystallites," *Phys. Rev. Lett*., Vol. 68, pp.1200.

[5] J. Wang, W.J. Blau (2009), "Inorganic and hybrid nanostructures for optical limiting," *J. Opt. A: Pure Appl. Opt*., Vol. 11.

[6] R.C. Hollins (1999), "Materials for optical limiters," *Curr. Opin. Solid State Mater. Sci*., Vol. 4 pp. 189.

[7] R. A. Ganeev, A. I. Ryasnyansky, S. R. Kamalov, M. K. Kodirov, T. Usmanov (2001), "Nonlinear susceptibilities, absorption coefficients and refractive indices of colloidal metals," *J. Phys.D: Appl. Phys*., Vol. 34, pp. 1602.

[8] R. Philip, G. Ravindra Kumar, N. Sandhyarani, T. Pradeep (2000), "Picosecond optical nonlinearity in monolayer-protected gold, silver, and gold-silver alloy nanoclusters," *Phys. Rev. B,* Vol. 62, pp.13160-13166.

[9] H. Pan, W. Chen, S. H. Lim, C. K. Poh, X. Wu, Y. Feng, W. Ji, J. Lin (2005), "Photoluminescence and Optical Limiting Properties of Silicon Nanowires," *Journal of Nanoscience and Nanotechnology*, Vol.5, pp.733-737.

[10] Z. Liu, Y. Liu, J. Du, S. Yuan, X. Dong (2007), "Switchable triple-wavelength erbium-doped fiber laser using a single fiber Bragg grating in polarization-maintaining fiber," *Optics Communications,* Vol. 279, pp.168–172.

[11] R. Zia and M. L. Brongersma (2007), "Surface plasmon polariton analogue to Young's double-slit experiment," *Nature Nanotechnology,* Vol. 2, pp.426-429.

[12] K. Yu. Bliokh, Yu. P. Bliokh, V. Freilikher, S. Savelev, and F. Nori (2008), "Colloquium: Unusual resonators: plasmonics, metamaterials, and random media," *Rev. Mod. Phys*., Vol. 80, pp.1201-213.

[13] S. Savelev, V. A. Yampolskii, A. L. Rakhmanov, and F. Nori (2010), "Terahertz Josephson plasma waves in layered superconductors: spectrum, generation, nonlinear and quantum phenomena," *Rep. Prog. Phys.,* Vol. 73.

[14] W. L. Barnes, A. Dereux, and T.W. Ebbesen (2003), "Surface plasmon subwavelength optics," *Nature (London),* Vol.424, pp. 824.

[15] D. K. Gramotnev and S. I. Bozhevolnyi (2010), "Plasmonics beyond the diffraction," *Nat. Photon.,* Vol. 4, pp.83-91.

[16] S. I. Bozhevolnyi, V. S. Volkov, E. Devaux, J. Laluet, and T. W. Ebbesen (2006), "Channel plasmon subwavelength waveguide components including interferometers and ring resonators," *Nature (London)* , Vol. 440, pp.508-511.

[17] D. E. Gomez, K. C. Vernon, P. Mulvaney, and T. J. Davis (2010), "Surface plasmon mediated strong exciton-photon coupling in semiconductor nanocrystals," *Nano Lett.,* Vol. 10, pp.274-278.

[18] C. C. Chang, Y. D. Sharma, Y. S. Kim, J. A. Bur, R. V. Shenoi, S. Krishna, D. Huang and S. Yu Lin (2010), "A surface plasmon enhanced infrared photodetector based on InAs quantum dots," *Nano Lett.,* Vol. 10, pp.1704.

[19] E. Hwang, I. I. Smolyaninov, and C. C. Davis (2010), "Surface Plasmon Polariton Enhanced Fluorescence from Quantum Dots on Nanostructured Metal Surfaces," *Nano Lett.,* Vol. 10, pp.813.

[20] H. Gao, J. Henzie, and T. W. Odom (2006), "Direct Evidence for Surface Plasmon-Mediated Enhanced Light Transmission through Metallic Nanohole Arrays*," Nano Lett.,* Vol. 6, pp.2104-2108.

[21] D. Pacifici, H. J. Lezec, and H. A. Atwater (2007), "All-optical modulation by plasmonic excitation of CdSe quantum dots," *Nat. Photon.,* Vol. 1, pp.402-406.

[22] P. Zijlstra, J. W. M. Chon, and M. Gu (2009), "Five-dimensional optical recording mediated by surface plasmons in gold nanorods," *Nature (London),* Vol. 459, pp.410-413.

[23] B. Dragnea, J. M. Szarko, S. Kowarik, T. Weimann, J. Feldmann, and S. R. Leone (2003), "Near-Field Surface Plasmon Excitation on Structured Gold Films," *Nano Lett.,* Vol. 3, pp.3.

[24] K. L. Kelly, E. Coronado, L. L. Zhao, G. C. Schatz (2003), "The optical properties of metal nanoparticles: the influence of size, shape and dielectric environment," *J Phys Chem. B*, Vol. 107, pp.668.

[25] S. A. Maier, H. A. Atwater (2005), "Plasmonics: localization and guiding of electromagnetic energy in metal/dielectric structure," *J Appl. Phys,* Vol. 98.

[26] M. M. Miller, A. A. Lazarides (2005), "Sensitivity of metal nanoparticle surface plasmon resonance to the dielectric environment," *J Phys Chem. B,* Vol. 109, pp.21556.

[27] A. J. Haes, S. Zou, G. C. Schatz, R. P. V. Duyne (2004), "Nanoscale optical biosensor: short range distance dependence of the localized surface plasmon resonance of noble metal nanoparticles," *J Phys Chem. B*, Vol. 108, pp.6961.

[28] K. S. Lee, M. A. El-Sayed (2006), "Gold and silver nanoparticles in sensing and imaging: sensitivity of plasmon response to size, shape, and metal composition," *J Phys Chem. B,* Vol. 110, pp.19220-19225.

[29] L. Liz-Marzan (2006), "Tailoring surface plasmons through the morphology and assembly of metal nanoparticles," *Langmuir,* Vol. 22, pp.32.

[30] B. J. G. Diaz, A. G. Martin and G. A. Reig (2009), "Unusual magneto-optical behavior induced by local dielectric variations under localized surface plasmon excitations," *Nanoscale Research Letters,* Vol. 6, pp.408.

[31] A. P. Li, F. Muller, A. Birner, K. Nielsch, U. Gosele (1998), "Hexagonal pore arrays with a 50–420 nm interpore distance formed by self-organization in anodic alumina," *J. Appl. Phys.,* Vol. 84, pp. 6023.

[32] J. S. Suh, J.S. Lee (1999), "Highly ordered two-dimensional carbon nanotube arrays," *Appl. Phys. Lett.,* Vol.75, pp.2047.

[33] P. Lehana, S. Khan, S. Arya (2011), "Fabrication and investigations of cufe nanowires based sensors," *International Journal of VLSI and Signal Processing Applications,* Vol. 1, pp. 32-37.

[34] C. R. Martin (1994), "Nanomaterials: A membrane-based synthetic approch," *Science*, Vol.266, pp.1961-1966.

[35] X. J. Wu, F. Zhu, C. Mu, Y. Liang, L. Xu, Q. Chen, R. Chen, D. Xu. (2010), "Electrochemical synthesis and applications of oriented and hierarchically quasi-1D semiconducting nanostructures," *Coordination Chemistry Review*, Vol. 254, pp.1135–1150.