Metallic nanowires and polymeric composites

NANOWIRES (NW)

Nanomaterials.it develops and sells a wide range of metallic nanowires that can be employed in many scientific and industrial applications such as: electrode sensors, catalysts, magnetic devices, and others.
The nanowires that we produce are characterized by:

- High metal purity
- Diameter and length with low standard deviation

We provide our nanowires in different types and forms of supply, for example:

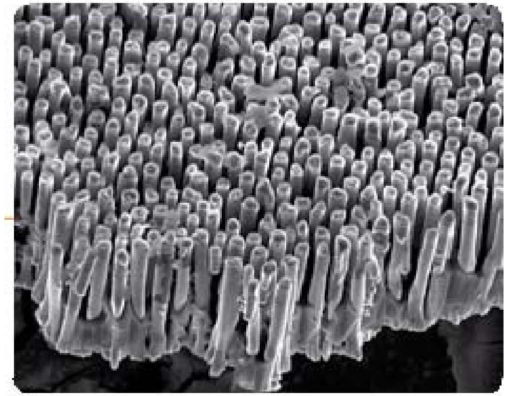
- Metallic nanowires of Gold, Nickel, Copper, Cobalt and, on demand, of other metals
- Dispersed in organic or aqueous solution
- Embedded into porous anodic alumina templates

Metallic nanowires (NW)

- Metal: Gold, Nickel, Copper, Cobalt

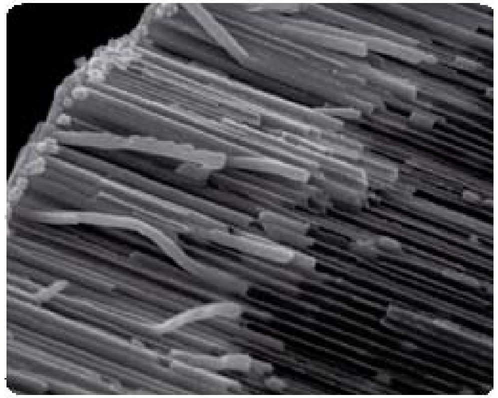
Wire diameter	35nm (S.D. 15%) 90nm (S.D. 10%) 200nm (S.D. 20%)
Wire lenght	25μm ± 5μm 40μm ± 5μm
Concentration	On demand, up to few g/l
Solution	Organic or aqueous solutions (others on demand)
Packaging	Glass bottles of 100ml (others on demand)

Nickel nanowires



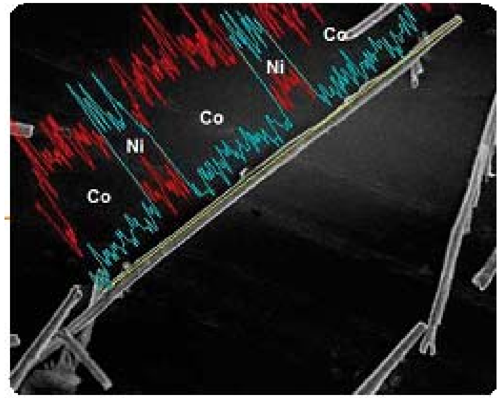
1μm

Gold nanowires



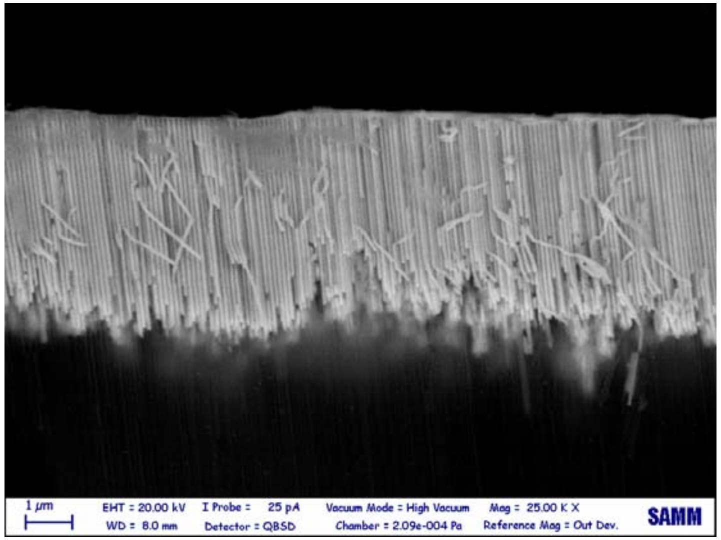
1μm

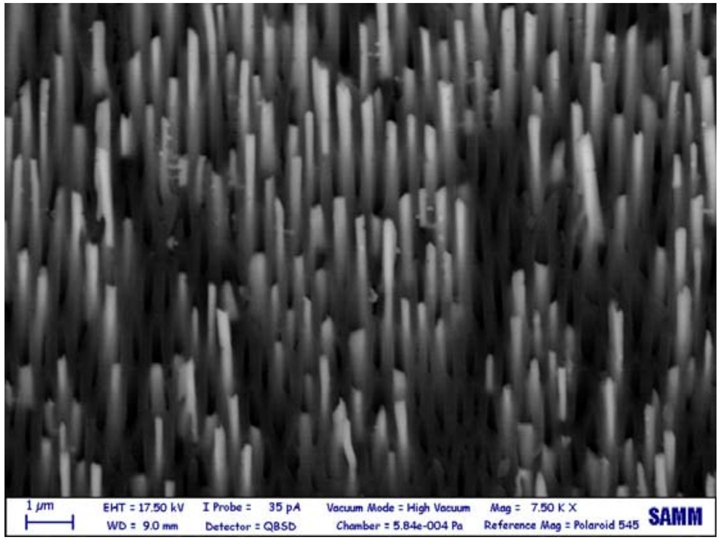
Nickel-Cobalt nanowires

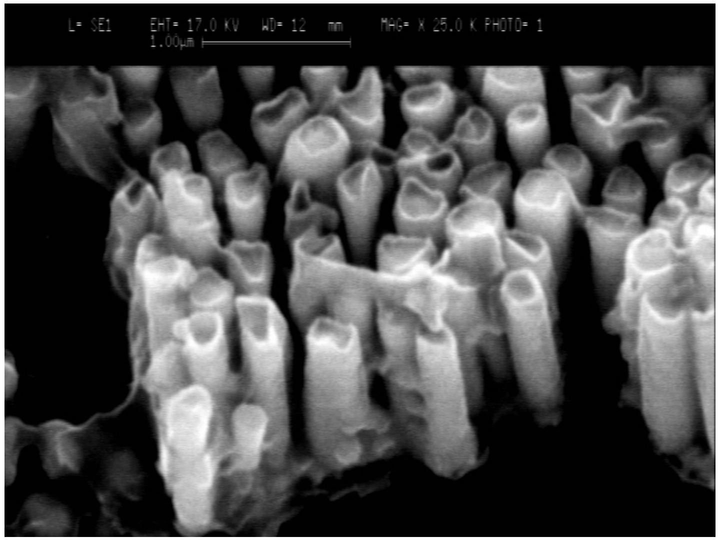


6μm

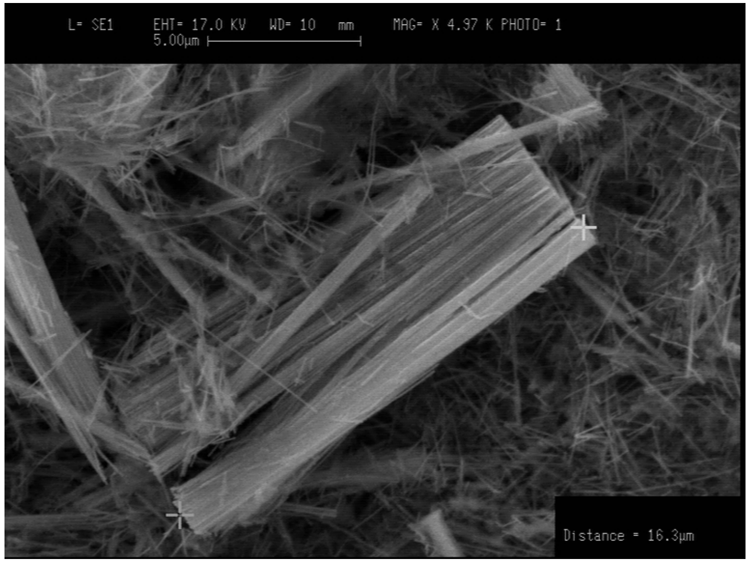
Metallic NWs in PPA

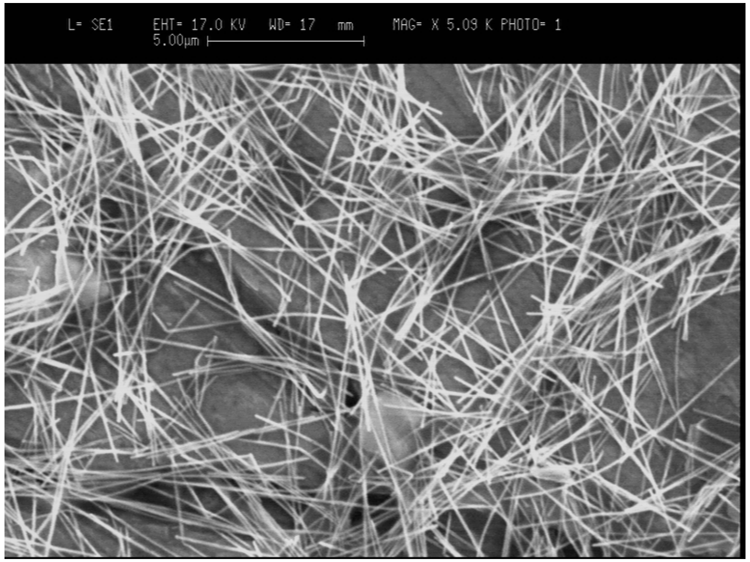






Dispersed Metallic NWs





Characterization of metal nanowires used as fillers in a polymer matrix

Fabrication of polydimethylsiloxane composites with nickel nanoparticle and nanowire fillers and study of their mechanical and magnetic properties

Denver, Heather Heiman, Timothy Martin, Elizabeth Gupta, Amit Borca-Tasciuc, Diana-Andra
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Journal of Applied Physics Sep 2009

ABSTRACT

This work presents the fabrication and characterization of mechanical and magnetic properties of polydimethylsiloxane (PDMS) nanocomposites with nickel nanoparticles and nanowires as fillers. To enhance filler dispersion and polymer-filler interface bonding, allyltrimethoxysilane was used for nanofiller coating. Sample preparation was carried out by speed mixing and curing at 100 °C. Nanowire-PDMS composites were exposed to magnetic field prior to full curing in order to facilitate nanowire alignment. Composites with concentrations of 5, 10, and 15 vol % of nanoparticles and 5 vol % of nanowires were prepared and tested. An increase in elastic modulus of ~30% was observed for composites with 5 vol % nanoparticle concentration. A much higher increase in elastic modulus, of ~80%, was observed for nanowire-based composites of same concentration. The measured elastic modulus agrees well with predictions that assume strong interface bonding between the polymer and the filler. Magnetic anisotropy and higher remanent magnetization and coercivity are observed for the nanowire composite. These multifunctional materials could have a wide range of applications, from active structural components to sensing elements in macro- and particularly microsystem applications.

Mechanical material characterization of Co nanowires and their nanocomposite

Wen-Hwa Chen [a], Hsien-Chie Cheng [b,*], Yu-Chen Hsu [a], Ruoh-Huey Uang [c], Jiong-Shiun Hsu [d]

A B S T R A C T

The study attempts to evaluate the complete set of effective transversely isotropic properties of a nanocomposite at various nanofiber-volume fractions through effective continuum modeling and experimental testing. The investigation starts from the theoretical and experimental assessments of the elastic properties the nanoscale Co metal using molecular dynamics (MD) simulations and nanoindentation testing, respectively. For determining the thermal-mechanical material properties of the nanocomposite, an effective finite element modeling (FEM)-based continuum modeling approach are introduced. Results show that the nanoscale Co metal presents inhomogeneity in the elastic material properties, the degree of which increases with a decreasing dimension of nanomaterials. Comparisons of the present results with experimental and existing theoretical data demonstrate the effectiveness of the proposed methods. Furthermore, as a result of the Co filament, significant anisotropy can be found in the effective thermal-mechanical properties of the nanocomposite but surprisingly not in the effective Poisson's ratio and coefficient of thermal expansion (CTE).

Composites Science and Technology 68 (2008) 3388–3395

Low Electrical Percolation Threshold of Silver and Copper Nanowires in Polystyrene Composites**

By *Genaro A. Gelves*, *Bin Lin*, *Uttandaraman Sundararaj*,* and *Joel A. Haber**

Silver and copper nanowires have been synthesized using a scalable method of AC electrodeposition into porous aluminum oxide templates, which produces gram quantities of metal nanowires ca. 25 nm in diameter and up to 5 and 10 μm in length for Ag and Cu, respectively. The nanowires have been used to prepare polystyrene nanocomposites by solution processing. Electrical resistivity measurements performed on polymer nanocomposites containing different volume fractions of metal indicate that low percolation thresholds of nanowires are attained between compositions of 0.25 and 0.75 vol %.

We believe that nanocomposites containing high-aspect-ratio conductive metal nanoparticles should be considered as alternatives to carbon nanotube composites for use in electrostatic dissipation, electromagnetic interference, and other electronic applications, such as heat sinks, that utilize the good thermal conductivity of metals. [15,16] For example, a few studies have been dedicated to the preparation and characterization of epoxy filled with spherical silver nanoparticles for applications such as in embedded capacitors [17–19] and electromagnetic shielding.[20] Promising results have been demonstrated. Nonetheless, polymer nanocomposites containing metal nanowires have not been studied, which is likely due to the unavailability of these nanoparticles in gram quantities.

Adv. Funct. Mater. **2006**, *16*, 2423–2430

Electrical Conductivity in Polymer Composites Containing Metal Nanowires: Simulation and Experiment

White, Sadie; Vemulkar, Tarun; Fischer, John; Winey, Karen

American Physical Society, 2009 APS March Meeting, March 16-20, 2009, abstract #P19.008

The study of rod percolation behavior has resurfaced in recent years, because it explains electrical conductivity in polymer nanocomposites containing carbon nanotubes and metal nanowires. Common processing techniques result in fillers with L/D < 50, so traditional models, which are only strictly correct in the limit of L/D ˜∞, are ineffective at predicting percolation in these systems. We present a simulation that constructs percolated networks of finite-aspect ratio rods and calculates their electrical conductivity. We will compare our simulation results with polymer composites containing silver nanowires with aspect ratios of ˜10 and ˜30. Finally, we will present the temperature-dependent electrical conductivity of these composites and interpret the results using the thermal expansion coefficients of polystyrene and silver. These materials act as ``thermal switches,'' wherein electrical conductivity of certain composites can be manipulated by several orders of magnitude over the temperature range from 80K-425 K.

Polymer Composites with Oriented Magnetic Nanowires as Fillers

Li Sun, Kusuma Keshoju

Metallic nickel nanowires with excellent physical properties have been introduced into polydimethylsiloxane matrix to form polymer nanocomposites. Nanowires were synthesized by template-assisted electrochemical deposition. By utilizing ferromagnetic nickel nanowires, small external magnetic field can be used to control their alignment and distribution during composite synthesis. Unlike dielectrophoresis, optical tweezers, and microfluidic flow control, magnetic manipulation provides a cost-effective, non-contact, and versatile approach to control nanostructured materials in fluids over a large area. Polydimethylsiloxane composites with nanowires arranged in longitudinal, transverse, and random orientations with respect to the applied load direction were studied. Tensile tests showed that the composites with longitudinal arrangement have higher elastic modulus and tensile strength than the other composite samples. Experimentally obtained elastic modulus values were compared with the prediction of classical Halpin-Tsai model. Metallic nickel nanowires with excellent physical properties have been introduced into polydimethylsiloxane matrix to form polymer nanocomposites. Nanowires were synthesized by template-assisted electrochemical deposition. By utilizing ferromagnetic nickel nanowires, small external magnetic field can be used to control their alignment and distribution during composite synthesis. Unlike dielectrophoresis, optical tweezers, and microfluidic flow control, magnetic manipulation provides a cost-effective, non-contact, and versatile approach to control nanostructured materials in fluids over a large area. Polydimethylsiloxane composites with nanowires arranged in longitudinal, transverse, and random orientations with respect to the applied load direction were studied. Tensile tests showed that the composites with longitudinal arrangement have higher elastic modulus and tensile strength than the other composite samples. Experimentally obtained elastic modulus values were compared with the prediction of classical Halpin-Tsai model.

Paper #: 1058-JJ06-26

Applications

Applications

- Electrostatically dissipative polystyrene nanocomposites containing copper nanowires
- Metal nanowires-polymer nanocomposites as thermal interfasce material
- Metal nanowires and nanoparticles as polymer fillers for microelectronics applications

- Highly Conductive Nickel Nanowire-Filled P(VDF-TrFE) Copolymer Nanocomposites
- Copper Nanowire-Polymer Composites for Electrostatically Dissipative Nanocomposites
- Polymer Composites with Oriented Magnetic Nanowires as Fillers
- Novel Metal Nanowire/Polymer Nanocomposites for Electromagnetic Interference Shielding

Novel Metal Nanowire/Polymer Composites for EMI Shielding and Methods of Making Such Composites

G. Gelves, *University of Alberta, CA*

Keywords: nanowires, nanocomposite, polymer, electromagnetic interference, electrically conductive, metal nanofiller

Novel polymer matrix compounds comprising electrically conductive metal nanowires and non-conductive polymers with outstanding EMI shielding capabilities are presented.

Novel Metal Nanowire/Polymer Nanocomposites for Electromagnetic Interference Shielding

G.A. Gelves, M.H. Al-Saleh, U. Sundararaj
University of Alberta, CA

Keywords: nanocomposites, nanowires, EMI, ESD

Novel Polymer Nanocomposites containing high aspect ratio metal nanowires with outstanding potential for Electromagnetic Interference applications will be introduced in this presentation. The development and characterization of these novel materials will be presented. Processing-structure-property relationships will be discussed. Our most recent findings in the development of nanowire/polymer nanocomposite materials indicate that these novel nanocomposites can be an alternative to traditional filled composites for EMI applications.

Self-sensing and actuation of CNF and Ni nanowire/polymer composites using electro-micromechanical test

Park, Joung-Man; Kim, Sung-Ju; Kim, Pyung-Gee; Yoon, Dong-Jin; Hansen, George; DeVries, K. Lawrence

Reliability, Packaging, Testing, and Characterization of MEMS/MOEMS VI. Edited by Hartzell, Allyson L.; Ramesham, Rajeshuni. Proceedings of the SPIE, Volume 6463, pp. 64630B-64630B-11 (2007).

Self-sensing and actuation were investigated for CNF and Ni nanowire/epoxy and silicone composites. Electro-micromechanical techniques can be used for self sensing for loading, temperature. CNF/epoxy composites with smaller aspect ratio showed higher apparent modulus due to high volume content in case of shorter aspect ratio. Apparent modulus and electrical resistivity change were evaluated as functions of different carbon fiber types. Interfacial properties of CNF/epoxy with different aspect ratios were obtained indirectly. Using Ni nanowire/silicone composites with different content, load sensing response of electrical contact resistivity was investigated under tensile and compression condition. The mechanical properties of Ni nanowire with different type and content/epoxy composites were indirectly measured apparent modulus using uniformed cyclic loading and electro-pullout test. Ni nanowire /epoxy composites showed temperature sensing within limited ranges, 20 vol% reinforcement. CNF-PVDF and Ni-silicone actuator were made successfully. Electrochemical actuator of CNF-PVDF was responded in electrolyte solution. Magnetic actuator of Ni nanowire-silicone composites was monitored under electro-magnetic field. CNF-Ni nanowire-silicone actuator having meaningful merits can be expected to be new smart structural materials at a various applications. Nanocomposites using CNF and Ni nanowire can be applicable practically for multi-functional applications nondestructively.

Copper Nanowire-Polymer Composites for Electrostatically Dissipative Nanocomposites

Genaro A. Gelves1, Bin Lin2, Joel A. Haber1, and **U. Sundararaj**

(1) Chemistry, University of Alberta, Edmonton, AB T6G 2G2, (2) Chemical and Materials Engineering, University of Alberta, 536 Chemical and Materials Engineering Building, Edmonton, AB T6G 2G6, Canada

Polymer nanocomposites are an emerging class of materials that have properties that are often superior to conventional composites, and may be synthesized using surprisingly simple and inexpensive techniques. Layered inorganic clay is the most commonly used nanoscale filler, while carbon black, fullerene nanotubes (eg. MWNT) and metal nanoparticles are less studied but show great promise. High aspect-ratio conductive filler are mixed with polymer to produce a percolated, conducting network at much lower volume fractions than nearly spherical carbon black or metal nanoparticles, enabling the production of conductive or electrostatically dissipative composites without reduction in polymer processiblility or degradation of polymer properties. Herein, we report the gram-scale electrosynthesis of copper nanowires similar in size to MWNTs, modification of their surface chemistry, and preparation of polystyrene matrix nanocomposites displaying similar behavior to MWNT-containing nanocomposites by solution processing. Porous aluminum oxide (PAO) template was used with an adapted AC deposition technique to produce ~1 g quantities of copper nanowires. PAO templates were grown in sulfuric acid to produce pores 16 nm in diameter and ~20 or ~40 micron in depth. The pores were filled with Cu using a method similar to the ac deposition method of Moskovits, using 200 Hz, 10 Vrms sine-waves, a 0.50 M $CuSO_4$ solution and high purity Cu counter electrodes.

The percolation threshold for the “bare” nanowires in polystyrene is close to 2 vol %. Nanowires were also functionalized using alkyl-thiol. Interestingly, the $C_{18}H_{37}SH$-functionalized nanowires produced no conductive specimens, even up to 10 vol % loading, despite the better dispersion of the nanowires observed by SEM. These results serve to illustrate that achieving a percolated network at low volume fraction of conductive filler requires not only good dispersion of the nanoparticles into the polymer, but also good contact between the conductive particles. The relatively thick alkyl thiol coating improves dispersion, but also acts as an electrically insulating layer on each wire. Thus, reduced electrical conductivity results due to the insulating nature of the coating.

Further improvements in processing and control of the nanowire surface chemistry to tailor the nanowire-nanowire and nanowire-polymer interactions is required to improve the electrical properties of these composites.

http://aiche.confex.com/aiche/2005/techprogram/P24814.HTM

New Highly Conductive Nickel Nanowire-Filled P(VDF-TrFE) Copolymer Nanocomposites: Elaboration and Structural Study

Antoine Lonjon, Lydia Laffont, Philippe Demont, Eric Dantras and Colette Lacabanne

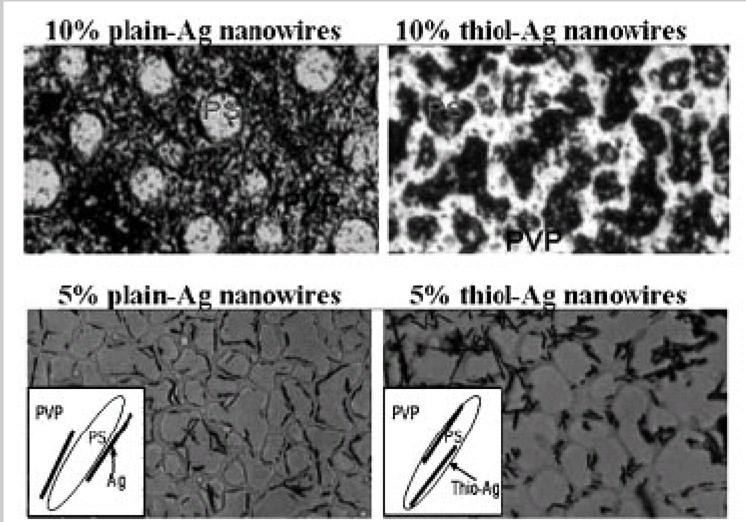
New highly electrical conductive nanocomposites were prepared by dispersing nickel nanowires into a poly(vinylidene difluoride)-trifluoroethylene P(VDF-TrFE) matrix. A suspension of individual nickel nanowires with a regular high aspect ratio (ξ ≈ 250) was elaborated. The nickel nanowires were fabricated by electrodeposition using templates in anodic aluminum oxide with a nominal pore diameter of 200 nm, allowing a close control of nanowire crystallinity. Polycrystalline or single crystal nickel nanowires were obtained. An oxide layer was observed on nanowire surfaces after their extraction from the template. Physical and chemical treatments were used to completely remove the oxide layer. Scanning and high resolution transmission electron microscopy studies were performed. The elemental composition and the nature of the nanowires surface were investigated by electron diffraction and energy dispersive spectroscopy. Nickel nanowires without oxide layers were elaborated. The electrical conductivity of nanocomposite films was performed as a function of treated nickel nanowire volume fraction. A very low percolation threshold of 0.75 vol % was determined. Percolated nanocomposites filled by treated nanowires displayed a highly electrical conductivity value. The conductivity value obtained above the percolation threshold is the highest value known up to now in the case of a conductive nanoparticle dispersion.

J. Phys. Chem. C, ***2009***, ***113*** (28), pp 12002–12006

Preferential Partition of Nanowires in Thin Films of Immiscible Polymer Blends

*Kuen-Hua Wu, Shih-Yuan Lu**

Summary: The preferential partition of silver nanowires in thin films of polystyrene/poly(vinyl pyrrolidone) (PS/PVP, with a 30/70 weight ratio) blends, that induces drastic blend morphology variation, is reported. The silver nanowires are fabricated with the anodic aluminum oxide templating method, and have a diameter of 300 nm and length of 10 µm. At a higher nanowire loading of 10 wt.-%, the silver nanowires are entangled and selectively concentrate within the continuous PVP domain. If surface modified by thiols carrying hydrophobic tails, the silver nanowires become hydrophobic and prefer to stay within the discrete hydrophobic PS domains. At a lower nanowire loading of 5 wt.-%, the nanowires are non-entangled and concentrate at regions near the interfaces of the PS and PVP phases, which induces the formation of interconnected PS domains.



Preferential partition of silver nanowires in thin films of PS/PVP (30/70) blends at a casting temperature of −10 °C.

Macromol. Rapid Commun. **2006**, *27*, 424–429

Electrical and rheological percolation of polymer nanocomposites prepared with functionalized copper nanowires

G A Gelves *et al* 2008 *Nanotechnology* **19** 215712 (12pp)

The morphological, electrical and rheological characterization of polystyrene nanocomposites containing copper nanowires (CuNWs) functionalized with 1-octanethiol is presented. Characterization by SEM and TEM shows that surface functionalization of the nanowires resulted in significant dispersion of CuNWs in the PS matrix. The electrical characterization of the nanocomposites indicates that functionalized CuNWs start to form electrically conductive networks at lower concentrations (0.25 vol% Cu) than using unfunctionalized CuNWs (0.5 vol% Cu). The organic coating on the nanowires prevents significant changes in the electrical resistivity in the vicinity of the percolation threshold. Percolated nanocomposites showed electrical resistivity in the range of 106–107 Ω cm. The transition from liquid-like to solid-like behavior (rheological percolation) of the nanocomposites was studied using dynamic rheology at 200 °C. Unfunctionalized CuNWs result in electrical and rheological percolation at similar concentrations. Functionalized CuNWs show rheological percolation at higher concentration (1.0–2.0 vol%) than that required for electrical percolation. This is attributed to the decrease in the interfacial tension between nanowires and polymer chains and its effect on the viscoelastic behavior of the combined polymer–nanowire networks.

Polymer Nanocomposites, Printable and Flexible Technology for Electronic Packaging

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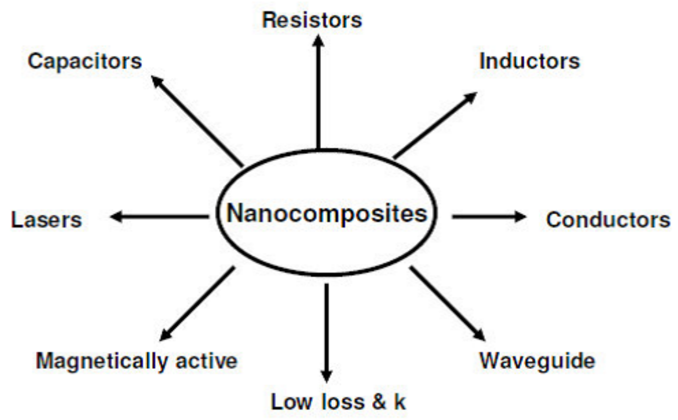
Overview of some of the potential applications of nanocomposites in microelectronics

Addition of different fillers into the polymer matrix controls the overall electrical properties of the composites. For example, addition of zinc oxide nanoparticles into the polymer shows laser-like behavior upon optical pumping, and addition of barium titanate ($BaTiO_3$) nanoparticles results in high capacitance



Silver nanowire array-polymer composite as thermal interface material

Xu, Ju[1]; Munari, Alessio[2]; Dalton, Eric[2]; Mathewson, Alan[1]; Razeeb, Kafil M.[1] **Source:** *Journal of Applied Physics*, v 106, n 12, **2009**
ISSN: 00218979 **CODEN:** JAPIAU
Publisher: American Institute of Physics

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Abstract: Silver nanowire arrays embedded inside polycarbonate templates are investigated as a viable thermal interface material for electronic cooling applications. The composite shows an average thermal diffusivity value of 1.89×10^{-5} m^2 s^{-1}, which resulted in an intrinsic thermal conductivity of 30.3 W m^{-1} K^{-1}. The nanowires' protrusion from the film surface enables it to conform to the surface roughness to make a better thermal contact. This resulted in a 61% reduction in thermal impedance when compared with blank polymer. An ~30 nm Au film on the top of the composite was found to act as a heat spreader, reducing the thermal impedance further by 35%. A contact impedance model was employed to compare the contact impedance of aligned silver nanowire-polymer composites with that of aligned carbon nanotubes, which showed that the Young's modulus of the composite is the defining factor in the overall thermal impedance of these composites. © 2009 American Institute of Physics. (28 refs.)

Metal Nanowire-Polymer Nanocomposite as Thermal Interface Material

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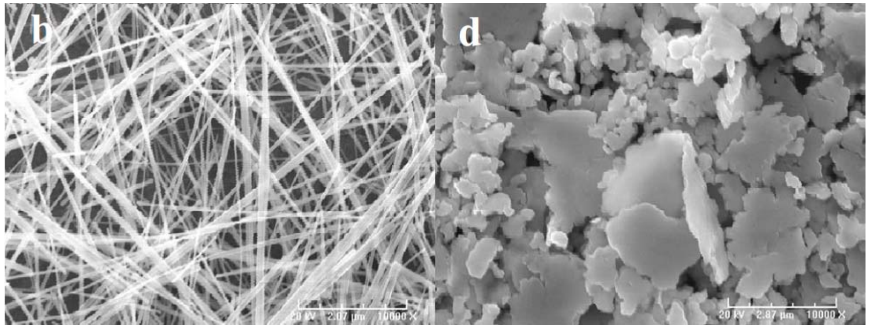
Abstract

Thermal properties of silver nanowire-silicone (AgNW-silicone) composites at different weight percentage of AgNW in the polymer were studied. The thermal conductivity of these composites was measured using the heat stack method according to D5470 standard. The silver nanowires were synthesized using a polyol process. The nanocomposites were prepared by solution mix processing. The effective thermal conductivity of the AgNW-silicone nanocomposite increased with the enhancement of AgNW concentration and the thermal conductivity were found higher than that of traditional silicone composites using micron sized silver flakes as fillers with the same concentration.



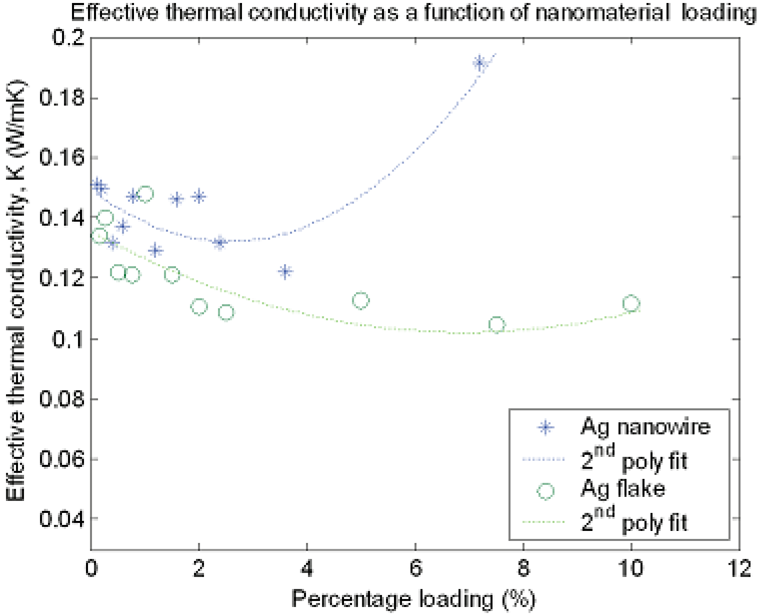


Fig. 9: Effective thermal conductivity of AgNW-silicone and Ag flake-silicone composites as a function of percentage loading of fillers at the maximum pressure of 0.6 MPa.

Electrostatically Dissipative Polystyrene Nanocomposites containing Copper Nanowires

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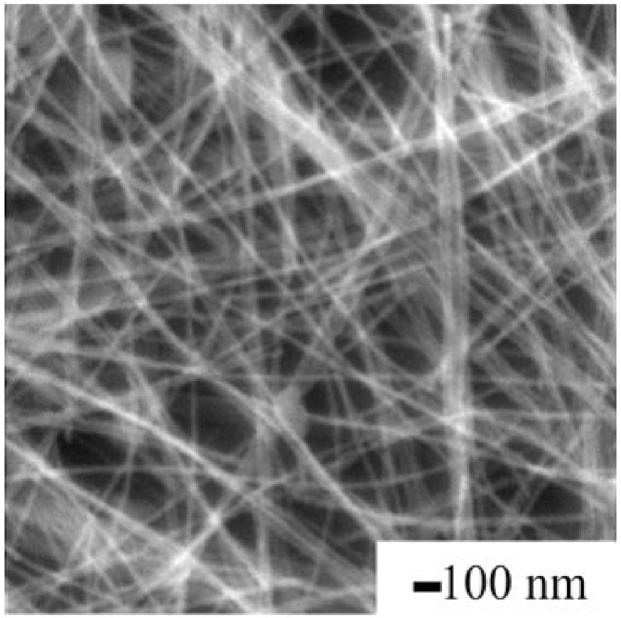
Received: July 11, 2005; Accepted: August 29, 2005; DOI: 10.1002/marc.200500490

Keywords: copper nanowires; nanocomposites; polystyrene; porous aluminium oxide; template-directed synthesis

Summary: A scalable synthesis of copper nanowires by alternating current electrodeposition into porous aluminium oxide was used to produce multigram quantities of 16 nm diameter by >2 μm long nanowires. Polystyrene nanocomposites were prepared by solution processing. The composites containing unpassivated nanowires were non-uniformly dispersed and showed electrical percolation at ≈2 vol.-% Cu loading, while the composites containing $HSC_{18}H_{37}$-passivated nanowires were uniformly dispersed, but remained resistive up to at least 10 vol.-% Cu loading.



Copper nanowires prepared by alternating current electrodeposition into porous aluminium oxide templates.