Transparent and Stretchable Metal Electrodes

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Abstract:

Thin layers of lamellar-forming polystyrene-*block*-poly (methyl-methacrylate) (PS-*b*-PMMA) provide the templates for fabricating nanowires with a "fingerprint" morphology. The electrical characteristics of the nanowires were measured, and largely deviated from simulated devices due to high defect density. Their highly curved conformation makes the nanowires strong candidates for electrical testing on flexible substrates under compression and elongation. The wires' high transmittance on glass substrates reveals that they can function as transparent metal electrodes for use in electronic devices.

Introduction:

Diblock copolymers are macromolecules composed of two chemically distinct blocks, each a linear repetition of a particular monomer, that self-assemble to create periodic microdomains, each of which exclusively contains one of the polymers that make up the copolymer [1]. Varying volume fractions of the blocks generates different morphologies. When the volume fractions of the two blocks are similar, block copolymers self-assemble into the lamellar morphology [1], where the block with the higher volume fraction shows greater connectivity [2].

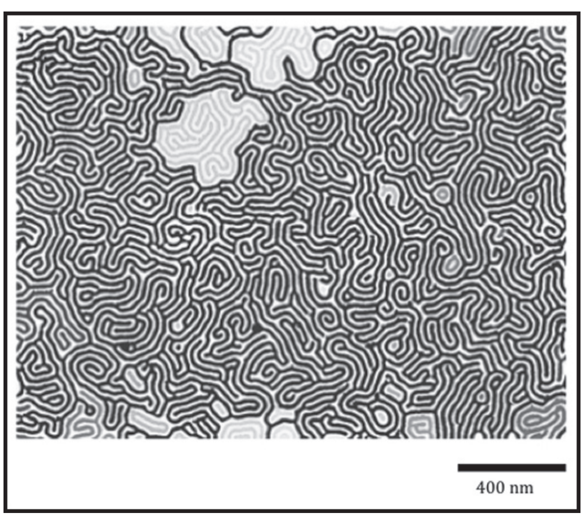

Figure 1: Color-coding for each PMMA backbone under a volume fraction f_{PMMA} of 0.55. (See cover for full color version.)

Figure 1 illustrates different continuous networks, each a different color, of PMMA, when the volume fraction of PMMA, f_{PMMA}, is 0.55 (see the cover of this publication for the full color rendition of this image). A single dominant network exists (blue) among small isolated networks. The high-connectivity, which offers redundant pathways from one point in the network to another, and the tortuous network conformation make block copolymers attractive for the fabrication of nanowires (NWs) [2-4]. Removing one block while preserving and using the other for patterning by thin-layer metal deposition allow for the formation of NWs. On transparent and stretchable substrates, these NWs should possess useful electrical properties, have high transmittance [5], and continue to perform well under mechanical strain.

Experimental Procedure:

Neutral brush solution was spin-coated and annealed onto cleaned glass slides or silicon wafers, allowing the block copolymer to orient perpendicular to the substrate [3]. Block copolymer blends were spun onto the neutral substrates and annealed to produce self-assembled thin films. The samples were exposed to ultraviolet light to break down the PMMA and developed using acetic acid, creating a polystyrene template. After five seconds of oxygen plasma to remove the brush, 1 nm of chromium (Cr) and 5 nm of gold (Au) were evaporated into the vacancies left by PMMA. Sonication in toluene removed the polystyrene, leaving the NWs on the substrate.

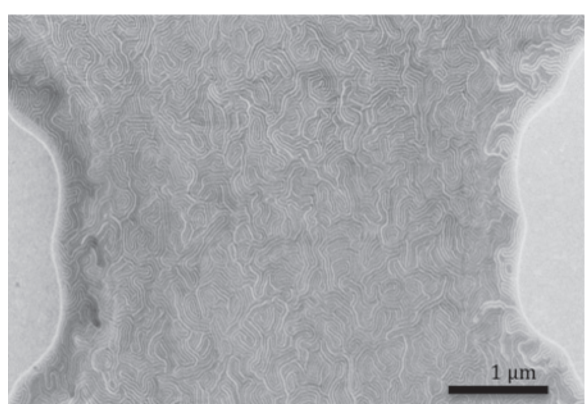

Figure 2: Nanowire network between micro-extensions from contact pads. Ideally, current must pass through these NWs.

Negative photoresist NR71 was spin-coated onto the nanowire samples for 40 seconds at 4000 RPM and exposed for 55 seconds using a mask-aligner and prepared mask containing contact pads with varying microwire features. The exposed samples were heated before development in RD6 for eight seconds, creating the pattern for the contact pads. After plasma treatment of 30 seconds, 10 nm of Cr followed by 100 nm of Au were evaporated, creating contact pads upon removing the remaining photoresist by sonication in acetone. Figure 2 illustrates the result of applying contact pads onto the nanowire samples, with a small gap between the microwire connectors to force current to pass through the NWs.

Current was measured using two probes from the probe station pressed onto the contact pads with potentials ranging from -10 millivolts to 10 millivolts applied across the samples.

Extinction coefficients for the NWs across the visible spectrum were measured on glass substrates using an Ocean Optics spectrometer and used to calculate transmittance.

Results and Discussion:

Figure 3 demonstrates the electrical characteristics of the NWs with $f_{PMMA} = 0.55$. A linear relationship between current and voltage exists for systems with continuous nanowire pathways between contacts, indicating a constant resistance. Increasing contact width increases sheet resistance because out-of-plane transport constitutes a larger fraction of the current for thin contacts. Simulations predicted that increased contact width would cause decreased sheet resistance, but defects in the fabricated NWs led to comparatively large resistances.

Figure 4 is a graph of the transmittance of two NW samples with $f_{PMMA} = 0.55$. The similar spectra indicate consistency in the transparency of these devices. Approximately 90-95% of light across the visible spectrum passes through the glass samples, demonstrating high transparency in these thin films.

Block copolymers are a useful template for fabricating NWs. The electrical characteristics of these NWs show potential for electronic devices while the transmittance through these samples displays the possibility for these NWs to become incorporated into devices requiring high transparency. These block-copolymer templated NWs are competitive with state-of-the-art materials in many solid-state devices. The high curvature of these NWs predicts that they will continue to function under strain and compression.

Future Work:

Improvements include producing defect-free samples for consistent device performance. A transfer process must be developed to test device performance under compression and strain. If the nanowires perform well under strain and compression, they can be incorporated into flexible solid-state devices.

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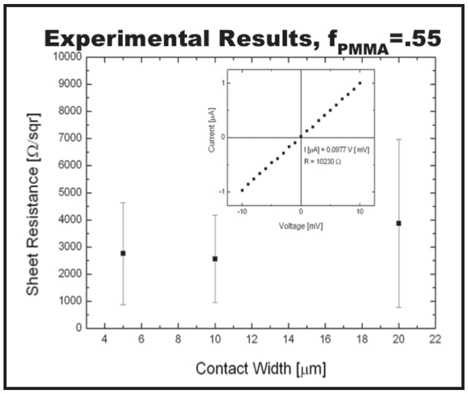

Figure 3: Sheet resistance and sample current-voltage curve with a nanowire network for f_{PMMA} = 0.55.

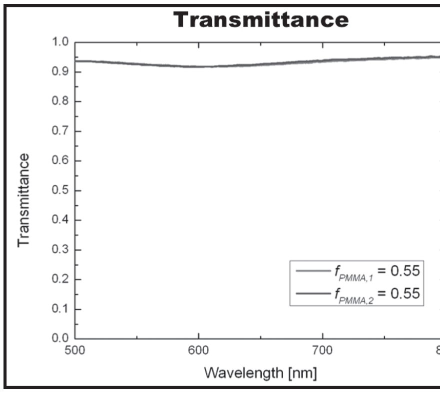

Figure 4: Transmittance across visible spectrum through two NW samples with f_{PMMA} = 0.55.