Investigation into fabrication and characterization of vertically aligned hexagonally patterned carbon nanopillars and their applications

Abstract

The precise control over surface morphology and material composition at the nanoscale enables novel functionalities that are unattainable in conventional materials. Large area nanopillar fabrication on a polystyrene surface has been explored as a self-cleaning functional surface. Nanopillars are first fabricated with a reusable AAO mould with an ordered pore size of 75 nm. Hexagonally ordered domain nanopores were made with different anodization parameters, further improved by pore widening. A single-step approach of hot embossing is used to make different aspect ratio nanopillars of polystyrene. Hot embossing process parameters, such as embossing pressure, temperature, and holding time, are optimized for contact angle as a response parameter. The moth-eye type textured nanopillars have the maximum water contact angle. The water contact angle obtained increased from 63.1˚ to 153˚for for moth-eye type nanopillars. Moreover, vertically aligned and hexagonally patterned carbon nanopillars (CNPs) were fabricated by the growth of carbon atoms through anodized aluminium oxide, followed by mechanical polishing and chemical etching. This nano-template was investigated to understand the effects of varying the carbon deposition time for 0.5 h and 4 h at flow rates of 20 sccm and 100 sccm. Hot embossing process parameters, such as embossing pressure and temperature, are optimized to fabricate nanoholes on a large area of a polystyrene sheet. The best results for replicated nanoholes were achieved at an embossing pressure of 3 MPa and slightly above the glass transition temperature. Additionally, the tunable antireflective behavior of nanoholes across varying operational wavelengths has been analyzed using the Finite-Difference Time-Domain (FDTD) simulation technique. Experimental findings reveal that hot embossed nanohole architectures can achieve minimum reflectance values of 5%, within the 400–700 nm wavelength range. A non-conventional alternative to nano-

indentation was demonstrated for carbon nanopillars supported in AAO pores by utilizing an atomic force microscopy tip as a nano indenter by applying a load in the nanometer range. The CNPs pillars' Young's modulus was calculated to be 15 GPa by using the Hertz equation in the elastic regime. In addition, large area, vertically aligned one-dimensional (1D), hexagonally patterned materials have been found to efficiently explore the surface enhanced Raman spectroscopy (SERS). Here, we have a facile substrate for SERS performance as vertically grown carbon nanopillars inside the porous hexagonally patterned anodic aluminium oxide was developed. This facile SERS substrate was prepared by depositing Au to form SERS-active hot spots. This CNP-Au hybrid substrate for 30 nm Au deposition shows the uniform sub-10 nm gap between subsequent nanopillars. Rhodamine (R6G) dye was investigated for its very low concentration up to 10^{-9} M due to its genotoxic and carcinogenic effects on human life. The electric field enhancement was validated with a 3D FDTD Lumerical simulation for CNP-Au-30 nm substrate for a 10 nm gap. Additionally, a new approach has been developed in this study to engineer efficient electrodes for high-performance supercapacitors based on zinc oxide (ZnO) nanosheets (NSs) grown on carbon nanopillars synthesized within an anodic aluminium oxide template. A three-electrode system incorporating a KOH/PVA gel electrolyte was employed to assess the electrochemical properties. The CV curves of the AAO/CNP electrode showed a near-rectangular form, indicative of ideal electric double-layer capacitor performance with a maximum current density of 370 μA/cm², showing fast ion diffusion and efficient charge storage. In contrast, the AAO/CNP@ZnO electrode revealed a nearly symmetric triangular profile with a specific capacitance of 3.1 mF/cm² at a current density of 0.5 mA/cm² in galvanostatic charge–discharge tests These finding indicates that the AAO/CNP@ZnO hybrid electrode is a viable solution for high-performance next-generation supercapacitor applications.