Austin Journal of Nanomedicine & Nanotechnology

Austin Publishing Group

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Full Text Article

Editorial

“Nanostructured Systems for Wetting, Bio-analytics and Directed Neuronal Growth Studies”

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Received: June 24, 2014; Accepted: June 26, 2014;
Published: June 27, 2014

Introduction

Articular cartilage lesions are quite common and constitute a significant financial issue. For e With advances in technologies in the last decade, there is a phenomenal growth in research interest in nanoscience and nanotechnology. Recently, a concerted effort has been made to merge the well-established microtechnology with nanotechnology or nanostructured material sciences (e.g., “Nanoarchitectonics”) in meso-porous materials, assembly methods, growth or manipulation of nanotubes or nanoparticles. We have devoted substantial research effort in this direction in the last ten years by employing the “top-down” and “bottom-up” strategies that involved optical and interference lithography (IL), metal-assisted chemical etching (MACE) and plasma etching, to create regular and irregular silicon- or polymer-based nanostructures for our research work. We engaged the MACE technique with IL to create regular nanostructures for the fluidic study on nanoscale surfaces; combining the glancing angle deposition (GLAD) technique with MACE to create nanowires for bio-analytic study, and using IL and plasma etching to provide polymer nanostructures for neurite directed growth study.

Wetting on Nanostructured Surfaces

Wetting is a pervasive phenomenon that governs many natural and artificial processes. Asymmetric wetting along a single axis, in particular, has generated considerable interest but has thus far been achieved only by the creation of structural anisotropy [1-3]. We have obtained directional wetting by anisotropically coating polymer based nanostructure surfaces (obtained from IL and plasma etching) with materials that modify the nanostructure surface energy [4]. Moreover, by combining the chemical influence on wetting with topographic features, we are able to restrict wetting in one, two and three directions. We proposed a model that explained these findings in terms of anisotropy of the pinning forces at the triple phase contact line.

We also investigated the wetting and spreading phenomena on nanopillars and nanofins produced by the IL-MACE technique. We carried out a theoretical study on the dynamics of wicking on silicon nanopillars based on a balance between the driving capillary forces and viscous dissipation forces and predicted that the invasion of the liquid front follows a diffusion process and strongly depended on the structural geometry [5]. The dynamics of imbibition into the roughness of a surface was then investigated with hexagonal arrays of nanofins [6]. We found that the viscous drag caused by the nanofins was similar to that caused by open nano-channels of equal length and height containing the same volume of liquid. The energy dissipated by form drag for a given driving pressure was determined to be directly proportional to the volume of fluid between nanofin planes that were flat and normal to the imbibition direction. The dynamics of droplet spreading on 2-D wicking surfaces were studied using square arrays of Si nanopillars and nanofins [7]. We observed that the wicking film always preceded the droplet edge during the spreading process causing the droplet to effectively spread on a Cassie-Baxter surface composed of solid and liquid phases. Unlike the continual spreading of the wicking film, the droplet would eventually reach a shape where further spreading becomes energetically unfavorable. We put forward a quantitative model for the displacement-time relationship and predicted the contact angle at which the droplet would stop spreading. The influences of structural and chemical anisotropy on 2-D spreading has also been investigated and modelled.

Creation of Surfaces of Different Wetting Properties

We used the GLAD-MACE method to fabricate large-area, highly scalable, “hybrid” superhydrophobic surfaces on Si substrates with tunable, spatially selective adhesion behavior by controlling the morphologies of Si nanowire arrays [8]. During MACE, Au nanoparticles with different size distributions resulted in Si nanowires with clumped and straight nanowire surfaces. The clumped nanowire surface demonstrated the lotus effect, and the straighter nanowires demonstrated the ability to pin water droplets while maintaining large contact angles (i.e., the petal effect). We demonstrated the spatial patterning of both low- and high-adhesion superhydrophobicity on the same substrate by the simultaneous synthesis of clumped and straight Si nanowires.

We also created large-area hybrid superhydrophobic surfaces with selective adhesion properties on Si substrates by exploiting liquid-medium-dependent capillary-force-induced nanocohesion of nanowires [9]. The GLAD-MACE nanowires were etched and dried in either deionized water, 2-propanol or methanol to vary the capillary forces exerted on the Si nanowires during the drying process to tune the extent of clustering of nanowires and hence the adhesion properties of the resulting superhydrophobic surfaces. Drying in deionized water resulted in small clusters of nanowires which produce a low-hysteresis superhydrophobic surface that mimicked a lotus leaf. Drying in methanol resulted in large nanowire clusters that lead to a high-hysteresis superhydrophobic surface. Further, we demonstrated the ability to fabricate both small and large nanowire clusters by controlling the drying of the nanowire arrays in order to selectively define and modulate adhesion of water on the same

Citation: Kiong CW. “Nanostructured Systems for Wetting, Bio-analytics and Directed Neuronal Growth Studies”. Austin J Nanomed Nanotechnol. 2014;2(4): 1026.

superhydrophobic substrate.

Nanowire based Bio-analytics

We demonstrated the fabrication of a novel platform based on GLAD-MACE Si nanowire arrays integrated with a programmable DNA-directed homogeneous-phase analyte-capture strategy for robust detection of bio-analytes [10]. Our GLAD-MACE process was capable of producing thousands of testing sites per chip, and the sites could be fabricated over entire wafers, with precise control of size and positioning, using conventional microelectronics technology. The analyte-capture strategy used eliminated the well-known interference of the heterogeneous-phase (substrate) with the capturing of analytes. With the unique feature of the substrates (nanowire porosity), we showed that the fabricated microarrays were robust, had high efficiency and capacity, and provided significantly enhanced signal-to-noise ratio in the detection of bio-analytes. The role of porosity of the nanowires had been examined in detailed by the thermoporometry technique [11].

Nanogrooves for Study in Neurite Directed Growth

Emerging evidence of the striking differences that can be induced in the behavior of biological cells through topographical modulation of physically and chemically patterned nanostructured surfaces provides a great impetus for developing novel cellular-scale and sub-cellular-scale nanopatterned substrates and for employing them for exciting new applications in life and medical sciences and biotechnology. However, the lack of availability of cost-effective, large-surface-area nanofabricated substrates of appropriate dimensions and features has proved to be a major impediment for research in this area. We demonstrated a simple and cost-effective method based on IL-plasma etching method to produce spatially precise and wide-surface-coverage polymer-based nanostructures to study how cells react to nanoscale structures or surfaces [12]. We investigated the involvement of micro RNAs (miRNAs) in topological guidance of neurite outgrowth in a NGF treated PC12 cell model cultured on nano-patterned polyethylene terephthalate (PET) substrates. The expressions of 38 neuronal miRNAs were measured and 3 were found to be differentially regulated during topological guidance of neurite outgrowth. Altering the intracellular levels of these miRNAs disrupted the orderly growth of neurite along nano-patterned substrate. These experiment findings strongly suggested that miRNAs played a crucial role during nano-topological guidance of neurite outgrowth in PC12 cells.

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Austin J Nanomed Nanotechnol - Volume 2 Issue 4 - 2014
ISSN : 2381-8956 | www.austinpublishinggroup.com

Citation: Kiong CW. “Nanostructured Systems for Wetting, Bio-analytics and Directed Neuronal Growth Studies”. Austin J Nanomed Nanotechnol. 2014;2(4): 1026.