Self-Reporting Porous Silicon Arrays as a Playground for Microorganisms

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The attachment of microorganisms, bacteria and fungi, to abiotic surfaces is of great interest to both the scientific and medical communities and numerous new methods and materials for quantitatively examining bacterial attachment and colony formation on surfaces have recently emerged. Intriguingly, most works have explored micro-/nano-structured substrates as potential antimicrobial surfaces, with an emphasis on antibiofilm properties; whereas, fewer have studied such patterned surfaces as artificial microbial arenas for observing and elucidating the behavior of bacterial communities. Using engineered porous silicon substrates with carefully designed nano/micro topographies, exhibiting photonic properties, we introduce an optical platform that enables real-time and label-free monitoring of bacterial surface adhesion and colonization. Thus, the porous substrates serve as both a preferable solid-liquid interface for microorganisms networking and a simultaneous transducing element that monitors their response. Such platforms do not require sophisticated microscopy tools or any labels as most of the currently used methods, and it can be conveniently modified with different topographies and surface chemistries, presenting endless study opportunities in a single tool. We demonstrate the application of these platforms to study how different bacterial species, ranging from standard laboratory strains to genetically engineered mutants and clinical isolates, preferentially colonize surfaces with varying topography, wettability and charge and monitor over the formation of a biofilm [1], see Fig. 1. Moreover, we employ these manipulated porous surfaces for solving some critical bottlenecks in clinical microbiology. For example, we have developed a chip-based culture-free method for rapid screening of resistant/susceptible bacteria directly from a clinical sample within only 90 minutes, where current clinical state-of-the-art methods require at least 24 hours.

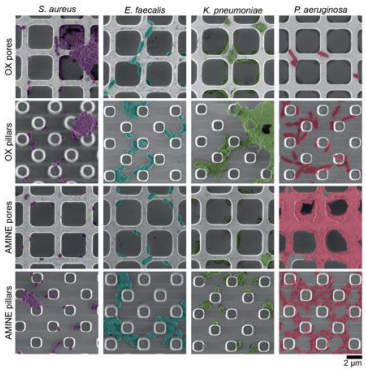

Fig. 1: Investigation of pathogenic, clinically relevant bacterial strains (S. aureus, E. faecalis, K. pneumoniae, and P. aeruginosa) on oxidized (OX) and amine-terminated silicon pore and pillar microtopologies. Bacteria are false coloured for clarity.

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Novel Device Concepts using Nano-Florets Metal-SC Hybrid Nanosystems

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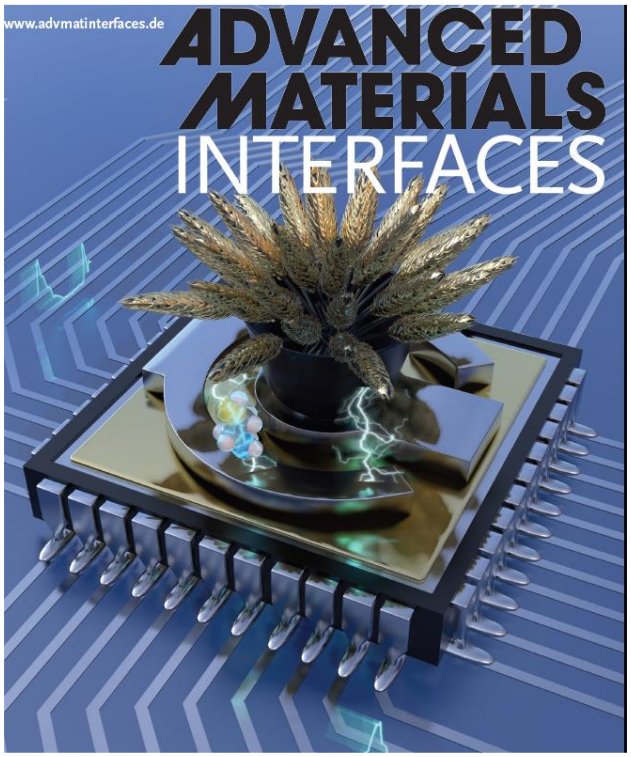
Nano-florets (NFs) are versatile hybrid nanoscale building blocks derived from SiGe nanowires by tip-specific metal deposition. The unique structural motifs of NFs include a well-defined metallic tip functioning both as a nano-scale electrode and as a broad-band plasmonic antenna directly coupled to a high aspect ratio, crystalline semiconducting NW. NFs offer a highly versatile platform for device applications. Such devices utilize the electrical, optical, and mechanical characteristics of the NF hybrid nanostructures.[1]

NF-based emerging device concepts:

(I) Electronic tunneling spectroscopy devices for molecular detection by direct measurement of tunneling currents through molecules under ambient conditions and in liquids. Molecular fingerprint tunneling data is obtained by employing a robust, scalable, portable and water-compatible device.[2]

(II) Electro-optical detectors covering the short-wave infrared (SWIR) demonstrated by utilizing the plasmonic absorption of the SiGe-coupled metallic tip extending to the NIR. Plasmonic gain of three orders of magnitude is demonstrated with improved temporal response.[3]

(III) Molecular level circular dichroism (CD) electro-optical detectors. A nanoscale chirality sensor, for continuously monitoring molecular chirality using an electric circuit readout.[4]



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WS_2 & MoS_2 from 3D to 1D structures: Curvature and chirality induced properties of nanotubes

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Inorganic nanotubes (INTs) of WS_2, a member of the 2D transition metal dichalcogenide (TMD) family, demonstrate unique properties due to their nanosize, closed-cage arrangement of the layers into chiral tubes and mechanical strength. Wide investigation of this nanomaterial, became possible due to the breakthrough in their vapor-gas-solid (VGS) synthesis, resulting in pure phase and macroscopic amounts. Recent theoretical calculations demonstrated that mechanical properties of MoS_2 are superior to that of WS_2, as well as their excitonic emission. An advance in extremely complicated synthesis of INT-MoS_2 by VGS of Mo oxides with H_2/H_2S gases will be reported here. The availability of MoS_2 semiconductive 1D nanocrystals will enable their wide investigation as well.

Bulk photovoltaic effect (BPVE) was recently discovered in INT-WS_2. The photocurrent in the nanotube-based device was orders of magnitude larger than in other BPVE materials. The BPVE does not require p–n junctions of traditional photovoltaic effect (PVE) for generation of electric current, and occurs due to the intrinsic properties of INT-WS_2: small band gap (1.4-2.1 eV), broken inversion symmetry and polar structure. This progress is particularly important for environmentally benign energy harvesting because the efficiency of traditional PVE has been almost reached the theoretical limit. An exponential increase of the resistivity with tensile strain was demonstrated up to a recorded elongation of 12 %, thereby making INT-WS_2 suitable for piezoresistive sensor applications. Low temperature cathodoluminescence of single-wall few nm diameter WS_2 nanotubes, produced by high-power plasma irradiation of multiwall WS_2 INTs, demonstrates blue shift, evidencing quantum confinement and strain effect. Bandgap engineering via size and number of layers control in these INTs will be discussed. An artificial vision system based on the memory effect produced by sliding ferroelectricity in multiwalled tungsten disulfide nanotubes will be presented.

Infrared Irradiated Reversible Shape Memory Polymers - Mechanisms and Applications

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Abstract

Remote propulsion of miniaturized mechanical devices forms a great challenge for the scientific community. Here we present a light-weight two-way shape memory polymer (2WSMP)-based motor and demonstrate the propulsion of a miniature vehicle via a unique IR irradiated 2WSMP actuator.

Most of the polymers that possess 2WSMP properties suffer from low mechanical properties and low durability to harsh environments. In this work we unveil a 2WSMP bilayer actuator based on Kapton and polyPOSS (PP) that as a bilayer possess superior 2WSMP and mechanical properties, high lifting abilities, and durability to harsh environments. Kapton is well known for its outstanding physical properties. PP, a polyhedral oligomeric silsesquioxane (POSS)-based epoxy-like thermoset, was developed uniquely for this project. Its ability to maintain mechanical properties over a range of temperatures while presenting a constant coefficient of thermal expansion is essential for its 2WSMP actuation properties.

A detailed study is given regarding the effect of the layers' thickness on the force and deflection generated by the 2WSMP actuators during heating. A theoretical model is used to predict the actuator's deflection, based on the layers' thickness. These unique actuators present outstanding force/weight ratio of 6500 and a lifting capacity 400 times of their own mass.

Messy or Ordered? Multi-scale Mechanics Dictates Shape-Morphing of Hierarchical 2D Fiber-Networks

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Shape-morphing networks of mesoscale filaments are a common hierarchical feature in biology. Constructing a synthetic equivalent is highly challenging, because of the need to control the composition and arrangement with microscale precision yet hold significant potential for a range of technological applications, from soft actuators to shape-morphing optical devices.

Here, I present the fabrication of highly ordered 2D Cartesian network constructed of thermoresponsive mesoscale polymeric fibers and the characterization of its unique shape-morphing behavior. The morphing behavior strongly depends on the physical attributes of the single fiber - its diameter, as well as on the network's density. I will show that based on these parameters, such fiber-networks exhibit one of two thermally driven morphing behaviors: (i) the fibers buckle and the network become messy and highly disordered or (ii) the fibers stay straight, and the network preserves its ordered morphology, exhibiting a bulk-like behavior (**Fig. 1**). Notably, in both cases, the networks display memory and regain their original ordered morphology upon shrinking. The networks morphing behavior and its dependence on the fiber diameter is well-described by an empirical network of springs model.[1] Moreover, I demonstrate the programing of directional morphing of 2D networks using thermotropies fibers along one axis, and non-responsive fibers along the other axis.

This hierarchical principle that demonstrates here offers a new approach for controlling the shape-morphing of materials with mesoscale resolutions and elucidates that minute changes in the mesoscale structural attributes can translate to a dramatic change in the morphing behaviors at the macroscale.

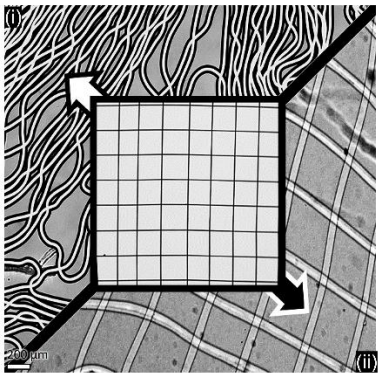

Figure 1: Each network can exhibit one of two behaviors upon swelling in aqueous environment (i) buckling-govern behavior and the network becomes messy, or (ii) shape-preserving behavior (a bulk-like behavior) where the fibers stay straight and the network swells isotopically. Upon heating the water, the network goes back to its original ordered morphology in both cases.

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Novel Bioelectronic Interface based on Mucin-Modified Electrodes

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Mucus is mainly composed of mucin proteins and it plays a key role in the oxidative homeostasis of the gut. Mucin's thiol groups behave as sulfur switches that are controlled by reactive oxygen species and antioxidants, creating a tunable physical barrier between the host and the microbiome [1]. While mucin exhibits redox behavior, its bioelectronic properties have not been studied. Here, we electrochemically investigated the intestinal mucin-2 redox behavior. For this purpose, we electrodeposited mucin encapsulated in a calcium alginate hydrogel (Figs. 1A-C) onto a fabricated gold disk electrode (Ø=2mm). We characterized the electrochemical charge recorded (cyclic voltammetry; 0.1V/s; 10 cycles) from either the alginate- or the alginate-mucin- modified electrodes in the presence of the electro-active species hexachloroiridate (200µM; E_0 = 0.6V vs. Ag/AgCl) and chemical reducing molecule Tris(2-carboxyethyl)phosphine hydrochloride **(**TCEP) (Fig. 1D). We divided the charge transferred during the electrochemical reaction to anodic (positive) and cathodic (negative) charges, focusing on the mediator oxidation charge measured by the electrode with/without mucin in the coating. We observed that a more concentrated mucin coatings (0.05mg/ml: 0.767±0.231µC for the first cycle, 0.639±0.167µC for the last cycle, 0.1mg/ml: 0.781±0.128µC for the first cycle, 0.615±0.090µC for the last cycle) resulted in significantly higher oxidation charge than the alginate and the alginate-mucin 0.01mg/ml coatings (alginate: 0.395±0.083µC for the first cycle, 0.334±0.015µC for the last cycle, 0.01mg/ml: 0.289±0.013µC for the first cycle, 0.351±0.007µC for the last cycle) (Fig 1E). Furthermore, we observed a decrease in the anodic charge as the cycle progresses – caused by decreasing concentrations of reduced sulfur switches that reduced the redox mediators. For opening the sulfur switches, we used TCEP to reduce the mucin sulfur residues. Following TCEP treatment (1min-long dipping) we observed that the oxidative charge returned to its original value, measured in the first cycle (Fig. 1F). The obtained results present an electrochemical control of mucin spatial structure, suggesting a new bio-functional material that will be able to recognize oxidative or reductive environment.

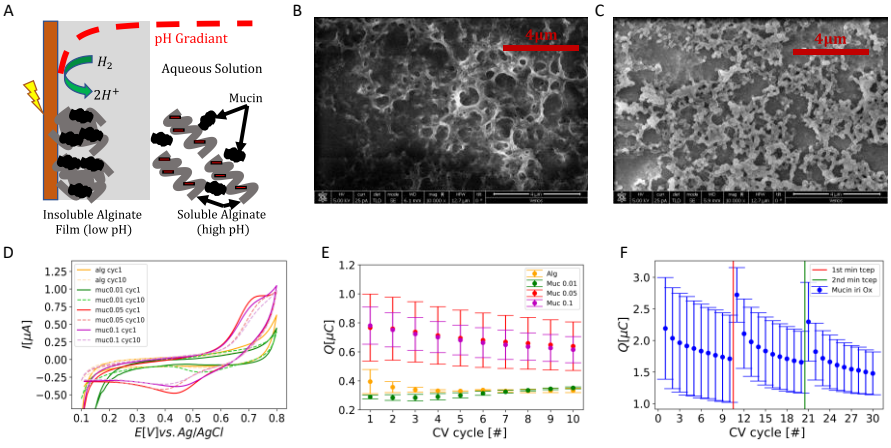

Fig. 1: (A) The mechanism of pH gradient near the electrode leading to calcium alginate polymerization and mucin encapsulation. SEM images of (B alginate and (C) alginate-mucin coatings. (D) Cyclic voltammogram cycle 1 and 10 of iridate with alginate-mucin coated electrodes in different concentrations 10 (E) Anodic charge collected by the electrode for every coating (F) Anodic charge of iridate in 0.05mg/ml mucin coating.

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