Direct Patterning of Copper and Silver Nanostructures Using a Solid State Electrochemical Imprint Process

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This paper describes a novel all-solid, electrochemical nanoimprint technique. This single-step, large-area, manufacturing approach is capable of producing silver and copper nanostructures with dimensions smaller than 40 nm for applications in electronic interconnects, chemical sensors, and plasmonic structures.

The approach directly produces nanopatterns of metals such as copper and silver by solid-state electrochemical etching. This involves bringing a nano-patterned stamp of a suitable solid ionic conductor, for example Cu_2S, into contact with the metallic substrate to be patterned (for example, a copper film). Held together with a light pressure, the application of an external electrical bias, drives an electrochemical reaction that results in the anodic dissolution of metallic film at the contact area, transferring the pattern from the stamp to the substrate.

With minimal process optimization, relatively standard laboratory equipment, and working at ambient conditions, we have achieved high patterning resolutions (line-widths of less than 50 nm), process speeds of 4nm/sec in terms of stamp penetration into the substrate and little degradation of the stamps over multiple (several 10's) stamping runs. Figure 1 shows a small collection of patterning results in, both, copper and silver films.

In summary, this solid state electrochemical nanoimprint process that we call, solid-state superionic stamping or S4[1], demonstrates the potential to achieve single-step transfer of nanoscale features directly to metals. Stamps can be economically produced using embossing against a silicon master. Integrated with positioning, registration and sensing systems, this imprint technique offers new pathways to an economical, high throughput, large-area process. Recent results, for example Figure 1(c), demonstrate a surprising capability of substitutive patterning, i.e., using a silver sulfide stamp to pattern copper films. This potentially allows S4 to address other material for which a solid ionic conductor is not readily available, or whose mechanical or chemical characteristics are undesirable.

[1] K. Hsu, P. Schultz, N. Fang, P. M. Ferreira, Electrochemical Nanoimprinting with Solid-State Super-Ionic Stamps, *Nano Letters* in press, 2006.

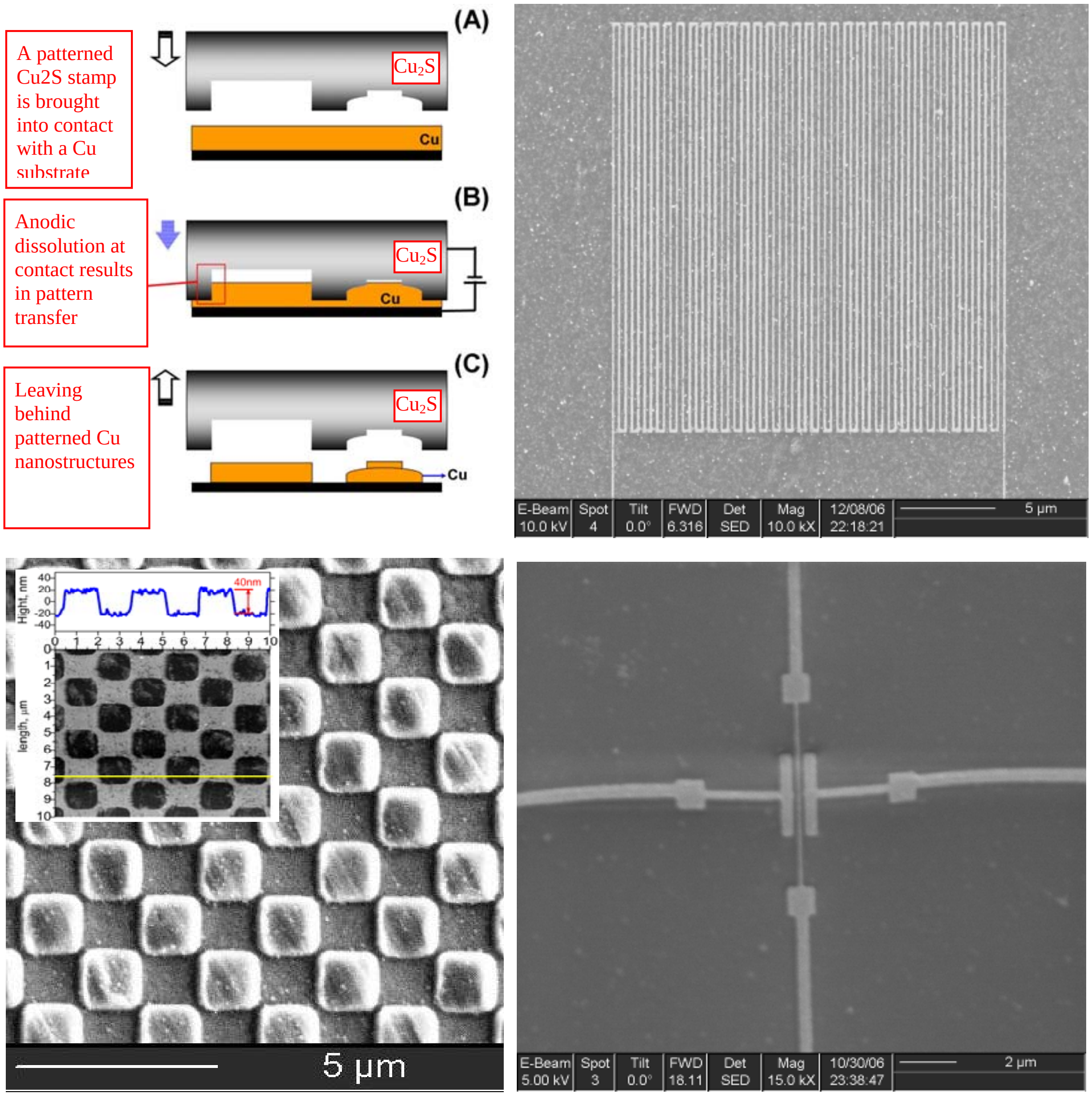

Figure 1: (a) Schematic of the electrochemical imprinting process. (b) A meandering copper nanowire 70nm wide 40 nm thick and 1.35 millimeter long made by the process. (c) An electron micrograph of an Ag_2S stamp for the process, made by embossing on to a calibration grid. The insert shows the results of substitutive patterning of a 40 nm copper film on a silicon substrate with the stamp. (d) A silver nanowire sensor with a 40 nm critical dimension.