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CMOS-Compatible Carbonization of 3D-Printed Nanoelectrodes via Global Annealing and Localized Joule Heating for Cell-on-CMOS Biosensing

This work details the development of a cell-on-CMOS biosensor system that integrates fully carbonized 3D-printed nanoelectrodes with CMOS readout circuits for real-time cellular monitoring. The electrodes were fabricated using a platinum-on-titanium metal stack, chosen for its superior adhesion and thermal stability. Electrode layouts were designed in the industry-standard GDSII format and patterned onto 100 mm silica wafers through contact photolithography and metal lift-off techniques. These wafers were diced into 25 mm × 25 mm chips for further processing.

To enable three-dimensional nanoscale sensing, bridge-on-pillars (BoP) microstructures were fabricated using two-photon polymerization (2PP) with the Nanoscribe Photonic Professional GT tool and IP-S photopolymer. After printing, uncrosslinked polymer residues were removed by immersion in SU-8 developer, followed by isopropanol washing and nitrogen drying. The printed structures underwent a two-step thermal annealing process, similar to standard carbon fiber manufacturing. Initially, the polymer was stabilized by heating in ambient air at 340℃ for 10 minutes to initiate oxidation. Complete carbonization usually requires temperatures exceeding 900℃, which are incompatible with CMOS chips due to their limited thermal tolerance (~400–450℃). To address this, carbonization was carried out in argon at 500–600℃ for 8–15 hours using a rapid thermal processing tool, maintaining CMOS compatibility.

In current work, electrical characterization of the thermally annealed, partially carbonized BoP structures was performed over a month using a FormFactor point probe system. Measurements conducted at a fixed 100 V bias over a temperature range of 20℃ to 270℃ showed that the structures had noticeable structural shrinkage (Fig.1) alongside consistent exhibition of nanoampere-level conductivity (Fig.1). Some mechanical failures were observed, likely due to the intrinsic fragility of these suspended nanoscale architectures. Future research will investigate the mechanisms behind these failures, hypothesizing that mechanical stress during handling or thermal cycling contributes to the degradation.

Topical Area

Soft matter: polymers, and complex fluids

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