A Microfluidic Method for Sensor Fabrication on Curved Surfaces

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We present a microfluidic technique for precision patterning thin-film metals (silver and gold) without the need for photolithography. This technique is employed for the fabrication of metal resistors that are subsequently utilized as temperature sensors, strain gauges, and fluid flow sensors. Patterns of thin film metal are fabricated by premixing and flowing electroless silver or gold plating solutions through predefined polydimethylsiloxane (PDMS) microchannels sealed against the surface of interest. The properties exhibited by PDMS, such as its tendency to adhere to clean surfaces and its flexibility, allow this technique to be carried out on both planar and curved surfaces.

We report a general strategy for producing precision patterns of thin-film metals, which employs microfluidics, on samples with a broad range of shapes, sizes, and curvature. The applications of this method are far-reaching as thin-film metals are widely used for creating electrical conductors, resistors, inductors, waveguides, optical diffraction gratings, and MEMS devices. Thin-film metal is typically deposited by evaporation, sputtering, or electroplating, and patterned via photolithographic methods.

The technique reported here exhibits several advantages over currently available patterning methods. (1) It allows deposition of precision thin film metal patterns on large objects. For example, metal resistors or diffraction gratings can be deposited on walls of beakers or Petri dishes for sensing and heating. It is projected that direct deposition can be performed to functionalize large surfaces such as automotive wind shields, aircraft wings, and many others objects currently off-limits to photolithographic processes. (2) By using a compliant material (PDMS) with a distributed fluidic network, large area lithography can be performed on non-planar surfaces. (3) This technique eliminates the reliance on special equipment and facilities.

This technique consists of two major steps. The first step involves the creation of PDMS microchannels. Channels are made by molding PDMS precursor polymer against a surface with precision-defined topographical features and peeling off the cured mold. In general, the topographical features on the negative mold can be made using patterned photoresist, electroplated metal, or by etching silicon or glass. Photolithography is typically necessary to create such features; however, the master can be used repeatedly. In the future, photolithography can be eliminated by utilizing low cost decal masters.

In the second step, the PDMS piece is sealed against the surface of interest to form enclosed microfluidic channels. Commercially available electroless plating solutions are drawn through the channels, subsequently allowing electroless deposition of thin film metal to occur. The PDMS is then removed, leaving only thin film patterns on the surface. The shape of the patterned thin film metal corresponds directly to that of the fluid channel.

While the practice of depositing silver in microchannels is not new[1,2], we have expanded the method to include gold deposition and extended the applications of this technique. We demonstrate the technique using metal resistors made of silver or gold, but other features such as gratings or coils can be easily fabricated as well. The silver and gold fabrication processes can be applied to curved substrates as well. The flexibility of the PDMS piece allows for enclosed channel creation on curled and rounded surfaces. So far, resistors were patterned on glass and polyimide surfaces with radii of 4.40 cm.

We have obtained the temperature coefficient of resistance (TCR) value by recording resistance at varying substrate temperatures. The TCR value of the silver resistors fabricated with this process was determined to be 1970 ppm/C, which is significantly lower than reported values for thin-film silver[3]. The finite TCR value establishes that the metal resistors can function as temperature sensors.

The resistors were tested as strain gauges. The gauge factor was calculated to be 3.37 for resistors fabricated on 100 um thick Kapton film (polyimide). Measurements were taken by measuring the resistance change when the silver resistor on polyimide film was placed over surfaces with varying curvatures. The strain was calculated using the formula: (1) $e = t / (2r)$ where t is the thickness of the polyimide film and r is the radius. It is assumed that the thickness of the metal film has a negligible effect on the strain since the thickness of the polyimide is several orders of magnitude thicker than the metal film.

The resistors were also tested as hot-wire flow sensors. Silver resistors were patterned on 100 um thick polyimide film. PDMS flow channels were then attached onto the polyimide film, thus enclosing the resistors inside the channels. Water was then pumped through the channels using a constant flow-rate syringe pump and the resistance change was recorded with a multimeter. The yield, reliability, and costs of this process were comparable to flow sensors fabricated by the well characterized AMANDA process[4].

We have demonstrated a technique for fabrication of patterned metal surfaces. The technique is applicable to the patterning of silver and gold on various substrates including glass, silicon, silicon dioxide, Pyrex glass, polyimide, and PDMS and can be carried out on both flat and curved surfaces. Different electroless plating solutions can be adopted to accommodate deposition of other metals. Additional substrates can be facilitated as well by employing the appropriate surface treatment. We have shown the application of this technique for the creation of temperature sensors, strain gauges, and flow sensors. Future work includes demonstration of applications such as heated microchemical reactors, thermal actuators, and tactile sensors.

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