POLYMER MICROMACHINING AND APPLICATIONS IN SENSORS, MICROFLUIDICS, AND NANOTECHNOLOGY

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Introduction
Polymer materials offer important advantages for microelectromechanical systems (MEMS) applications including (1) mechanical robustness compared with Silicon and other semiconductor materials; (2) potentially lower cost of preparation and processing; (3) low temperature processing and enhanced biocompatibility; (4) new methods of processing including molding, embossing, melt processing, and imprinting.

A variety of polymer materials have been used for MEMS, including photodefinable polyimide (e.g., Kapton), non-photodefinable polyimide, photoresist, SU-8 resist, silicone elastomer (e.g., polydimethylsiloxane, or PDMS), liquid crystal polymer, biodegradable polymer, Parylene, and wax.

This article discusses several MEMS research projects conducted at the Micro Actuators, Sensors, and Systems (MASS) Laboratory of the University of Illinois at Urbana-Champaign. These research projects use polymer as an enabling component or as a novel variation from conventional materials. The following projects will be reviewed:

1. Micro flow and tactile sensors using liquid crystal polymer (LCP) micromachining;
2. Realization of flexible membrane made of silicone elastomer with embedded magnetic materials;
3. A method for precision patterning of silicone elastomer and several applications based on this method;
4. Scanning probe microscopy (SPM) probes realized using efficient polymer micromachining and applications of such probes for nanotechnology applications including surface characterization and nanolithography;
5. Multi-modal sensory skin for slow sensing and tactile sensing based on polymer substrates and low-temperature processing.

Sensors Based on Liquid Crystal Polymer Thin Film. The liquid crystal polymer is a unique material with polymer molecules lined in a crystalline-like architecture. It offers unique advantages such as minimal adsorption of air and moisture, stable mechanical and electrical properties, and stable chemical properties. The LCP material offers many advantages not found in the polyimide films (e.g., Kapton).

We have developed a set of fabrication processes for micromachining commercial LCP films. To demonstrate the capability, flow sensors and tactile sensors based on LCP polymer materials have been built. A tactile sensor array is shown below.

Flexible Silicone Elastomer With Actuators. We developed thin silicone elastomer membranes with extremely high degree of flexibility. We also developed such membranes with embedded electromagnetic material such that the membrane maybe deformed using an externally applied magnetic field. The application of such films is integrated tetherless micropumps for microfluid applications. A photograph of a membrane is shown in the figure below, illustrating the transparency of the membrane as well as micromachined magnetic bars located inside the membrane itself.

Figure 1. A tactile sensor array on a flexible LCP substrate.

Figure 2. Optical micrograph of a silicone elastomer with embedded magnetic material (electroplated Permalloy). The membrane is 200 micrometer on each side and 10 micrometer thick.

A Method For Precision Patterning Of PDMS. Polydimethylsiloxane (PDMS) elastomer is widely used in microfluidic applications to form components such as channels, valves, and diaphragms. The PDMS material offers many advantages. It is transparent and biodegradable. It can be easily processed by molding and acquired for low costs. It is elastic and can form fluid seals effectively.

PDMS is commonly used as a bulk material. The predominant fabrication process associated with PDMS is bulk molding. First, PDMS is not photo-definable and cannot be photolithographically defined like photoresist. Secondly, PDMS pre-polymer is viscous. It is impossible to form thin films of PDMS using spin coating. Earlier work showed that even when spinning at 8,000 rpm, the resultant PDMS thickness is greater than 40 µm.

We have developed a unique method for precision patterning of PDMS material with fine spatial features, much like performing photolithography on spin-on photoresist films. The process flow is shown in the figure below. The process involves using photoresist to build a mold. The precursor of PDMS is poured on the mold. Excess precursor materials are removed using a blade. After curing the elastomer, the photoresist is removed and a fine feature made of PDMS is left. The dimensions of the PDMS correspond to the resolution of regular photolithography. Thickness of the film is determined by the thickness of the photoresist mold.

Figure 3. Schematic diagram of a process for patterning PDMS with fine spatial features.

Results of patterned PDMS features are shown below. A micro O-ring with 30 µm diameter has been made. The PDMS thickness can be as small as 5 µm.
SPM Probes Made Using Polymers. SPM probes are performance-limiting devices that are useful for surface characterization (e.g., scanning tunneling microscopy, atomic force microscopy) and nanolithography (e.g., dip pen nanolithography\(^5\) and nanoimprinting). We have developed polymer-based SPM probes in order to reduce the costs and to introduce novel materials. Polymers such as polyimide and Parylene have been used as the shank of SPM probes. Materials such as silicone elastomer have been used as the tip of SPM probes for nanolithography applications.

Multi-Modal Sensitive Skins. We have applied MEMS technology on polymer materials such as polyimide to realize multimodal tactile skins, which is a two-dimensional array of flexible sensor substrate with high density sensors of the following types: hardness sensor, temperature sensor, sensor for thermal conductivity, and sensor for surface roughness measurement. An optical micrograph of a multi-modal tactile skin is shown in Fig. 5 and 6\(^6\). Comprehensive measurement results of sensors on this multimodal sensor skin can be found in the paper referenced.

Conclusions
This article reviews a few applications developed at the MASS group of the University of Illinois. These applications involve polymer materials for realizing novel electromechanical functionalities, increased mechanical robustness, or lowered costs. Polymer micromachining also introduces a number of constraints, such as the mechanical relaxation of polymer, lower temperature tolerances, and difficulties to package such sensors.

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References