Fabrication of Flexible Microfluidic Strain Sensor by Laser Micromachining for Hand Motion Tracking

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***Abstract*—Various types of strain sensors have been developed for providing reliable monitoring of human health. Microfluidic strain sensors is favourable for such an application due to its outstanding performance under a variety of three-dimensional deformations on the basis of elastic channel deformation. In this study, we report for the first time laser-machined micro-channels on fabricated epoxy substrate. Fabrication of flexible microfluidic sensor using soft clear epoxy is investigated. A ratio of 100:30 of epoxy resin-to-hardener results in a flexible and elastic epoxy layer. Laser micromachining (ablation) technique at varying parameters is conducted using Taguchi Experimental Design. Low number of passes for both kerf depth and kerf width gives an optimum response, while laser power and laser cutting speed differs for kerf width and kerf depth. Microstructure imaging is carried out using scanning electron microscopy for heat-affected zone examination.**

***Index Terms*—Microfluidic, strain sensor, laser, micromachining, motion, tracking, flexible, wearable.**

I. Introduction

Emerging technologies and innovation in wearable sensors have paved the ways for continuous monitoring of human's health and motion. These wearable sensors allow individuals to closely monitor vital signs (e.g., heartbeat and brain activity) and provide feedback on their health status. Robust tactile sensing capabilities on curved surfaces are often required in the applications of robotics and synthetic fingertip [1]. Due to the irregular shape of human's anatomy, development and fabrication of flexible and stretchable sensors have been continuously researched using silicon and polymer. Elastomer is a natural or synthetic polymer and has an elastic property making it the right material for flexible sensors fabrication. Various elastomers have been used which include polydimethylsiloxane (PDMS), EcoFlexTM and rubber.

Wong *et al*. [1] demonstrated a fabrication of flexible, capacitive, microfluidic sensor for normal force sensing. A flexible elastomer (used to reciprocate the properties of human skin) and a liquid metal (serves as flexible plates for the capacitive sensing units) were used to fabricate the capacitive, microfluidic sensor containing four layers of PDMS. Pang *et al*. [2] used a reversible interlocking of nano-fibres to fabricate a flexible and highly sensitive strain-gauge sensor in which claimed to be able to distinguish numerous 'skin-like' mechanical loadings using metal-coated, high-aspect-ratio (AR) polyurethane-based nano-fibres.

Microfluidics deal with the flow of liquids inside micro meter-sized channels. Whilst, microfluidic sensors are sensors with embedded micro-channels, and usually filled with a specific conductive liquid. When the microfluidic sensor elongates due to applied stress, the geometry of the sensor will be affected resulting in the change in resistance of the (liquid) sensor. In this way, a correlation can be obtained between resistance and motion.

Casting is one of the most commonly used methods to fabricate microfluidic sensor. A mould master with the desired shape of the sensor will first be created [3]. This mould master contains the desired geometry as well as the desired micro-channel pattern. Flexible material such as rubber or latex will be poured onto the mould master to cover the template and finally heat treated. This method is time-consuming as the thermal treatment alone took approximately 10 hours to be completed. Other method such as hot-embossing is only suitable for a specific substrate only.

In view of this, laser micromachining offers some crucial benefit over other more-established micro-fabrication methods due to its low-cost operation and rapid fabrication [4]-[6]. Suriano *et al.* [7] performed a thorough study of the properties of femtosecond laser-ablated polymer surfaces for microfluidic channel fabrication. Several thermoplastic polymers such as PMMA, cyclic olefin polymer (COP) and polystyrene (PS) which were commonly used for microfluidics were studied and different characterization techniques were applied to investigate the degradation mechanisms and surface properties following laser ablation.

Teixidor *et al.* [8] conducted an experiment involving the outcome of nanosecond laser processing parameters on depth and width of micro-channels fabricated from PMMA polymer. Polymers are said to display a strong absorption in UV and deep infrared (IR) wavelengths. However, they have weak absorption at visible and near-infrared spectra. This leads to the ablation process to become a multiplex mixture of photo-chemical and photo-thermal processes.

Rahimi *et al*. [9] demonstrated the application of direct laser carbonization to fabricate high-performance stretchable electrochemical pH sensors for wearable point-of-care applications. Polyimide (PI) sheets, Eco-flex, proton-selective polymer and polyaniline (PANI) were the materials used in the experiment. Fabrication includes

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