Flexible photonic sensors realized using printing technologies

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Summary

Photonic sensor systems require the integration of microstructures (e.g. polymer waveguides), nanostructures (e.g. gratings), which can be realized using nanoimprint lithography, but may also need additional active or passive optical components, which can be integrated using aerosol jet and laser printing technologies.

Introduction

Making sensors flexible and thin, is key to apply them on curved, moving surfaces, e.g. for wearable applications or to embed them in mechanical structures. However, realizing flexible sensor devices asks for alternative fabrication technologies as compared to e.g. wafer-level production. This contribution highlights our recent developments in the field of printed photonics technologies and will be illustrated for the realization of flexible polymer Bragg grating sensor foils. This polymer approach allows realizing very thin foils with multiple sensors which can be embedded and used for multi-axial strain sensing.

Polymer micro- and nanostructuring using nanoimprint lithography

A Bragg grating sensor consists of a (single mode) waveguide, in which a grating is implemented as a periodic corrugation. Both the waveguide (typical cross-sectional dimensions 5 x 5 μm^2) and gratings (grooves with a typical pitch between 300 and 500 nm and depth of 100-300 nm) can be realized using an imprinting technique. Therefore, first, a master is fabricated using e-beam or standard lithography and then the patterns are transferred to a transparent polymeric working stamp. This working stamp is then used to imprint a coated (UV-curable) polymer layer and is peeled off after a UV-curing step.

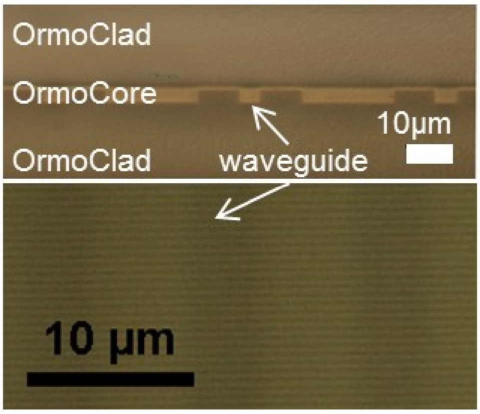

Fig. 1. (cross-section) Imprinted Ormocer® waveguides and (top view) grating imprinted on top of the waveguide core.

With a number of small modifications, a large range of micro- and nanostructures can be realized in various optical polymers, according to this basic concept. For example, Ormocer®-based waveguide sensors can be realized by first imprinting channels in a layer of Ormoclad (an Ormocer® formulation with a lower refractive index), then spin-coating a thin layer of OrmoCore (an Ormocer® formulation with a higher refractive index) on top and subsequently imprinting this core layer with another stamp having the grating structures, see Fig. 1. The thickness of the residual core layer that can be seen in the figure should be kept minimal. This can be achieved by precisely controlling the spin-coated layer thickness and by using larger dummy structures between the functional waveguides which act as reservoirs to capture the excess material.

The behavior of these Ormocer® sensors was compared to similar sensors realized in epoxy (EpoCore and EpoClad materials from MicroResist Technology were used). Both types of sensors were designed for single mode operation around λ=1550 nm requiring a grating pitch of about 500 nm. It was found that the Ormocer® sensor is almost 3 times more sensitive (250 pm/°C) to temperature as compared to the epoxy sensor (90 pm/°C). The Ormocer® material has relatively low losses, which allowed multiplexing 3 sensors (with different orientations) in a single waveguide on a foil to realize a multi-axial sensor. The epoxy material on the other hand, allowed realizing very thin sensor foils (down to 50 micron) which were embedded in composite material test specimen without compromising functionality.

Integration of optical components using laser and aerosol jet printing

The Bragg grating sensors as discussed above require an optical source and detector for their readout. The most straightforward approach is to connect an optical fiber to the sensor foil so that it can directly be plugged in a standard interrogator. However, this requires a rather bulky connector which is not always convenient. Alternatively, sources and detectors can be integrated with the sensor on the foil. They can either be embedded face-up [1] or flip-chip surfaced mounted [2]. In the latter approach, a solder can locally be printed using a laser transfer printing technique which is especially interesting for flexible photonics since it can be performed at low temperature. Furthermore, (sub 100 µm) electrically conductive tracks can be deposited using aerosol jet printing, a process which uses aerodynamic focusing to precisely and accurately deposit functional inks in a direct way as defined in a CAD model.

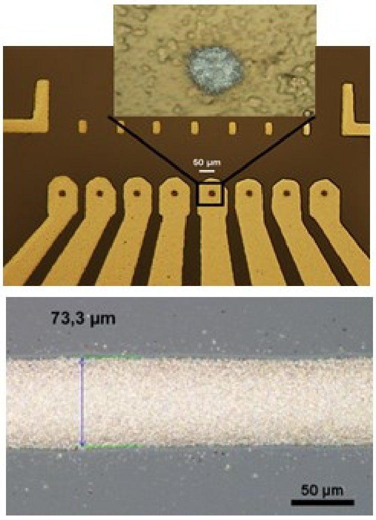

Fig. 2. (top) laser printed Indium solder bumps and (bottom) aerosol jet printed silver ink track.

Conclusions

Printing technologies are very well suited for realizing flexible photonics. Nanoimprinting can be used for defining a large range of micro- and nanostructures in various optical polymers, laser transfer printing can be used as a low-temperature process to locally deposit solder and aerosol jet printing allows definition of fine-pitch electrically conductive tracks.

References

[1] E. Bosman, et al., IEEE J. Sel. Top. Quant. Elect., **17(3)**, p. 617-628, 2011.
[2] K.S., Kaur, et al., Appl. Phys. Lett., **104(6)**, p. 061102, 2014.