Proceedings

Uniform Fabrication of Moems Arrays Using Dry Thick Resist Films †

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Abstract: This study aims at focusing a laser beam at the center of a microfluidic channel for optical bio-sensing applications thanks to the collective integration of tunable microlens arrays on VCSELs devices. High aspect-ratio polymer-based MOEMS are successfully fabricated on small-sized samples using thick dry photoresist films. Such dry films are easier to use and less expensive than standard thick SU-8 and can be efficiently stacked on fragile GaAs samples using a soft-thermal-printing technique. By combining double UV exposure and planar metallization, uniform fabrication of MOEMS arrays is enabled and fabricated devices exhibit reproducible electro-thermal behavior.

Keywords: MOEMS; micro-optics; dry thick resist film; SU-8; wafer-scale fabrication; VCSELs; dynamic beam shaping

1. Introduction

VCSELs (vertical-cavity surface-emitting lasers) are semiconductor laser diodes presenting unique properties such as low threshold current, circular emitted beam and parallel operation. Consequently, they are more and more used in short distance optical links and in optical sensors. Real-time control of laser beam waist position during VCSEL operation is one of the key issues in incorporating these devices into compact portable systems. To this aim, a polymer-based MOEMS (micro-optical electro-mechanical microsystem) that can be collectively integrated onto VCSELs arrays at a post-processing stage was designed by the authors [1]. A first demonstration based on SU-8 resist technology was reported on large silicon wafers. A vertical displacement of 8 µm of the microlens plane was obtained under electro-thermal actuation (42 mW applied), with a slope efficiency of 0.2 µm/mW. However, spin-coating of thick SU-8 resist onto small-sized samples, such as VCSELs ones, lead to too detrimental edge beads. As a result, precise fabrication remains very tricky on such samples. In this work, uniform fabrication of MOEMS fabricated on small-sized samples is achieved thanks to a fabrication process based on a dry resist film soft transfer.

2. Materials and Methods

2.1. Design

The goal of this study is to focus a laser beam (size < 20 µm) at the center of a microfluidic channel of a miniaturized sensor based on optical feedback velocimetry [2]. In order to insure a dynamic positioning of the beam waist over 100 µm, a polymer-based MOEMS is directly integrated on the VCSEL device (Figure 1). This MOEMS is composed of a suspended membrane associated with a microlens deposited at the membrane center (Figure 2). MOEMS dimensions were first set by optical modelling (ZEMAX-EE), taking into account the initial single-mode VCSEL beam divergence (12°FWHM) and the VCSEL array footprint (pitch 500 µm) as well as several technological constraints (size and focal length of the polymer microlens). In these conditions, the distance between the VCSEL and the lens has to be at least equal to 92 µm. This implies the use of a thick resist for MOEMS fabrication. SU-8 material was first chosen because this negative tone resist allows high aspect ratio patterns definition combined to high transparency in the near infra-red spectral range. Moreover, it exhibits a high thermal expansion coefficient (52 ppm/°C) suitable for an efficient thermal actuation. Additional advantages of SU-8 rely on its low temperature process compatible with the collective integration on a semiconductor laser wafer at a post-processing stage.

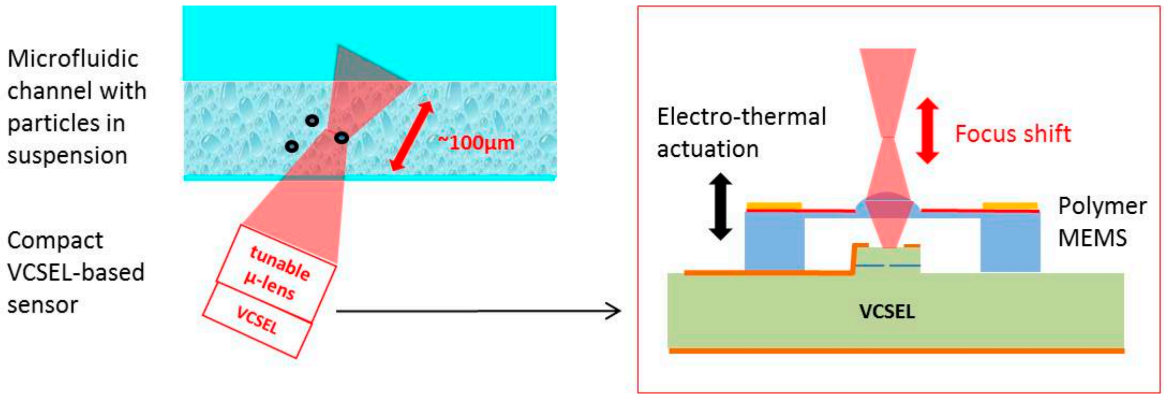
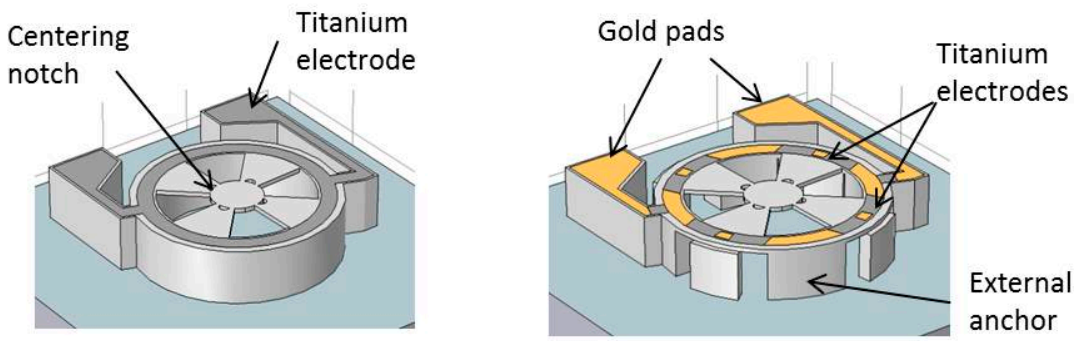


Figure 1. VCSEL-based optical interferometric sensor for flow measurement in a microfluidic channel. Laser focus position adjustment in the channel is achieved thanks to a polymer-based electro-thermal MOEMS (tunable microlens) directly integrated on the VCSEL device.

A 3D simulation was also developed using COMSOL™ to optimize MOEMS electro-thermo-mechanical behavior and to obtain the largest vertical displacement of the membrane with a minimal applied actuation power with a maximal temperature of 120 °C (Figure 2) [4]. In particular, heating zones were limited to small areas of thin titanium electrodes (50 nm) and thicker gold access pads (300 nm) were used to reduce access resistances values. Moreover, additional anchors were inserted outside the suspended active zones to improve heat extraction, and to guide the dilation towards the center. This study showed that these electro-thermo-mechanical improvements should lead to an efficiency of 0.8 µm/mW (compared to 0.2 µm/mW for the previous device).



(**a**) (**b**)

Figure 2. (**a**) Previous design of the electro thermally-actuated polymer-based MOEMS already including centering notches for lens positioning (**b**) New design including localized heating areas and external anchors

2.2. Fabrication

The MOEMS fabrication process is described in Figure 3. It requires two successive UV exposures in a single 100 µm-thick SU-8 layer: a first exposure at 365 nm to define the 100 µm-thick anchors (Figure 3b) and a second one, through a different photomask and at a shorter wavelength (320 nm, owing to the use of an optical filter placed in the optical path of the mask aligner), allowing the definition of a thin (~8 µm) membrane (Figure 3c). Membrane release is achieved after resist development. Unfortunately, this process is difficult to apply as written to small-sized GaAs samples such as VCSELs ones, because spin-coating of 100 µm-thick SU-8 lead to large edge beads at sample periphery and to too detrimental inhomogeneity problems.

To avoid them, standard spin-coating of SU-8 was replaced by the deposition of two DF-1050 dry films photoresists (from Engineered Material Systems Adhesives) (Figure 3a). Such films present similar optical and mechanical properties than SU-8, while being much easier to implement as they have a calibrated thickness (48 µm) regardless of the film size and shape [4]. Moreover, they can be easily transferred on a sample using film lamination. Unfortunately, lamination is not recommended for fragile samples. The process was thus adapted to make the use of dry films on such samples possible using a new transfer method called "soft thermal printing" and based on the use of a nanoimprint setup. Thanks to this new method, it was possible to reduce the thickness variation along the whole sample to less than 3% compared to the greater than 40% variation obtained by standard SU-8 spin-coating on the same surface (quarter of wafer of 2" in diameter) [5]. Two metallization steps were then achieved before DF-1050 development (Figure 3d). This "planar" process insured a good definition of the electrode and suppressed the risk of an unwanted metallization in the optical axis. Two local selective wet etchings were then performed to define the gold pads and the titanium electrode (Figure 3e). Standard development and baking steps were applied. Finally, lens deposition was achieved using inkjet printing of thermo-curable liquid droplets and final baking (Figure 3f).

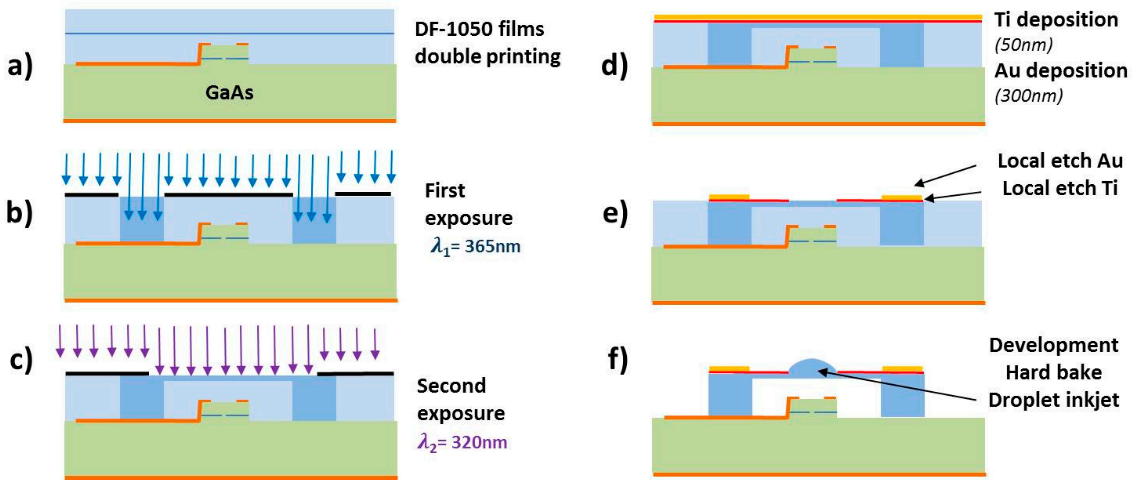
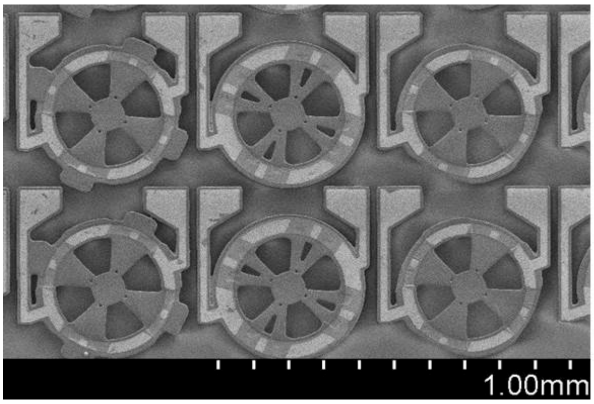


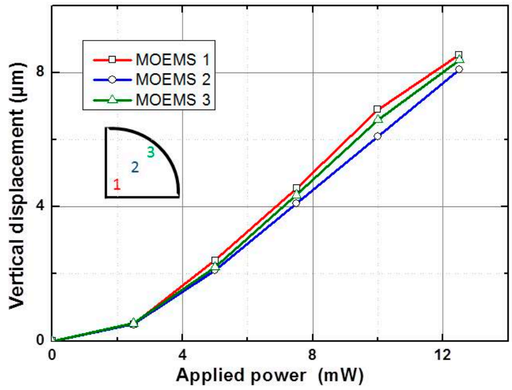
Figure 3. MOEMS fabrication process onto GaAs VCSELs devices using soft thermal printing of 2 thick dry resist DF-1050 films, 2 UV exposures and planar metallization before final development and lens inkjet printing.

3. Results and Conclusions

A SEM view of a complete MOEMS fabricated using the above-mentioned process is shown in Figure 4a. The electro-thermal response of this MOEMS was characterized under probes. As seen in Figure 4b, the efficiency slope is in very good agreement with the simulation (slope efficiency: 0.85 µm/mW). Note that this modeling does not take into account the initial deformation of the actuation arms due to thermomechanical stress induced during fabrication and that can delay the effect of electro-thermal actuation. Furthermore, this behavior is reproducible for all MOEMS of the whole sample, showing thus the high uniformity achievable using dry resist films for MOEMS fabrication. Optical characterization is undergoing. This study paves the way for the integration of tunable microlens arrays on small and fragile VCSELs wafers and for the realization of miniaturized optical interferometry sensors.



(**a**)



(**b**)

Figure 4. (**a**) SEM (Scanning Electron Microscopy) view of a DF-1050 MOEMS arrays with different tested designs (**b**) Vertical displacement of the membrane for MOEMS located in different arrays of the GaAs sample and comparison with modeling.

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Conflicts of Interest: The authors declare no conflict of interest.

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