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# A new SU-8 process to integrate buried waveguides and sealed microchannels for a Lab-on-a-Chip

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**Abstract**

This paper shows a novel use of SU-8, a photodefinable epoxy, to monolithically integrate low cost optical sensors and microfluidic structures. The chip consists of optical connectors, multimode waveguides and sealed microfluidic channels patterned in SU8 on a silicon substrate. We describe in detail an SU-8 microfabrication process consisting of (i) four successive photolithographic steps, (ii) a bonding process and (iii) a final releasing step. The core of the waveguide is made of standard SU-8, whereas its cladding, with a lower refractive index, is achieved by diluting the SU-8 in a liquid aliphatic resin. Despite the dilution, the SU-8/aliphatic mixture is still patternable by photolithography allowing us to fabricate microchannels. The input and output optical fibres are horizontally aligned to the waveguides by their insertion in U-Grooves, and vertically aligned by the elevation of the waveguide using a lower cladding layer that allows us to lift it up to meet the centre of a standard optical fibre. Microfluidic channels with smooth vertical walls (125 μm height and 30 μm width) have been achieved. Microchannels are sealed by low temperature adhesive bonding of the SU-8 photopatterned thick-films at a wafer level. Liquid flows in the channels verify good sealing of the microchannels. In order to validate the interaction of these optical-fluidic microcomponents, we carried out an absorption chemical assay. The fabrication procedure described in this article is a fast, reproducible, CMOS compatible and simple way to develop optical Lab-on-a-Chip devices using standard photolithography and bonding equipment.


*Keywords:* SU-8; Waveguides; Lab-on-a-Chip; Packaging; Microfluidics; Microoptics; Microfabrication

## 1. Introduction

The development of chemical and biological microdevices has started to play a significant role in improvements to public health, by providing new applications with rapid detection, high sensitivity, portability and high specificity devices. Taking into account the specific, reliable and precise information that an optical signal can obtain in a chemical assay, the development of the optical microtechnologies would lead us to an optical Lab-on-a-Chip platform. Nevertheless, the commercialisation of these devices is limited, mainly because these intrinsic advantages cannot currently be offered at low cost. Most of these devices require quite large and expensive external instrumentation (i.e. bulk optical elements) that needs to be accurately aligned.

The advent of micro-electro mechanical systems (MEMS), with technologies, such as hot embossing, injection moulding and lamination techniques, is developing some interesting advances in this topic due to the low cost fabrication of 3D microchannels [1]. These techniques have addressed the microfluidic interface (connectors), the embedded channels and optical components, such as waveguides [2]. However, further compatibility with CMOS devices is not guaranteed avoiding a higher level of integration of electronics and optics. In this manner, integrated silicon nitride or silicon dioxide waveguides, extensively used in the telecommunication industry, have been presented to overcome this hurdle [3,4]. These technologies provide very well controlled refractive index waveguides with low losses and pigtail-

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ing solutions [5,6]. However, these processes require high temperatures that limit their biological use as well as thin deposited layers that limit further optical alignment and packaging stages. Recently, polymers have been presented as an alternative to these complex methods to fabricate not only telecommunication devices but also sensor devices. These possibilities lead to the simplification from an optical table set-up to a self-contained device.

Zhao et al. [7] fabricated polymer waveguides by dry etching cyclotene or poly(methyl methacrylate) (PMMA) to create a core with a non-photodefinable polymer (Cytop$^{TM}$) as cladding. Kane et al. [8] fabricated the core by using a photodefinable version of benzocyclobutene (BCB), while the cladding remained unpatterned. A remarkable step was done by Mogensen et al. [9] to integrate waveguides and microchannels using SU-8. However, the limitations of this approach were three-fold: (i) both the microfluidic channels and the waveguides were made of the same SU-8 layer, (ii) the height of the waveguides was determined by the outer diameter of the optical fibre since they were not buried and (iii) finally the sealing process was carried out by a non-photodefinible and non-cross-linked layer.

The fabrication process proposed here overcomes these issues by modifying the negative photoresist SU-8-50 with a liquid aliphatic epoxy resin. This approach has the following advantages: (i) it creates a 3D sealed microfluidic structure independent of optics, (ii) it works as an optical waveguiding material, core and cladding, achieving a more control of the index difference as compared to the waveguides using air as cladding and (iii) both cladding and core layers are photodefinable allowing us to integrate optical fibre connectors and microchannels. Nevertheless, the polymeric nature of this waveguides has some disadvantages in comparison to classical waveguides. For example, polymeric waveguides lack thermal and time stability that might limit their commercial impact.

Similar to the method used here, Wu et al. modified the SU-8 hydrophilic properties [10] and Kragh et al. changed the fluorescence properties of SU-8 [11] showing how versatile SU-8 is by modifying its properties through dilution with other substances. Chan-Yen and Gale modified the surface of an SU-8 waveguide to make possible the adhesion of a fluorescence dye [12].

A simple biological assay is performed to show how this straightforward and low cost microfabrication technology can be used for the mass fabrication of optical Lab-on-a-Chip devices.

## 2. Materials and methods

### 2.1. Materials and equipment

A commercially available SU-8 50 negative epoxy photoresist and a propylene-glycol-monoether-acetate developer (PGMEA) from Microchem Corp. (USA) were used. The liquid aliphatic epoxy resin (D.E.R. 353$^{TM}$) was from DOW Plastics. Reagent grade isopropanol, methanol and diethyl ether were from Aldrich (UK). The bromophenol blue indicator (0.04%) was ordered from Scharlau (Spain).

Single-side polished 4 in. ⟨1 0 0⟩ Si wafers (525 μm thick) and 4 in. Pyrex 7740 wafers (700 μm thick) were employed. The photomasks were generated using a layout software (Odin, C2V software, The Netherlands) and were printed on a plastic film photomask by a photoplotter of 64,000 dpi (J.D. Photo-Tools Ltd., UK). The photolithographic and bonding processes were carried out in a mask aligner and in a substrate bonder, respectively. Direct inspection of the bonded area was realised using an optical microscope. In order to obtain a quantitative measurement, the bond strength was evaluated by tensile strength tests in a DAGE 4000 shear test station. The thickness uniformity of the SU8 layers was measured by PLμ confocal profiler (Sensofar-Tech, S.L., Spain). Finally, the wafers were diced in a DAD 321 Automatic Dicing Saw (Disco, Japan) to characterise the interface between SU-8 layers. The study of quality of fabricated cavities and channels was performed by a scanning electron microscope (Quanta 200, FEI Company).

### 2.2. Design

The buried waveguides were based on the principle of total internal reflection [13]. Therefore, high and low refractive index materials were needed in order to confine the light. The higher refractive index material worked as a core and the lower as cladding. The waveguide multilayer fabrication approach consisted of three layers: bottom cladding, core and top cladding. The core was made of pure SU-8, whereas the bottom and top cladding consist of a mixture of SU-8 with a liquid aliphatic epoxy which decreases the refractive index.

Fig. 1a describes the overall schematic representation of the optical and microfluidic circuitry, whilst Fig. 1b shows a photograph of the whole device. The overall size of the chip is 10 mm × 5 mm. Each device features a waveguide interrupted by a microchannel to carry out an absorbance assay. The waveguides' width is 40 μm, with a height of 20 μm, yielding a multimode propagation behaviour for a wavelength of 633 nm. This wavelength was chosen because (i) it is easy to work with since it is visible, (ii) low cost and small light sources are available and (iii) there are optical assays, such as fluorescence measurements, based on this wavelength [3].

As can be seen in Fig. 1a, the buried waveguide is crossed by a micro-analytical chamber, 200 μm ($L$) × 40 μm ($W$) × 125 μm ($D$) [3,14], connected to two reservoirs through 200 μm wide and 125 μm deep micro-channels, giving a sub-nanolitre volume structure of ca. 1 nL. A fourth SU-8 layer sealed the microchannels.

In addition to the microchannels, an optical fibre connector consisting of a U-Groove [15] is placed just in front of the input and of the output of each waveguide (see Fig. 2). Hence, the optical fibre is pigtailed by the U-Groove, whose 3 mm