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Strengthened poly(methacrylate) materials for optical waveguides and integrated functions

D. Bosc *, A. Maalouf, F. Henrio, S. Haesaert

CCLO, UMR CNRS 6082 FOTON, ENSSAT, 6 Rue de Kérampont, BP 80518, 22305 Lannion Cedex, France

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Abstract

We studied the property adjustments of polymers such as PMMA poly(methylmethacrylate) and PMMI poly(methylmethacrylimide) for optical waveguide applications. The standard generic process to yield ridge waveguides requires the PMMA to undergo thermal treatment to avoid worm-like defects. We analysed the occurrence of these defects and found a solution to make the PMMA strengthened to pass the whole process. Then, the optical losses of both the polymers are investigated at two wavelengths and with two methods. Finally, small singlemode ridge waveguides are produced with mode diameters around 3–4 μm and linear optical losses ~1–3 dB/cm at 1550 nm. The index contrast is sufficiently high to perform, for example, wavelength micro-ring resonators based filters.

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Keywords: Poly(methylmethacrylate); Optical losses; Glass transition temperature; Ridge waveguides; Micro-ring resonators

1. Introduction

More and more, optical processing needs many functions to be assembled. Planar lightwave circuits are generally expected to give a solution for integrated optical functions [1]. For this purpose, both low cost technology and high density scale integration are required. Currently technologies based on inorganic glasses or crystalline semiconductor materials provide many solutions, however the complexity of their manufacture is likely to prevent their use for the most sensitive applications. Polymers offer a great deal of potential for performing integrated circuits with potentially low cost. Etched polymer waveguides can be used to perform a large integration scale of optical circuits and functions, even with usual technology such as standard 365 nm UV photolithography. Nevertheless to make it possible, further improvements of suitable polymer materials are needed, and the technology must be adapted to yield well defined and small size structures. Considering the materials, we report that the strengthening of the polymer is required in some cases in order to withstand the process for standard integrated optical circuit (IOC). A large variety of polymers has been studied to fabricate IOC [2,3]. However the most frequently used materials are poly(methacrylate) materials owing to their good optical properties and their easiness to film forming. Nevertheless to perform waveguides with a high definition, these materials must pass thermal treatment without any surface defects occurring. For these reasons poly(methylmethacrylate) (PMMA) cannot be used without modifications. In this report we show the possibility of overcoming the appearance of surface defects by strengthening the PMMA or by using a modified PMMA such as PMMI (that is an imidized PMMA). The experiments indicate that it is necessary for both the elastic modulus and the glass transition temperature to be high enough to avoid shortcoming. We report that these requirements are especially necessary if photolithography is used. Besides this kind of process,

* Corresponding author.
E-mail address: dbosc@enssat.fr (D. Bosc).

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UV writing technique has recently been used since it is much simpler for the fabrication of waveguides [4–6]. However UV induced waveguide technique yields only a contrast around 0.03 at the wavelength of 1550 nm. In this study, the main application concerns micro-ring resonators which require small sizes and high confined waveguides. For this purpose high index contrast (>0.1) is needed at this wavelength and only the production of ridge waveguide usually allows such a contrast. In this paper, we report the first results on ridge optical waveguides and integrated micro-ring resonators made with these strengthened polymers.

2. Experimental

2.1. Polymer and film preparation

For this study we used PMMA poly(methylmethacrylate) as a core waveguide material from Aldrich, with an average molecular weight M_w around 1.2×10^5 Da and an I_p of ~3, its T_g (glass transition temperature) is 105 °C. We also used PMMI (Fig. 1) a modified PMMA from Degussa that had a Vicat softening point at 150 °C. The cladding material (under and over the core) is chosen to be the PMATRIFE poly(trifluoro-ethyl methacrylate) (Fig. 1). We measured the refractive index of these polymers at the wavelength of 1550 nm and at room temperature (20 °C). They are 1.409, 1.481 and 1.522 for PMATRIFE, PMMA and PMMI, respectively. The low refractive index of PMATRIFE leads to a high index contrast when the core is PMMA or PMMI that also ensures to build relatively small radius of curvature, between 90 μm (with PMMI as core) and 120 μm (with PMMA as core) with minimized radiative losses [7]. This curvature range can lead to build micro-ring resonator based filters with free spectral ranges suitable for wavelength division multiplexing (WDM) networks (around the wavelength of 1550 nm).

Polymers were dissolved in trichloro-1,1,2 ethane (TCE) with concentration between 200 and 300 g/l. The solutions were filtered through a 0.2 μm PTFE poly(tetrafluoro ethylene) membrane filter. They were spin-coated at 1000–4000 rpm on a silicon wafer (3″ diameter) coated with 12 μm of PECVD (plasma enhanced chemical vapour deposition) silica layer. The polymer film thickness was controlled by adjusting the solution concentration and the spin speed. All the samples were dried at 120 °C in an oven for 15 min to remove residual solvent.

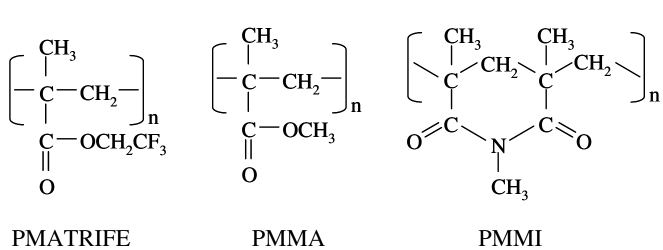

Fig. 1. Cladding polymer PMATRIFE on the left, core polymers PMMA in the middle and PMMI on the right.

2.2. Waveguides and optical functions fabrication

The schematic realization process is shown in Fig. 2. In a class 100 clean-room, all the polymer solutions were filtered at 0.2 μm before the spin-coating stage. Three inch silicon wafers were used. Lower and upper claddings have about a 7 μm thickness. The core thickness may vary from 1 to 3 μm according to the polymer. Over the core's polymer, a thin layer of gold or a layer of silica (~20 nm) is deposited to protect the polymer from the solvent of the photoresist solution. Moreover the barrier layer ensures a high selectivity during the following dry etching step. Then the photoresist (Shipley resin SPR700 0.8) was deposited by spin-coating and the sample is annealed at 115 °C during 90s (PEB, post exposure bake). This annealing temperature is required by the photoresist provider and it allows minimizing the roughness of patterns' sidewalls. Following this stage, the wafer sample is UV exposed (365 nm) through a mask by using a mask aligner (Süssmicrotech MA 750). After developing the resin mask, a selected etching is performed to remove the thin silica (Plasma SF_6) or gold etching (with Au etch solution) and then to shape the ridge by O_2 plasma etching of the core layer. The gold or silica layer onto the ridge surface prevents from reducing of the ridge height during this step. Finally, the wafer is coated with an overcladding material based on a polymer with suitable refractive index (PMATRIFE in this study).

2.3. Thermal and optical characterizations

Thermal properties are evaluated in order to find out the behaviour of the polymer layer that has to undergo the PEB when it is covered by a thin barrier film of gold or silica. For this purpose thermal mechanical analysis (TMA,

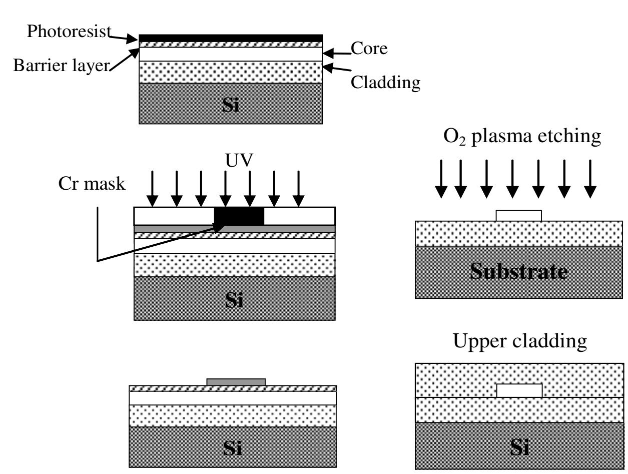

Fig. 2. Scheme of the process for the realization of integrated polymer circuits.