



Optimized inductively coupled plasma etching for poly(methyl-methacrylate-glycidly-methacrylate) optical waveguide

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ABSTRACT

Optical loss is a crucial quality for the application of polymer waveguide devices. The optimized oxygen inductively coupled plasma etching conditions, including antenna power, bias power, chamber pressure, O₂ flow rate and etching time for the fabrication of smooth vertical poly(methyl-methacrylate-glycidly-methacrylate) channel waveguide were systematically investigated. Atomic force microscopy and scanning electron microscopy were used to characterize the etch rate, surface roughness and vertical profiles. The increment of etch rate with the antenna power, bias power and O₂ flow rate was observed. Bias power and chamber pressure were found to be the main factor affecting the interface roughness. The vertical profiles were proved to be closely related to antenna power, bias power and O₂ flow rate. Surface roughness increment was observed when the etching time increased.

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1. Introduction

Polymeric waveguide components are promising alternatives for the application of optical interconnects [1,2], wavelength division multiplex [3], and sensors [4] due to the merits of low optical loss, controllable refractive index, easy fabrication and good chemical stability [5,6]. Conventional semiconductor processing technologies, such as spin-coating, photolithography and etching can be used in the fabrication of polymer waveguides [6,7]. As a widely used technique, plasma etching is reported to be an effective method to form good waveguide morphology [8,9]. However, the roughness at interface is an unfavorable consequence of plasma etching. This roughness may induce significant waveguide scattering loss and severely impede scaling down of waveguide dimensions [10,11]. Thus, the interface roughness needs to be well studied and understood. It is well known that both isotropic chemical etching and anisotropic ionic bombardment exist in plasma-etching process. Many efforts have been devoted to study the roughness evolution during etching, and optimize the etching conditions to obtain smooth vertical profiles to reduce optical loss due to scattering [12–15].

Oxygen-based reactive ion etching (RIE) is a well established process for polymer waveguide fabrication [16,17]. However, the ion density and energy cannot be regulated individually in the RIE

process. They are both controlled by one radio-frequency (RF) power. Though high RF power accelerates the etching process, it may induce serious ions sputtering and damage the film surface. Different from RIE method, inductively coupled plasma (ICP) etching adopts a secondary RF power to generate high-density plasmas ($>10^{11} \text{ cm}^{-3}$), which is more suitable for submicron and uniform process. This plasma source is independent of plasma energy that is controlled by another bias power source [18]. Thus, ICP etching can provide smoother interface, higher etch rate and vertical figure for polymer devices than RIE approach [19]. Previous work has published some experimental results about oxygen ICP etching with polymers. It just focused on a few aspects of ICP etching, such as antenna power or etching chamber pressure. The research of different factors affecting etching results still needs to be done, especially for those commonly used materials.

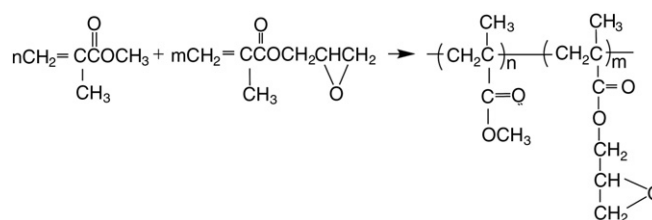


Fig. 1. Molecular structure of P(MMA-GMA).

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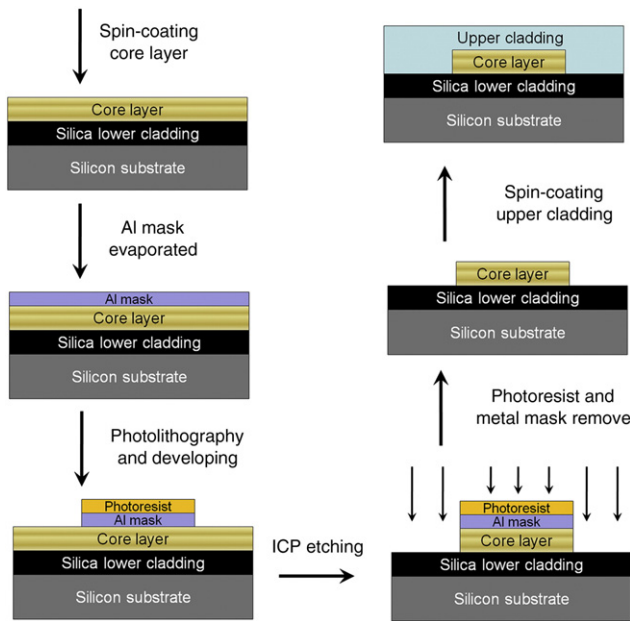


Fig. 2. Process flow for the fabrication of channel waveguide using ICP etching.

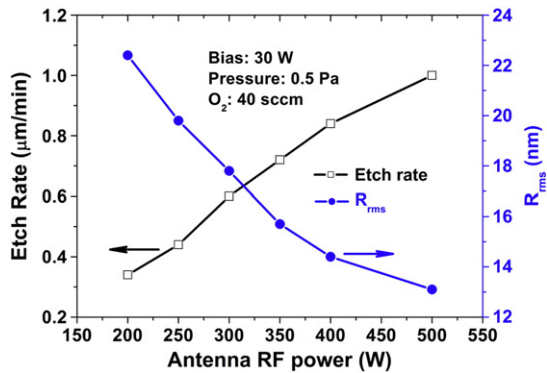


Fig. 3. Etch rate and R_{rms} as a function of antenna RF power at 30 W bias RF power, 40 sccm O_2 flow rate and 0.5 Pa chamber pressure.

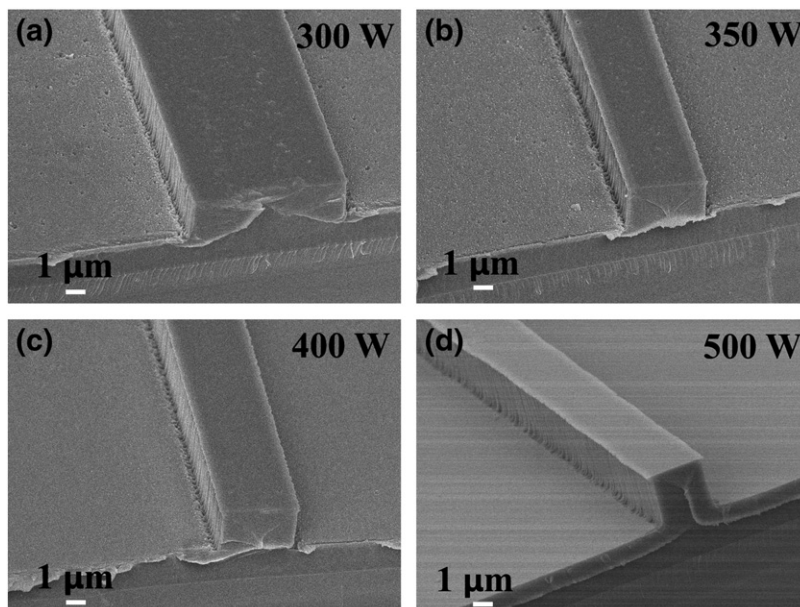


Fig. 4. SEM images of P(MMA-GMA) waveguide vertical profiles when antenna RF power is set to (a) 300 W, (b) 350 W, (c) 400 W, (d) 500 W, at 30 W bias RF power, 40 sccm O_2 flow rate, and 0.5 Pa chamber pressure.

In this study, the etch rate, surface roughness and vertical profiles were evaluated as a function of antenna RF power, bias RF power, chamber pressure and O_2 flow rate for poly(methyl-methacrylate-glycidyl-methacrylate) (P(MMA-GMA)) channel waveguide fabrication.

2. Experimental details

2.1. Materials

P(MMA-GMA) material synthesized by ourselves was used in this study due to its desirable characteristics [20]. The molecular structure of P(MMA-GMA) is shown in Fig. 1. It can be used for arrayed waveguide gratings (AWGs), optical switches, modulators, and other optical devices. The refractive index (RI) of P(MMA-GMA) was measured to be 1.48 at 1550 nm. Bisphenol-A epoxy was adopted as the RI regulator in P(MMA-GMA) to form the core material. The root-mean-square roughness (R_{rms}) of P(MMA-GMA) film was 0.32 nm for an area of $20 \mu m^2$.

2.2. Channel waveguide

A channel waveguide was used to study the optimization of oxygen ICP etching conditions. Fig. 2 presents the schematic diagram of fabrication process. Firstly, P(MMA-GMA) was spin-coated onto the silica lower cladding on a silicon substrate at 2500 rpm. After a subsequent bake at $120^\circ C$ for 2.5 h, a layer of 100 nm thick aluminum film was thermal evaporated onto the top of P(MMA-GMA) film as the metal mask. To define the waveguide patterns on Al film, BP212 photoresist was spin-coated and patterned by traditional photolithography [7]. No significant sawteeth were observed at the edge of Al etch mask. The oxygen ICP etching process was performed for 150 s under different conditions in a 13.56 MHz CE-300I (ULVAC Co. Inc, Japan) etching machine. A He-cooling system was used to control the bottom electrode temperature. To obtain smooth vertical optical waveguides, the etching parameters were optimized under the condition that one parameter was changed while the other parameters were fixed [21,22]. Atomic force microscopy (AFM) images were recorded with a multimode scanning probe microscope CSM5000 that operated in contact mode (Being Nano-Instrument Ltd., China). The tip of Contact-G was used for AFM measurements (Innovative Solutions

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