Wet Chemical Patterning of KTP Thin Films for Nonlinear Optical Waveguide Applications

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ABSTRACT

A new and simple method to etch and pattern potassium titanyl phosphate (KTP) thin films has been developed. We found that KTP films on fused quartz subtrates can be etched down using a wet chemical mixture of $HCl:2H_2O$ at 75°C. Using the etchant, rib waveguide structures have been fabricated with photolithography.

Introduction

Potassium titanate phosphate ($KTiOPO_4$ or KTP) is a premier nonlinear optical material. It exhibits several superior properties, including high nonlinear coefficients, large angular and temperature bandwidths, and high damage threshold.[1-3] These make KTP an attractive crystal for high efficiency frequency conversion. Recently, there has been much interest in the fabrication of optical waveguides with KTP for nonlinear and electro-optic applications. A few of the methods involve the fabrication of optical waveguides on the surface of bulk crystals. These methods often use an ion-exchange technique where the potassium ions in KTP are replaced with univalent ions such as Rb, Ti, or Ce, [4,5] resulting in an increased index of refraction and forming a waveguide on the crystal surface. However, such fabrication requires precise control of the ion diffusion which gives rise to reproducibility problem. Moreover, this homofabrication process is limited by the availability of expensive KTP bulk crystals. The widespread use of NLO device would benefit greatly if KTP thin film could be heterofabricated on a non-KTP substrate.

Wet chemical etching is a frequently used processing step in the fabrication of semiconductor electro-optic devices.[6] It has the advantage of accuracy, convenience, and economy. However, this method has not been applied to KTP waveguide fabrication. In this article, we report the first use of wet chemical etching with hydrochloric acid system for waveguide channel patterning on KTP thin films.

KTP thin films were deposited by pulsed excimer laser ablation method.[7,8] Fused quartz substrates were used. As quartz has a lower index of refraction than KTP films, it acts as a cladding layer for optical confinement. The film thickness ranges from 0.5-1.0 μm.

The structure of the rib waveguides fabricated is shown in Fig. 1. The waveguide pattern consists of stripes of 6 mm long lines with widths varying from 8-25 μm placed on the KTP thin film using photolithographic procedure with AZ1350J as the photoresist. The etchant was composed of hydrochloric acid and deionized water in the volume ratio of $HCl:H_2O = 1:2$. The etching step was performed in a fresh solution without stirring. The etchant temperature was varied from room temperature to 80°C and in each case the temperature was kept constant to within 1°C using a temperature controlled water bath.[9] The etch depth was measured by a profilometer (Alpha-step 200). The reduction in mesa dimension was estimated by comparing the mesa width before and after etching.

The etching process was tested with different etchant temperature and etching time. We vary the etchant temperature systematically from room temperature to 80°C. It was found that no significant etching occurs at room temperature, but elevated temperature increases the etching rate to a level suitable for waveguide fabrication. The optimal result in terms of reproducibility and etch depth control was found to take place at around 75°C. Figure 2 shows the measured etching depth as a function of the etching time. The etching depth was found to be proportional to the etching time with an average etching rate of 47 nm/min.

Figure 3 (a) shows the depth profile of an etched waveguide pattern on KTP films (600 nm thick). The corresponding optical microscopic picture is shown in Fig. 3 (b). In addition to the chemical etching, there is also horizontal etching. We found that a 25 μm wide photoresist pattern gives a 24 μm wide waveguide after a downward etching of

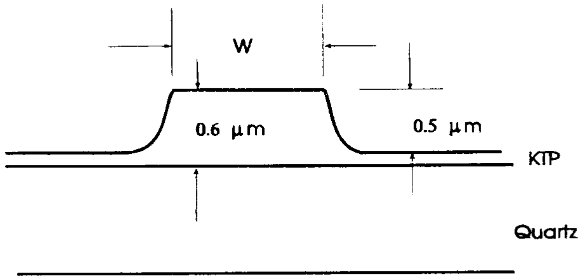

Fig. 1. The structure of rib optical waveguide to be fabricated. W: waveguide width.

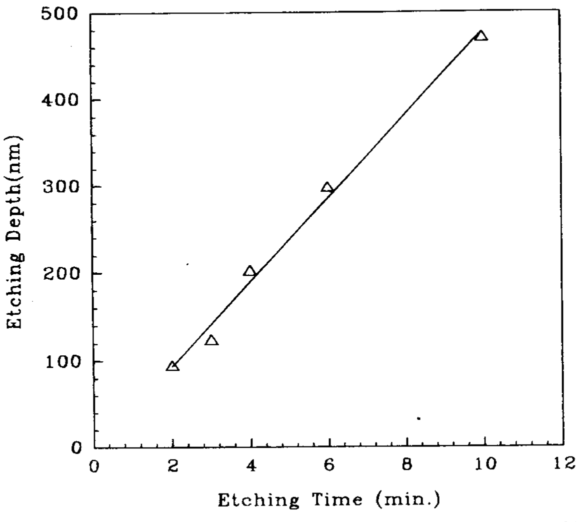

Fig. 2. A plot of the etching depth *vs.* the etching time for KTP films using $HCl:_2H_2O$ etchant at 75°C.

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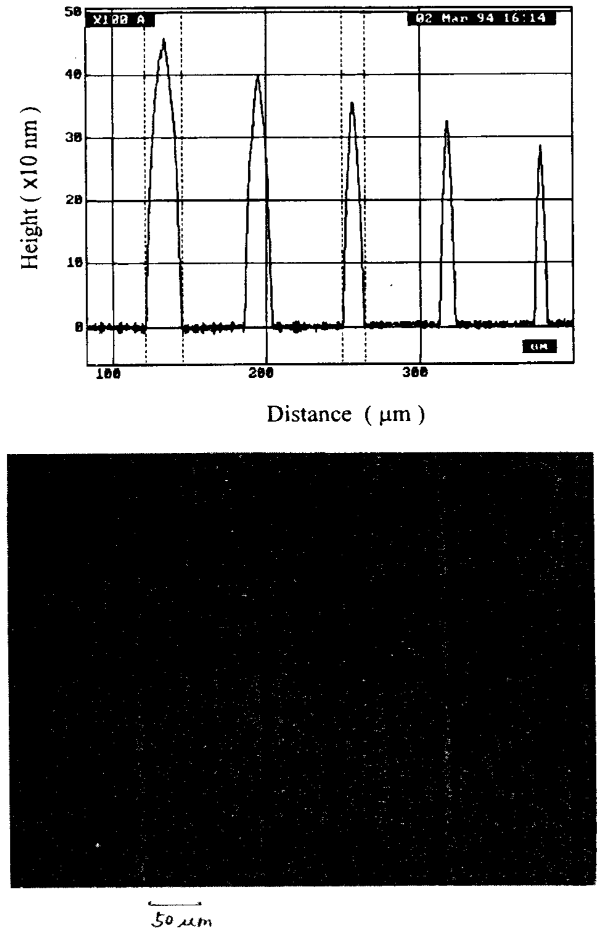

Fig. 3. (a) Depth profile and (b) optical microscope picture of etched structure on the KTP film.

about 0.5 µm. The reduction in the mesa dimension is attributed to lateral etching.

Nonlinear optical performance of the KTP thin film waveguide fabricated was tested by second harmonic generation. The experimental setup is shown in Fig. 4. A mode-locked Nd:YAG laser was used as the pump beam, which produced 100 psce pulses at 1.06 µm with 80 MHz repetition rate.

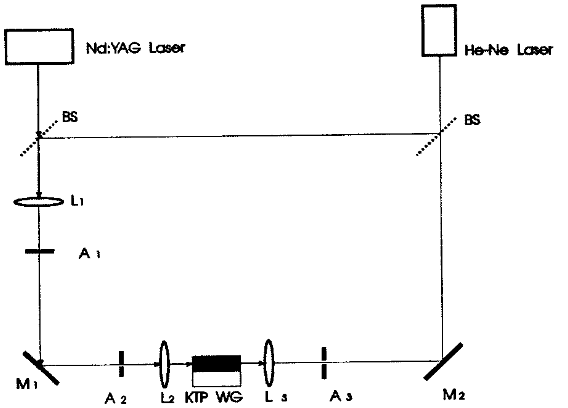

Fig. 4. Optical bench setup for the measurement of second harmonic generation from KTP films. BS: beam splitter. M: mirror. A: aperture. L: lens.

In order to end-couple into the waveguide, the end facets of the sample were polished carefully using an oil-based diamond polishing gel with 6 µm grain size, followed by the same type of gels with grain sizes of 1, 1/4, and 1/8 µm to obtain a smooth final polish. The pump beam was coupled into the waveguide via end-firing technique using a 40 times objective lens. The sample was mounted on a mechanical micrometer driver stage with 5° of freedom for easy alignment and coupling. An He-Ne laser was used for initial waveguide alignment. A CCD camera was used for visible light observation and imaging. An IR filter F was placed in front of the camera to remove the 1.06 µm component from the beam entering the camera. The polarization of the 1.06 µm pump beam is parallel to the substrate.

As the pump's average power was increased to 100 mW, green light was observed from the waveguide. The throughput is very weak for long waveguide (≥0.5 mm) as the thin film for this initial experiment is not dense enough resulting in a scattering problem. When the pump beam is moved down from the thin-film layer to hit only the substrate, no green light was observed, which verifies that the second harmonic generation is not from the substrate material. Currently, there is no phase matching for the second harmonic generation in this waveguide and green light is generated only at the beginning part of the waveguide. With a better KTP thin film in the future, phase matching could be achieved via quasi phase matching techniques.

In summary, we have developed a simple method to pattern the KTP thin film waveguides by wet chemical etching with hydrochloric acid system, which is proved to be efficient. Optimal etching condition for the waveguide fabrication was found to occur using a wet chemical mixture of $HCl:2H_2O$ at elevated temperature of about 75°C. The etching rate was found to be about 47 nm/min. Combining with photolithography technique, rib waveguide structures were fabricated. We found that bulk KTP crystal also etches with the same etchant.

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