Etching of lithium niobate: micro- and nanometer structures for integrated optics

H. Hu, R. Ricken, and W. Sohler
Angewandte Physik, Universität Paderborn, 33098 Paderborn, Germany
e-mail: sol_hu@physik.upb.de

Abstract: *Recent progress of etching methods for lithium niobate is reported, including wet etching, Ar milling, and plasma etching. It is demonstrated by the fabrication of low-loss ridge waveguides and optical "wires", micro-mechanical and photonic crystal structures.*

Introduction

The development of integrated optical devices in lithium niobate ($LiNbO_3$, LN) requires precise etching techniques for the fabrication of (sub-) micrometer structures, such as ridge waveguides, Bragg gratings, and photonic crystals. Among the relevant methods are wet chemical etching and dry etching with Ar-milling, (inductively coupled) plasma (ICP) etching, and focussed ion beam etching. Starting from the state-of-the-art we will report significant progress of wet and plasma assisted techniques demonstrated by the fabrication of different types of waveguides of micro- and nanometer cross section dimensions.

Wet etching of Z- cut LN: ridge waveguides and micro-mechanical structures

Wet etching is the simplest, but nevertheless very reliable method to micro-structure LN surfaces. It is based on a strong selectivity of the etching process; the –Z face of LN is attacked by the commonly used HF/HNO_3 mixtures [1]. We recently succeeded to prepare Ti-doped optical ridge guides of very low propagation losses (0.05dB/cm, TE) by performing the Ti-indiffusion after ridge definition (Fig. 1). The high diffusion temperature significantly reduces the roughness of the ridge walls and in this way the scattering losses.

Even steeper walls can be obtained by etching at lower temperatures. Fig. 1 (right) shows an interdigital finger structure etched at 8 ^oC.

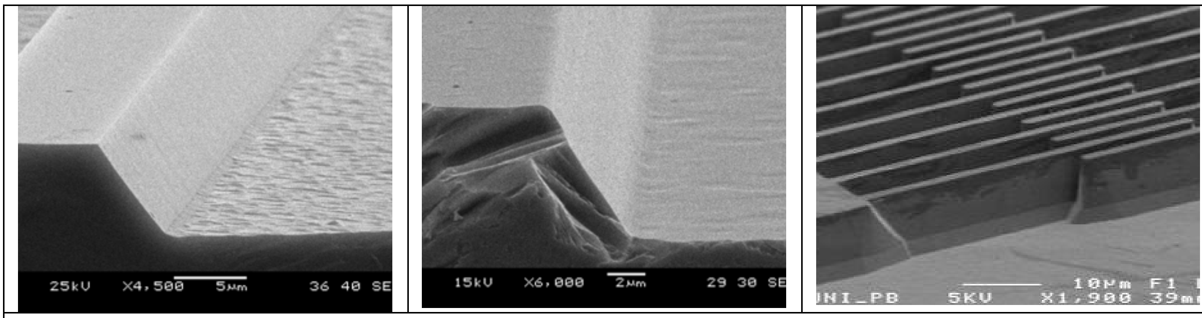

Figure 1: Wet etched ridge before Ti-indiffusion (left). Ridge guide after Ti-indiffusion (middle). Wet etched interdigital lamellas of 2.6 µm width, 2.8 µm separation, and 7.7 µm height (right).

Ar ion beam milling: ridge waveguides and optical "wires" in thin LN films

In contrast to wet etching, Ar milling can be used to etch LN substrates of any orientation. Moreover, underetching can be avoided and the walls of etched structures become smoother than with plasma etching processes. Unfortunately, the etching selectivity between LN and a metallic or photoresist mask is in general low, around 3 (metals) to 1 (photoresist). Therefore, it is hard to get a large etching depth (several micrometers), in particular for fine structures. Nevertheless, Ar-milling proved to be an excellent method to define ridge guides and optical "wires" of (sub-)micrometer cross section dimensions in crystal bonded thin LN films on SiO_2 or BCB [2, 3].

ICP etching of LN: ridge waveguides and microstructures

Plasma etching is a very efficient, precisely controllable process well-known from semi-conductor technology. Plasmas based on fluorine gases are generally used for LN etching due to the volatility of fluorinated niobium species at temperatures around 200 ^oC. The selectively between LN and a Cr-mask is larger than 10. However, a problem is the formation and re-deposition of LiF, which has a melting temperature above 800 ^oC. It will be deposited on all surfaces and will lower in this way the etching rate. Therefore, we do ICP-etching just for a few minutes in a C_4F_8/He plasma; then the sample is cleaned by SC-1 solution (70% H_2O, 20% H_2O2, 10% NH_4OH), and etching and cleaning are repeated several times until the desired depth is achieved. Fig. 3 shows examples on X-cut substrate.

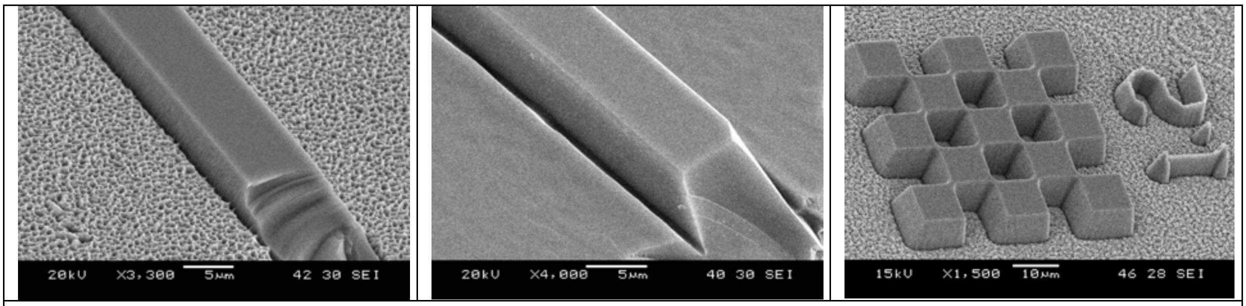

Figure 2: Ridge of 3 µm height before Ti-indiffusion (left). Ridge guide after Ti-indiffusion at 1060°C for 8.5 hrs (middle). Etched microstructures of 5.8 µm height (right).

ICP etching of proton-exchanged X- and Z- cut LN: photonic crystal structures

Another way to reduce the LiF deposition is to lower the lithium content in the LN surface by a proton exchange (PE) process before ICP etching [4]. Thus, the rate of LiF formation and deposition will be significantly reduced. Moreover, the ICP etching selectivity between PE-LN and a Cr mask rises to more than 16. We demonstrated the realization of this concept by performing first a PE in a surface of an X- or Z –cut LN substrate to a depth of 1.4 µm. Then a Cr mask of 120 nm thickness with photonic crystal structures was defined by optical contact photolithography. Afterwards, the sample was ICP etched for several minutes, cleaned in SC-1 solution, etched and cleaned again several times until the desired depth was achieved. Fig. 3 shows examples of photonic crystal structures in Z- and X-cut PE-LN with depths of 0.7 µm and 1.2 µm, respectively.

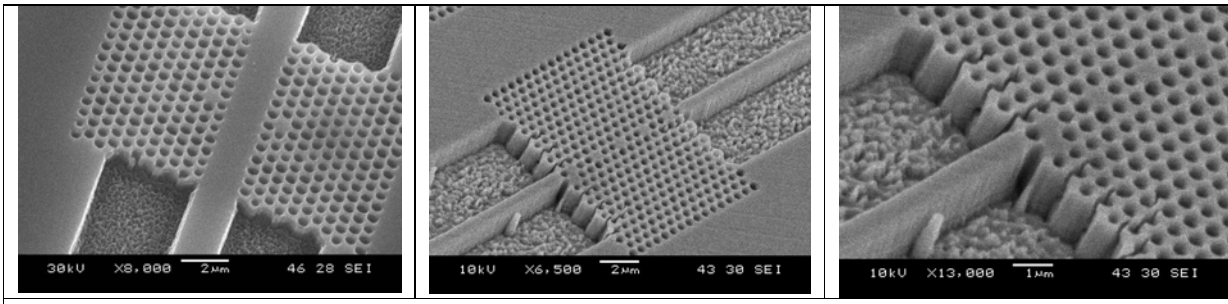

Figure 3: (Left): photonic crystal structure in Z- cut PE LN. (Middle, right): Photonic crystal structure in X- cut PE LN.

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