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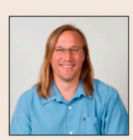

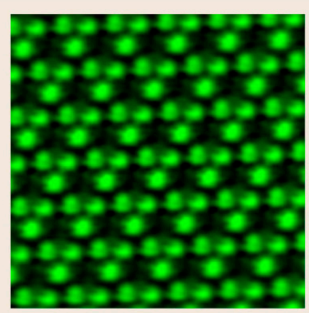

$LiNbO_3$ phase gratings prepared by a single excimer pulse through a silica phase mask

G. P. Luo,[a] Y. L. Lu, Y. Q. Lu, X. L. Guo, S. B. Xiong,
C. Z. Ge, Y. Y. Zhu, and Z. G. Liu
National Laboratory of Solid State Microstructures, Nanjing University, Nanjing 210093, People's Republic of China

N. B. Ming
CCAST (World Laboratory), P.O. Box 8370, Beijing 100080 and National Laboratory of Solid State Microstructures, Nanjing University, Nanjing 210093, People's Republic of China

J. W. Wu, D. S. Ding, and Z. H. Lu
National Laboratory of Molecular & Biomolecular Electronics, Southeast University, Nanjing 210096, People's Republic of China

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A transmission silica phase mask grating was used to fabricate $LiNbO_3$ wafer phase gratings by a single excimer pulse at 248 nm. The morphologies of the $LiNbO_3$ wafer gratings were studied with an atomic force microscope as well as an optical microscope. The crystal structures of the gratings were characterized by x-ray diffraction and three new crystal phases were found at the gratings' surface besides the substrate phase of LN (110). *© 1996 American Institute of Physics.* [S0003-6951(96)01736-6]

Fiber or planar waveguide Bragg gratings are attracting increasing interest for their potential applications in optical communication and integrated optics.[1–3] The method for fabricating Bragg gratings in optical fiber has developed rapidly in the past few years.[4–7] In the photolithographic method,[6,7] a silica phase mask was used to write Ge-doped fiber Bragg gratings by UV exposure. This method is very suitable for industrial environment because it is flexible, simple to use, insensitivity to the writing apparatus, and is functional even with low spatial and temporal coherence laser sources.

In semiconductors, Bragg gratings have been used as distributed reflectors to generate integrated semiconductor lasers, which are the key components for applications in optical communication and instruments. Recently, particular attention has been paid in the distributed feedback Bragg reflector (DBR) waveguide laser in erbium-diffusion $LiNbO_3$(LN) waveguide.[8] The above-mentioned Bragg gratings in the LN waveguide were fabricated by using the dry etching technique, which is complex, expensive, and is not suitable for mass production.

Our decision to use an excimer pulse to generate LN phase grating through a phase mask was triggered by the fact that focused excimer pulses have been employed to fabricate LN thin films or waveguidings from a LN bulk crystal target.[9,10] The energy of the incident excimer pulse was absorbed by the LN target crystal and transformed to a large amount of heat. The heat increases the temperature on the LN surface high enough to lead to fusing and spraying off of the exposured LN layer. Then a LN thin film can be formed by the annealing of the LN clusters deposited on the substrate.

In this letter, we report the direct etching of a LN phase grating by an excimer pulse through a silica phase mask. An atomic force microscope (AFM), as well as an optical microscope was employed to study the morphology of the LN gratings and, the structure of the LN grating was analyzed by x-ray diffraction pattern.

A commercial KrF excimer laser (Lambda Physik Model LPX205i) that delivered 50–200 mJ of energy per 30 ns pulse in a 7 mm×22 mm rectangular beam was used to generate the LN gratings. A schematic drawing of the experiment employed in this work is shown in Fig. 1. A cylindrical lens was placed before the silica phase mask to converge the long axis of the laser beam to about 5 mm at the surface of the LN wafer. A 5 mm×5 mm square filter with a thickness of about 100 μm, was placed between the mask and the LN wafer. The 5×5 mm^2 phase mask grating used in the present demonstration was formed by reactive ion etching of a fused quartz substrate with chromium mask patterned by electron-beam lithography. The chrome mask pattern consisted of equal lines and spaces with a 2 μm period. The etched channels in the silica were about 260±5 nm deep. The remaining chromium was removed with an acid etch.

The 248 nm zero-order diffracted beam of the silica phase mask was nulled below 10% and 40% of transmitted

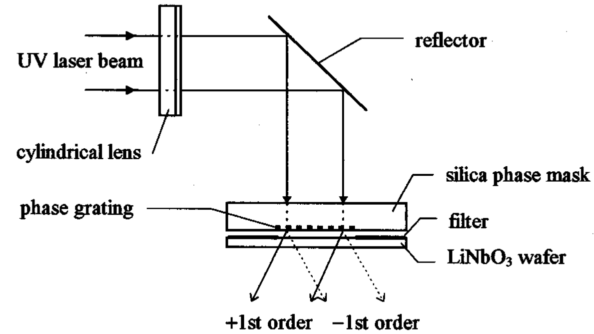

FIG. 1. A schematic drawing of photolithographic apparatus for etching a phase grating at the surface of $LiNbO_3$ wafer.

[a]Electronic mail: naiben@bepc2.ihep.ac.cn

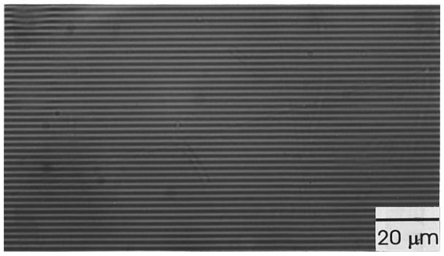

FIG. 2. Transmission optical microscope morphology of the as-etched LN phase grating.

light was contained by each of the plus and minus first order diffracted beams. An x-cut LN wafer, with a 10 mm×15 mm rectangular area and 1 mm thick, was polished carefully and cleaned in an acid solution before it was placed, with its a-axis parallel to the direction of the mask grating lines, in contact with the filter behind the silica phase mask.

Figure 2 shows the transmission optical microscopic morphology of the LN phase grating prepared by one excimer pulse with an incident energy of about 100 mJ, which results in the incident energy density of about 400 mJ/cm^2. The ablation lines on the LN wafer are straight and clear. The period of the lines is about 2μm, which is the same as that of the silica phase mask.

Figure 3 shows an AFM morphology of the as-prepared LN gratings. Compared with the unexposed LN wafer, the surface of the grating is uneven although the etched lines are sharp [as shown in Fig. 3(a)]. The period of the lines is about 2 μm and the depth of the trough is about 110 nm. The

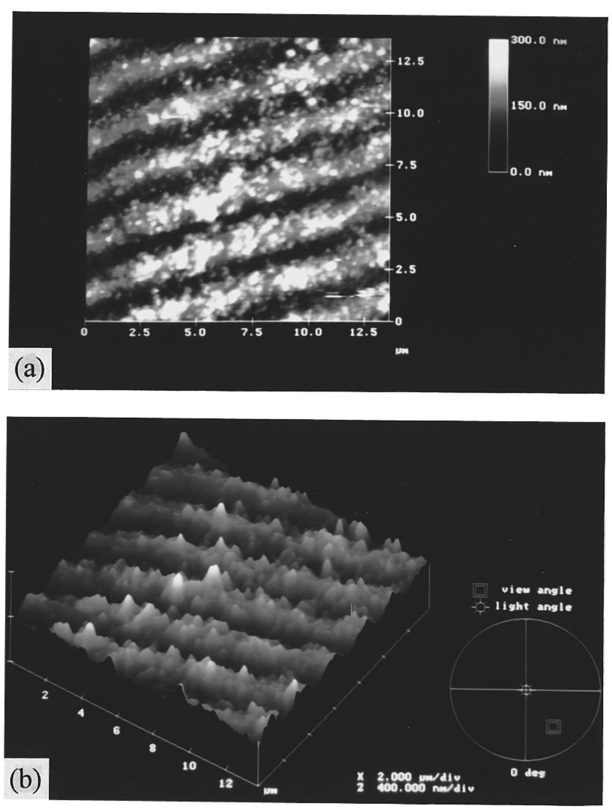

FIG. 3. The AFM morphology of the as-etched LN phase grating; (a) two-dimensional pattern of the LN grating in AFM, (b) three-dimensional pattern of the LN grating in AFM.

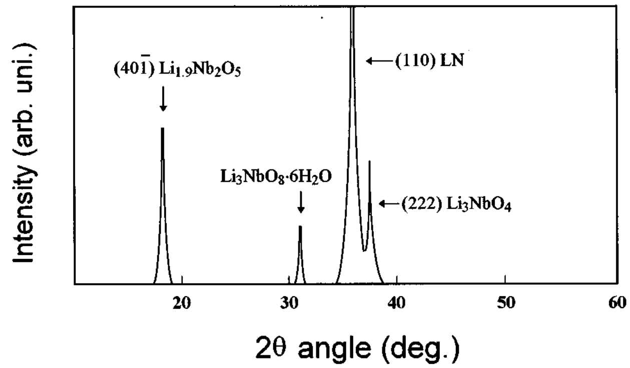

FIG. 4. The x-ray diffraction spectrum of the LN phase grating.

physical mechanism responsible for the excimer pulse ablation at the surface of the LN wafer is a thermal fusing and air annealing processing. The incident power of the excimer pulse is strong (12 MW/cm^2) enough to fuse a layer of the LN wafer. The interference pattern formed by the plus- and minus-order lines contains a sine period with the largest power about 24 MW/cm^2. A periodic thin layer of LN crystal will be fused and ablated by the incident light, which is strong and periodical with a sine power pattern. The fused LN layer of lines will spray from the bottom of the trough and will be redeposited at the LN surface, where the light strength of the interference pattern is the smallest. The morphology of the fused and redeposited LN clusters of the LN grating is shown in Fig. 3(b). We can also identify this processing with the observation of small clusters on the surface of the silica mask grating.

The structure of the ablated cluster on the surface of LN grating is characterized by the x-ray diffraction (as shown in Fig. 4). One can find that there exist three new phases ($Li_{1.9}Nb_2O_5$, Li_3NbO_8, and Li_3NbO_4) at the LN grating surface besides the substrate phase of LN (110). These three phases must be formed by the pulse ablation because the component of the exposured LN layer may be changed by the high energy density of the incident light.

We have obtained several LN gratings with different depth by using different incident power of the excimer pulse. The depth of the grating trough increases with the incident power of the laser pulse. It is worth noting that when the incident power of the laser pulse is small, there seems to be no depth to the grating lines; however, the color of the etched grating lines is darker than that of the unetched areas. This means that the exposed lines of the LN layer were not ablated by the laser pulse and instead, the crystal structure of the layer may have been changed to another one. The LN surface will be damaged heavily when the incident power is greater than 50 MJ/cm^2 and, the grating lines cannot be identified with the optical microscope because the surface of the LN layer was broken into a large number of blocks, which are very uneven and looks like hardened and impervious soil.

The diffraction patterns of the as-generated LN gratings were characterized by He–Ne laser beam. We find that the transmission spectrum of the grating is very clear and at least four orders of the diffracted beams can be formed. The spectra of the diffraction energy vary with the depth of the gratings which are etched by different excimer pulse energy.

In summary, we have demonstrated a method for fabricating LN phase gratings at the surface of a LN wafer by using an excimer pulse through a silica phase mask. The AFM morphology, as well as the optical microscope morphologies of the gratings are presented. The structure and the diffraction patterns of the gratings are analyzed and three new phases are found. We show that this method is very suitable for industrial evironments because the silica phase mask is easy to fabricate with the required period by computer control and the period accuracy of the one pulse (30 ns) generated LN grating is insensitive to the etching environment. This method can also be applied to fabricate Bragg gratings on the surface of UV-absorbing material waveguides, such as $LiTaO_3$ and ZnO, etc. Further experiments are just under way.

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