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Optical properties of ion implanted thin Ni films on lithium niobate

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Abstract. Ion implantation by keV Ar^+ ions creates blisters on the surface of thin Ni films deposited on lithium niobate and causes changes in optical properties and structure of Ni film and lithium niobate substrate. Processes of ion implantation and effects of increasing absorption, adhesion, damage threshold are described and explained in the paper. Development of pyroelectric photodetector "thin Ni film – lithium niobate" is proposed.

Keywords: ion implantation, thin Ni films, lithium niobate, optical properties.

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1. Introduction

Thin metal films on lithium niobate are widely used in infrared optoelectronics and known as high-sensitive systems of pyroelectric detectors, modulators, and power meters [1]. More sensitive triglycine sulfate and its isomorphic compounds have lower degradation stability what is unacceptable in a number of applications [2]. Weak adhesion of absorbing films to lithium niobate causes limitation of system application with power lasers. Usually, intensities over 2 W/cm^2 destroy absorbing coatings on the pyroelectric substrate [3]. Increasing adhesion of a metal film to lithium niobate by adding some transition layer is not permitted because of disfiguration of optical properties of the sample by 3rd compound. That is why, the method of ion implantation by ions of inert gas was selected for improvement mechanical and optical properties of the samples. Ion implantation stimulates defects generation, radiation-accelerated diffusion and other related effects by changing the surface structure of absorbing films and sub-surface layer of pyroelectric crystal. For this purpose, it was necessary to: 1) calculate energy and dose of selected ions for their maximal distribution at the interface film-substrate after implantation; 2) develop technology for sample preparation and processing; 3) investigate optical properties of ion implanted thin metal films on lithium niobate, compare with non-implanted and provide appropriate interpretation.

2. Experimental

Ar^+ ions were selected for ion implantation as the easiest and cheapest to obtain for environment. To determine the distribution function for Ar^+ ions and recoil atoms as a dependence on the ion energy, calculation of ion stopping ranges was made using the Monte-Carlo method [4] for Ni films on lithium niobate substrate. As shown in Fig. 1, the maximum number of ions accelerated to 50 keV stops at the depth of 20 nm from the sample surface, what corresponds to the interface film-substrate, if the film thickness is 20 nm. And for ion energies of 100 and 150 keV, the stopped ion distribution peak will be at 40 and 60 nm from the sample surface, accordingly. The optimal ion dose should be within 10^{15} to 10^{16} cm^{-2}. Obtained results were used for production of and processing the samples.

Slices of lithium niobate single crystal with the thickness of 100 µm were coated by Ni films with thicknesses 15, 20, 30, and 40 nm by using the ion plasma method [5]. Every second sample was implanted by Ar^+ ions with energies from 50 to 100 keV in dependence on its thickness according to Monte-Carlo calculations.

Spectral investigations (transmission and reflectance) were made using UR-20 spectrophotometer in the wide wavelength range from 0.2 to 15 µm varying source of light from quartz lamp to globar as well as prism of monochromator. Surface structure of the samples was investigated using DGSM-35 and Zeiss Ultra Scanning Electron Microscopies.

3. Results and discussion

Spectral investigations have shown that two absorption bands are observed for thin Ni films on lithium niobate substrate near λ = 5.5 µm and 6.2 µm (Fig. 2a), which can be related with presence of H – O – H groups in $LiNbO_3$ and by oscillation of H_2O molecular complexes and other inclusions. In the wavelength range near λ = 10.5 µm, an intense absorption band causes decrease in transmission. This band is related with valence bridge oscillations of oxygen in the octahedron NbO_6. These oscillations are fundamental phonons of lithium niobate single crystal [6].

The observed shift of the main absorption band from 11 to 10 µm in implanted Ni films on lithium niobate, as compared with non-implanted ones, is related with damaging the oxygen octahedron NbO_6 in the subsurface layer of lithium niobate single crystal during ion implantation. Bridges Nb – O – Nb are destructed. And valence bridge-like oscillation Nb – O – Nb transforms to regular valence oscillation Nb – O – Nb, the frequency of which is increased, and the peak wavelength shifts to 10.2 µm.

As shown in Fig. 2a, ion implantation causes rise of transmission of Ni-$LiNbO_3$ in visible and near infrared ranges (0.4–6.0 µm), what is the result of widening the transitional layer film-substrate owing to intensive ion intermixing at this interface as well as disordering and amorphization of Ni film and subsurface layers of lithium niobate substrate.

Results of spectral investigations of reflectance for Ni-$LiNbO_3$ have shown that the reflection coefficients decrease within the whole spectral range after ion implantation [7]. The maximal difference between non-implanted and implanted samples is 40% for the Ni film with the thickness of 15 nm. Comparing the optical properties with surface structure of the implanted and non-implanted samples, it is visible that decrease of reflectance spectra may be related with creation of a rough surface as a result of blister formation and decrease of heterogeneity of the interface film-substrate.

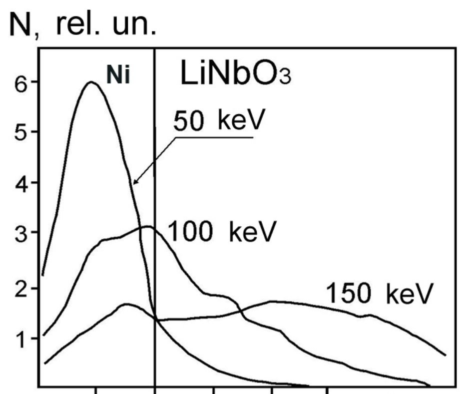


Fig. 1. Distribution of implanted Ar^+ ions along the depth (energy 50, 100, and 150 keV) in the system thin Ni film – lithium niobate substrate.

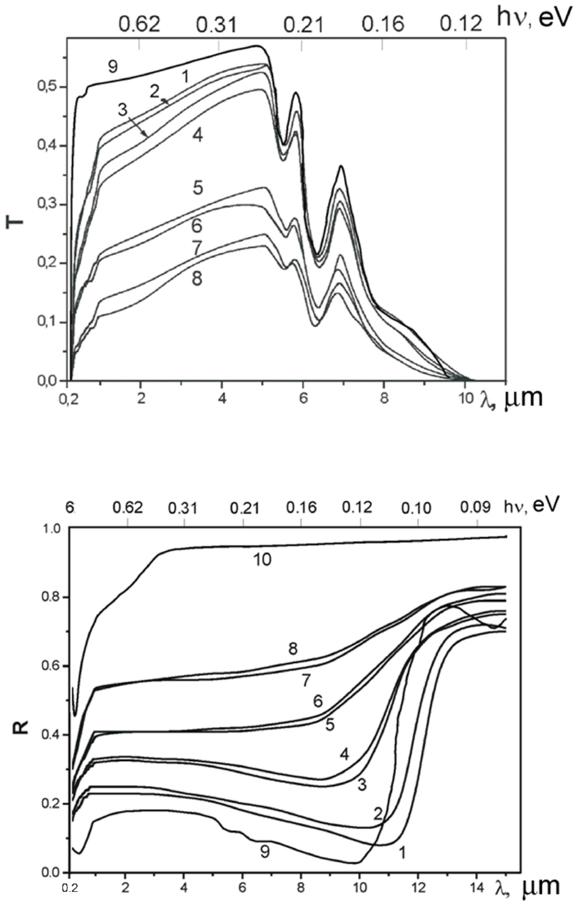
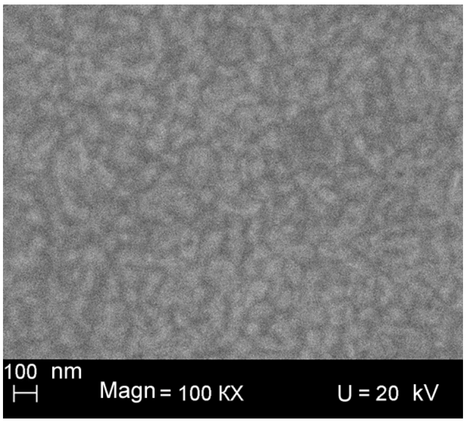


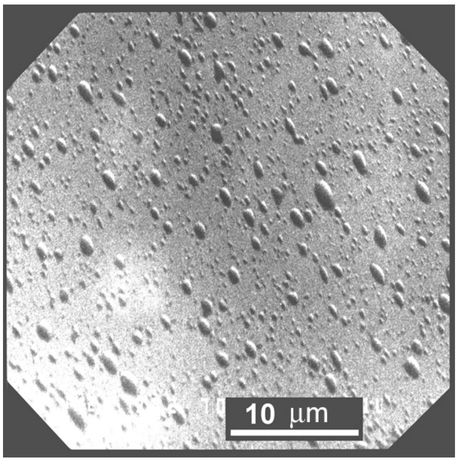
Fig. 2. Transmission (*a*) and reflectance (*b*) spectra of a thin Ni film with thicknesses of 15 (*1*, *2*), 20 (*3*, *4*), 30 (*5*, *6*), and 40 nm (*7*, *8*) before (*1*, *3*, *5*, *7*) and after ion implantation (*2*, *4*, *6*, *8*) in comparison with lithium niobate single crystal (*9*) and bulk Ni (*10*).

As shown by SEM investigations (Fig. 3), smooth thin 40-nm Ni film on lithium niobate before ion implantation (a) totally differs from the same sample after 100 keV Ar^+ ion (b), where blisters with the average dimension of 1 µm in diameter are observed, and amorphization of Ni film and subsurface layer of lithium niobate was observed using X-ray analysis.

Blisters appear as a result of argon exit from the film depth during thermal annealing after ion implantation [8]. Their formation makes surface rough and increases absorption of the surface coating. High coefficient of surface tension damage threshold doesn't allow blisters to prevent argon exit. Additionally, investigations have shown that adhesion between Ni film and $LiNbO_3$ substrate becomes at least two orders higher after ion implantation. This makes damage threshold of the samples over 50 W/cm^2. These advantages can be used for development of sensing system with enhanced radiation stability and sensitivity on the base of proposed implanted thin Ni films on lithium niobate [9].



a



b

Fig. 3. SEM image of thin Ni film (40 nm) on lithium niobate before ion implantation by Ar^+ ions (a) and after it (b).

4. Conclusion

It is found that ion implantation of thin Ni films on lithium niobate decreases reflectance and increases absorption in the wide wavelength range (λ = 0.2–15 µm) as a result of: 1) blisters formation on the samples surface, increase of diffuse scattering and absorption of the sample; 2) decrease of heterogeneity on the interface film-substrate by ion intermixing; 3) amorphization of subsurface layer of film and substrate.

Ion implantation destroys valence bridge bonds Nb – O – Nb and transforms corresponding oscillations to regular valence oscillations Nb – O , increasing frequency. Ion implantation led to bubble-like blisters formation with the average diameter of about 1 µm.

A sensing system based on the structure thin Ni film – lithium niobate implanted by Ar^+ ions has been developed for application in pyroelectric photodetectors. Their characteristics such as sensitivity, detectivity, radiation stability, time constant, durability do not yield a point to the corresponding characteristics of the best analogues.

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