BRILLOUIN LIGHT SCATTERING STUDY OF Cu IONS DOPING ON THE $LiNbO_3$ CRYSTAL ELASTIC PROPERTIES

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Influence of doping effects of Cu ions on the elastic properties of the $LiNbO_3$ crystal in were studied by the Brillouin light scattering method. Dopant concentration of Cu was equal to 0.05mol%. Comparison with pure samples showed relative decrease in frequencies falling in the range of 4-11 %. Measurements were done in different scattering configurations.

Keywords: Brillouin scattering, Lithium niobate

1. INTRODUCTION

The Lithium niobate single crystals are widely used in opto-electronic devices. In many situations, however, there is a need to use doped crystals. The doping process followed by appropriate thermal treatment, not only influences electronic and optic properties, but also is able to cause large-scale elastic modifications sensitive to acoustic methods.

There are many research results concerning the electro-optical properties of doped lithium niobate. For example: the investigations of the electro-optic properties in Er-doped material [1, 2]; measurements of refractive index in the Zn-doped crystal [3]; observations of photoconductivity spectra and electron mobility in $LiNbO_3$ co-doped with Cr^{3+} and MgO [4]; the effect of chromium doping on electro-optic properties [5]; as well as investigations of variations of lattice parameters and optical absorption spectra in Mg and/or Fe materials [6].

Brillouin scattering measures photon frequency changes caused by acoustic phonons in scattering processes. The frequencies of phonons from the 20-30 GHz range, and the acoustic wave-length of the $2 \cdot 10^{-5}$m value, are able to control long-range crystallographic order [7]. Relatively small amount of dopants, from a physical point of view, do not influence elastic

properties; however, because technological processes can modify the structure of crystals, Brillouin scattering is useful in the investigation of doping.

2. EXPERIMENT

Brillouin scattering measures changes of photon frequencies scattered in the annihilation or creation processes by phonons lying at the beginning of the first Brillouin zone. The method can be applied for small samples of arbitrary dimension. The measured frequencies provide, firstly, information such as is obtained in every Brillouin type experiment. Then, appropriate velocities and states of polarization of acoustic waves can be calculated, and additionally, elastic constants of the investigated crystals can be derived. Experimentally observed optical signals in Brillouin scattering experiments possess a characteristic pattern, where we see a set of strong lines from elastic scattering, the Rayleigh lines, and very weak Brillouin peaks resulting from inelastic creation (stokes line) and annihilation (anti-stokes line) of acoustic phonons by photons.

Brillouin scattering experiment used the equipment included: a single-mode Ar^+-ion laser working at 514.5nm wavelength, with a power of about 100mW; a single-pass pressure-scanned Fabry-Perot interferometer with a finesse parameter equal to about 35; and a single photon counting unit for low-level intensity light detection equipped with the R4240P Hamamatsu photomultiplier. Pressure-controlled interferometry with linear scanning was obtained by the use of pressure sensors, which provide voltage signals linearly proportional to the pressure in the chamber where the interferometer was placed. The polarizations of incident light and scattered light were controlled and (for the results presented here) were perpendicular in order to observe scattering on quasi-transverse waves. The full spectral range FSR of the Fabry-Perot interferometer was equal to 37.5 GHz, which enabled observation of scattering on transverse and quasi-transverse acoustic waves.

Samples of pure and doped $LiNbO_3$ crystals have been prepared under similar technological conditions. Cubes of the 1cm side cut in such a manner that main crystallographic directions were parallel to the sample edges. Scattering was made for three different situations, namely phonons can propagate in the [110], [101], or [011] directions. Results of measured frequencies for pure and doped samples are given in Tab. 1.

Tab. 1. Frequencies of quasi-transverse acoustic wave for the pure and Cu doped $LiNbO_3$ crystal. The provided values are valid for the level of confidence (standard deviation) equal to 0.7.

Phonon propagation direction	Measured frequency in a pure crystal (GHz)	Measured frequency in a doped crystal (GHz)	Relative change of frequency (%)
[110]	26.1 ±0.6	25.0 ±0.2	4
[101]	25.4 ±0.4	23.8 ±0.5	7
[011]	25.1 ±0.3	22.2 ±0.3	11

It is important to note that the relative changes of hypersonic frequencies, caused by doping, are equal to the relative changes of acoustic wave speeds; they are thus proportional to elastic module changes. In all the presented cases, frequencies for doped material were lower than for a pure crystal.

3. CONCLUSIONS

This paper reports the results of experimentally examined acoustic wave frequency changes caused by doping of the $LiNbO_3$ crystal. It is well known that an acoustic wave has a wavelength larger than the typical dimension of the elementary crystallographic cell, so it is sensitive to large-scale features. The measurements showed that even a very little amount of dopant (in our case the concentration of Cu atoms was of the order of $10^{16}m^{-3}$), influences the elastic and acoustic properties of the $LiNbO_3$ crystal. A brief look at the monoatomic chain model of the crystallographic lattice [8] assures us that such a little amount of dopant cannot influence acoustic modes. The reason for the observed changes lies in the technological process. Ones needs to examine a large number of samples to apply the presented method in industry. Brillouin scattering is especially suited for this task because of its nondestructive character as well as its applicability for little samples of arbitrary dimensions.

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