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Preface to Special Topic: Lithium Niobate Properties and Applications: Reviews of Emerging Trends

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Lithium Niobate (LN) is a synthetic dielectric material with large transparency windows in the visible and near IR, characterized by a remarkable combination of functional properties. It is piezoelectric, ferroelectric and presents high electro-optic and nonlinear optical coefficients. It can be used to generate intense local electric fields by pyroelectric or photogalvanic effects. A combination of electro-optic and photogalvanic effects makes also LN photorefractive without the need for any applied field, so that it can be conveniently employed for holographic recording or phase conjugate optics. The possibility to add dopants in a controlled way by standard material processing techniques such as bulk doping, ion implantation or thermal diffusion further expands the range of possible applications, so that LN can be considered as a sort of "toolbox" for integrated optics and beyond.

Thanks to these characteristics, since the pioneering experiments in the sixties for growing crystal boules of exploitable size, numerous optical devices and components were developed using this material either in bulk crystals (Q-switches, Surface Acoustic Wave filters), waveguides (modulators and other integrated optical circuits), or domain engineered structures (frequency converters and Optical Parametric Amplifiers). In turn, this has pushed the technology for its production to high quality standards so that nowadays this material is available in large wafers at a reasonable price together with sophisticated processing techniques. The development of this material is therefore somehow reminiscent of the explosive growth of the semiconductor industry, so that it could be guessed that LN has nowadays entered into its maturity, as several LN-based devices are mass-produced in a quantity that is nowadays relevant to industrial markets.

This is, however, only partly true. On one hand, a wealth of data is available concerning some specific aspects of this material such as the ferroelectric domain physics, the material processing technology for the fabrication of integrated optical devices, and the characterization techniques. Literature on these topics is very rich and witnesses the widespread interest of the scientific community on lithium niobate. On the other hand, there are several new aspects that are only recently being understood. LN structure is much more complicated with respect to that of standard semiconductor materials. In particular, intrinsic defects play a key role in determining the material response, either on its optical properties or on nucleation and growth of ferroelectric domains during electric field poling. The ability to master the material defect structure and the understanding of the related physics are nowadays much different than what it was only ten years ago. Finally, in the last years, several groups have started using LN for new applications, taking advantage of its pronounced polar properties for different purposes, such as the manipulation of small particles suspended in a fluid.

We felt therefore that it would be desirable to have a review series dedicated to this important material, which could provide an updated account of the state of the art concerning progress in the preparation and characterization of LN under various forms, and to have a look at the new research trends which are likely to characterize what will be done with this material in the next years.

We intentionally chose an application-oriented point of view without the presumption of covering all aspects, but rather trying to select some topics that seemed to us of special interest for present and future technological possibilities.

Six reviews are presented, each one devoted to areas having recently attracted special interest for new properties and/or applications. The first paper reports on progresses achieved in the preparation of samples with stoichiometric composition or with controlled defect content, which, as mentioned before, are crucial in determining many materials properties. This aspect stimulated also the need for versatile and convenient characterization techniques able to probe the defect structure. In the second paper, Raman spectroscopy is presented and used as a site-specific technique to probe the incorporation of intrinsic and extrinsic defects in LN and to control the structure of devices as well. Together with material composition, fabrication methods are one of the key points for LN–based applications. In the third paper, new waveguide fabrication methods are illustrated and compared with classical techniques, while in the fourth paper the physical principles and the new applications of micro- and nano-domain engineering in congruent, MgO-doped, and stoichiometric LN are reviewed. Finally, new and more explorative directions in the use of LN are reported. In the fifth contribution, the emerging role of LN is reported as an innovative substrate for manipulation of a large number of nano-objects, which paves the way for the use of LN in new research areas. In the sixth paper, instead, the use of LN as a nonlinear optical material in the era of ultra-fast lasers is considered, which nowadays have become quite popular and available in many different laboratories. At these regimes, the response of the material is governed by photo-induced, self-localized charge carriers (polarons), and the recent advances on this topic (often made possible precisely by experiments in LN) are presented.

All these aspects are somehow interrelated, so that, even if each contribution is self-consistent, it is particularly interesting to have them grouped together in this special issue.

In conclusion, the collection of these 6 review papers provides a wide survey of recent research on LN. 2015 is the International Year of the Light, and this gives a special interest to this issue on a material that is generally considered for photonics what Silicon is for electronics. We hope that this can stimulate new opportunities for a deeper basic understanding and innovative practical applications of this material in new devices.

Contents and authors

1. **Growth, defect structure and THz application of stoichiometric lithium niobate**

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2. **Microstructure and defects probed by Raman spectroscopy in lithium niobate crystals and devices**

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5. **$LiNbO_3$: A photovoltaic substrate for massive parallel manipulation and patterning of nano-objects**

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6. **Optical nonlinearities of small polarons in lithium niobate**

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