Unidirectional Cherenkov Radiation for Improved Terahertz Generation in the Si-Prism-Coupled $LiNbO_3$ Layer

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We show that a Cherenkov emission of terahertz waves from a femtosecond optical pulse propagating in a $LiNbO_3$ crystal can be strongly spatially asymmetric with respect to the direction of the optical pulse propagation. We propose using this phenomenon to improve the spectral characteristics of one of the most efficient optical-to-terahertz converters: a thin $LiNbO_3$ layer attached to a Si-prism outcoupler.

I. INTRODUCTION

One of the most efficient optical-to-terahertz converters is the structure consisting of a thin (30-50 µm thick) layer of $LiNbO_3$ (LN) attached to a Si-prism outcoupler [1, 2]. A femtosecond laser pulse propagates in the LN layer as a guided mode and produces nonlinear polarization, which emits a Cherenkov cone of broadband terahertz radiation in the Si prism. The prism couples the radiation into free space. An inherent disadvantage of the converter is a dip in the generated terahertz spectrum (for example, at ~1.4 THz for a 30 µm thick LN layer) originating from the destructive interference of the terahertz waves emitted to the Si prism from the LN layer directly and after reflections from the layer boundaries. The presence of the dip can limit application possibilities of the converter, particularly for spectroscopic purposes.

II. RESULTS

We propose a way of removing the dip from the generated terahertz spectrum. Our approach relies on the phenomenon of spatial asymmetry of the Cherenkov radiation emitted by a moving nonlinear polarization, $\mathbf{P}^{NL}$, which is tilted with respect to the direction of motion [3]. We show that in LN the orientation of the crystallographic axes can be arranged in such a way that the line-like (stretched along the y axis) nonlinear polarization $\mathbf{P}^{NL}(x, \xi)$, produced by a focused-to-a-line pump laser pulse ($\xi = t - z/V$, V is the group velocity), will be almost perfectly orthogonal to the electric field $\mathbf{E}$ (tilted with respect to the displacement $\mathbf{D}$) on a half of the Cherenkov wedge (Fig. 1) [4]. As a result, this half-wedge will be practically not generated and almost all terahertz radiation will be emitted in the direction normal to the other half of the Cherenkov wedge.

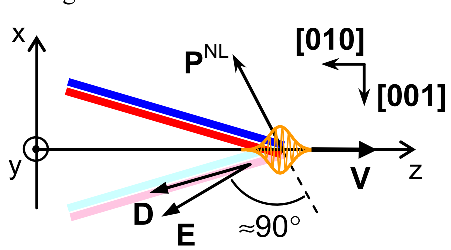

Fig. 1. Geometry of unidirectional Cherenkov radiation from a laser pulse in an infinite LN crystal.

We propose applying the phenomenon of unidirectional Cherenkov radiation to the converter to concentrate the terahertz emission in the direction of the Si-prism outcoupler, thus avoiding the reflection from the LN-air boundary [Fig. 2(a)]. Moreover, since the incidence angle of the Cherenkov radiation at the LN-Si boundary appears to be conveniently close to the Brewster angle, the reflection from this boundary (and therefore multiple reflections in the LN layer) will be also suppressed. Thus, the terahertz waves emitted to the Si prism directly will have practically no other waves to interfere with, and this should eliminate the dip in the terahertz spectrum. Figure 2(b) shows the terahertz spectrum (solid) accurately calculated on the basis of the Maxwell equations for the converter with a 30 µm thick LN layer excited by a Ti:sapphire laser pulse with a 100 fs duration. The reference spectrum for the standard converter with symmetric Cherenkov radiation [1] (dashed) is shown for comparison. Contrary to the converter with symmetric Cherenkov radiation, the converter based on the unidirectional Cherenkov radiation has no null in the generated spectrum.

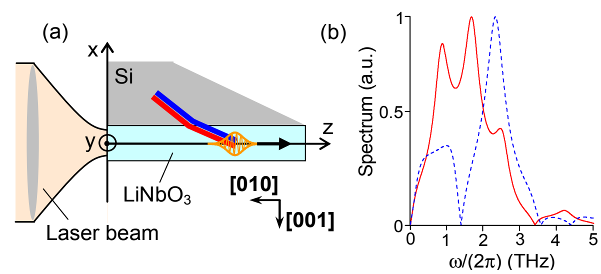

Fig. 2. (a) Converter schematic. (b) The emitted terahertz spectrum (solid) and the reference spectrum for the converter with symmetric Cherenkov radiation [1] (dashed).

III. SUMMARY

The phenomenon of strongly asymmetric (unidirectional) Cherenkov radiation of terahertz waves from a femtosecond laser pulse propagating in a $LiNbO_3$ crystal has been theoretically demonstrated. We propose to apply this phenomenon to suppressing the interference effects in one of the most efficient optical-to-terahertz converters: the Si-prism-coupled $LiNbO_3$ layer. As a result, a null in the emission spectrum of the converter, which limits its application possibilities, can be eliminated.

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