Characterization of terahertz generation based on the different structures of lithium tantalate crystals

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***Abstract*—Difference in the terahertz generations from three types of 1 mol % MgO-doped stoichiometric $LiTaO_3$ crystals were analyzed. Weak single-cycle, multi-cycles, and strong single-cycle terahertz pulses were radiated at bulk, periodically poled, and angle-cut structures, respectively. The three different types of terahertz generation depend on the phase-matching process.**

I. Introduction And Background

TERAHERTZ (THz) technology has been spotlighted in various industrial and academic fields during past decades. THz wave spectrum lies between millimeter wave and far infrared band, thus, both unfamiliar technologies, electrics and photonics, have been converged toward THz band due to its variety of benefits. Various applications such as imaging, spectroscopy, diagnosis, communication, and astronomy have been developed in THz region.

An efficient way for generating THz waves is using nonlinear optical crystals with ultrashort optical pulses due to its high conversion efficiency and wide applicability. Among many nonlinear materials, lithium tantalate ($LiTaO_3$, LT) and lithium niobate ($LiNbO_3$, LN) are mostly used owing to its high nonlinear coefficients. However, the strong dispersion in optical and FIR regions prohibits the phase-matching between fundamental and generated waves, decreasing THz output. Quasi-phase-matching (QPM) was introduced using periodically inverted poled structures and multi-cycle THz pulses were generated with narrow bandwidth of tens of GHz.[1, 2] Additionally, J. Hebling and co-workers demonstrated strong single-cycle THz generation using tilted pulse-front excitation method with LN crystals.[3]

In this report, we performed three different types of THz generation schemes. The bulk and periodically poled structures were used in simple transmission-type THz generation schemes, and the angle-cut structure was utilized in a tilted pulse-front pumping scheme. The phase-matching processes among the three-type structures were totally different and resulted in different THz electric field shapes with different field strengths. Based on this comparison, we would suggest the new scheme of THz generation that the QPM scheme is adopted in tilted pulse-front excitation methods, enabling tunable and high-power multi-cycle and narrowband THz generation.

II. Results

The Ti:sapphire regenerative laser system with a repetition rate of 1 kHz, a pulse duration of 190 fs, a center wavelength of 794 nm was used as an optical pump and probe. The 3 mm-long Z-cut bulk, 4 mm-long periodically poled with a QPM period of 80 μm, and angle-cut (71°) 1 mol% MgO-doped stoichiometric LTs (MgO:SLTs) were used. In the tilted pulse-front pumping scheme, the holographic grating of 1800 grooves/mm and the cylindrical lens with a focal length of 50 mm were utilized.

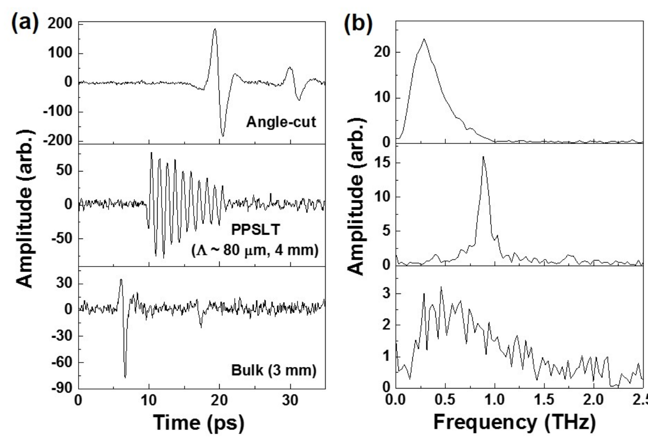

Fig 1. (a) Terahertz waveforms and (b) the corresponding spectra at each structure of MgO:SLT crystals.

As shown in Fig. 1, the THz pulses have different shapes, showing weak single-cycle, multi-cycle, and strong single-cycle electric fields from the different three SLT structures. The difference is based on the phase-matching. We confirm that the simple bulk crystal can contributes the THz generation only at the sample surfaces due to the strong phase mismatch based on the dispersion. The multi-cycle waveform is originated from QPM at the periodic structure of the PPSLT crystal. Due to the absorption, the decay of the THz electric field is obtained during propagation within the crystal. The cryogenic experiment can retrieve the whole multi-cycle of THz field corresponding to the domain number of the periodic structure. Subsequently, the relative peak ratio of electric fields are 1 to 1.37 at bulk and QPM structures, respectively. This confirms that the each domain of the PPSLT contributes the generation of the half-cycle of a THz pulse. However, the angle-cut SLT in the tilted pulse-front pumping scheme has about 2.4 times lager THz e-field strength than the QPM sample due to the improved phase matching condition. It means that the whole crystal length can contributes the THz generation in phase, showing the strong single peak of e-field.

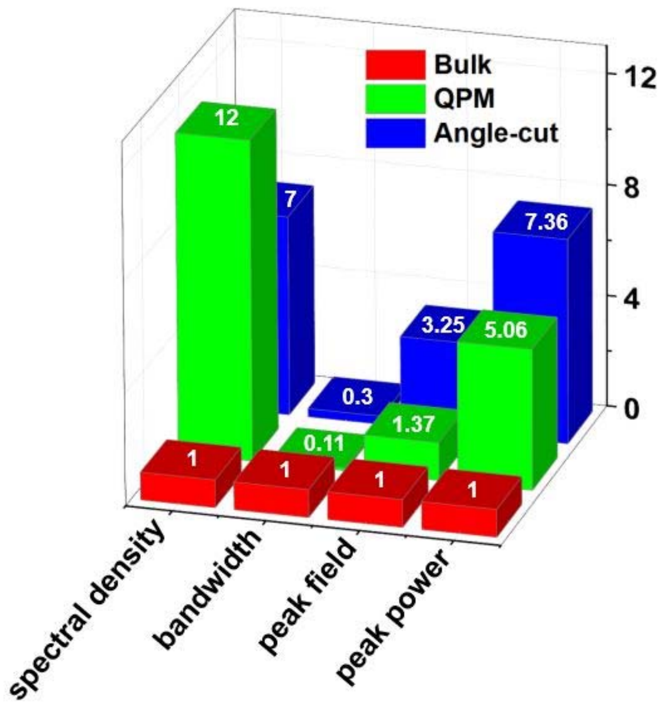

Fig 2. Comparison of THz outputs at the different 3 SLT structures.

The spectra analysis is shown in fig. 2. Due to the different phase matching condition, the corresponding spectra are changed. The spectral peak values of QPM and angle-cut samples are much larger than that of the bulk (more than about five and seven times, respectively). However, comparing between QPM and angle-cut structures, it is noted that the relative spectral density of QPM structure is much larger than that of the angle-cut sample. Because, the bandwidth of the QPM sample is much narrower than that of the angle-cut sample. It means that even QPM process in a periodically polled structure is weaker interaction than the perfect phase-matching in tilted pulse-front pumping scheme, a number of e-field cycle can contribute to improve the THz output. Such a strong narrowband THz pulse is a fundamental light source in high-resolution spectroscopy and imaging, etc.

In addition, the new scheme of THz generation would be suggested that the QPM scheme is adopted in the tilted pulse-front pumping scheme. Stronger narrowband THz pulse generation is possible than that of the ordinary QPM scheme. Thus, high-power tunable narrowband THz generation is prospective.

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