Cascading in THz Wave Generation by Optical Rectification

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Cascading effects were analyzed for the THz wave generation by optical rectification in an electro-optic crystal using intense femtosecond optical pulses. Coupled equations describing the propagation of the optical and THz fields were solved numerically. Cascaded difference frequency generation within the pump pulse spectrum was observed to leads to red shift of the pump light spectrum and almost linear growth of THz amplitude as a function of propagation distance. Conversion efficiency of THz waves higher than the Manley-Rowe limit, which corresponds to 100% quantum yield, was obtained in the simulation using a ZnTe crystal.

I. Introduction

Development of compact sources of intense terahertz (THz) waves is required for real-time applications of THz waves such as imaging [1]. Large-aperture photoconductive antennas have been used for this purpose, and its low-voltage version is being developed using interdigitated electrode structures [2]. The output of photoconductive antennas, however, is saturated at relatively low excitation intensity, and the bias field strength is limited by the occurrence of electric breakdown.

Optical rectification (OR) in electro-optic (EO) crystals can potentially emit intense THz waves under excitation by intense femtosecond optical pulses. Saturation of the output occurs at much high excitation level, and the THz spectrum can extend to much higher frequencies. An apparent limitation of the output of the OR method is given by the Manley-Rowe limit, which corresponds to 100% photon conversion efficiency from light to THz waves. Since THz photons have energy much smaller than the optical photons, 100% photon conversion corresponds to an energy conversion efficiency less than 1%.

By using cascaded processes, however, this limit can be lifted. In the present study, numerical simulations of the OR processes including the cascading effects were carried out using one-dimensional coupled differential equations describing the propagation of the optical and THz field.

II. Simulation Results

In the calculations, propagation of intense femtosecond optical excitation pulses (800 nm, 180 fs) and generated THz waves in a ZnTe crystal was simulated under various conditions. Typical results on the propagation-distance dependence of the optical spectrum are shown in Fig. 1, where absorption of optical and THz field is neglected. The spectra show gradual red shift during propagation, which is due to conversion of an optical photon to a THz photon and a lower-frequency optical photon (difference frequency generation process). The continuing red shift evidences that photon recycling, or cascaded OR processes, is taking place. The growth of the THz wave amplitude was observed to be almost linear to the propagation distance under perfectly phase matched condition, and sublinear under the actual ZnTe dispersion. Conversion efficiency beyond the Manley-Rowe limit was achieved under realistic conditions.

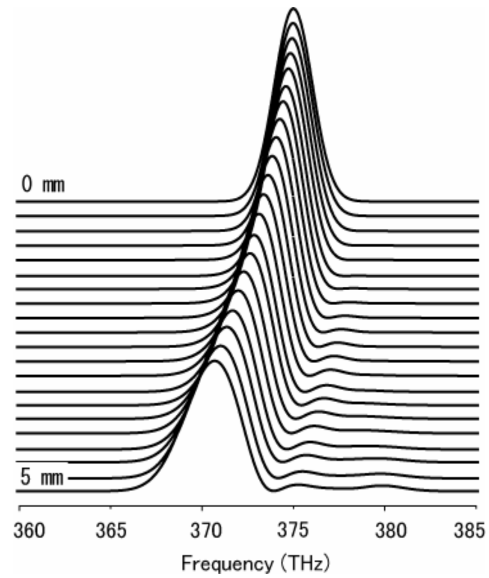

Figure 1. Propagation distance dependence of the excitation light spectrum. Gradual red shift corresponds to cascaded difference frequency generation. Peaks at higher frequencies are due to sum frequency generation, which takes place simultaneously.

It was found that a characteristic length describing the cascading process can be expressed by a simple function of the excitation intensity and other parameters. When finite losses of THz and optical waves are included in the simulations, the cascading length should be shorter than the absorption length for the cascading processes to be observed..

References

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