POLARIZATION DEPENDENCE OF OPTICAL PARAMETRIC GENERATION IN ORIENTATION-PATTERNED GaAs

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Gallium arsenide (GaAs) is a highly promising material for mid-infrared frequency conversion because of its broad infrared transparency range ($\lambda = 0.9$-$17\ \mu$m), large nonlinear susceptibility ($d_{14} = 94$ pm/V around $\lambda = 4\ \mu$m), and high thermal conductivity. The high symmetry in GaAs, in both its nonlinear susceptibility and its linear optical properties, leads to interesting polarization behavior. Usually, optical isotropy (i.e. lack of birefringence) in a crystal makes it unsuitable for efficient nonlinear optical conversion due to the inability to achieve phasematching. However, quasi-phasematching (QPM) can be achieved in GaAs by a growth process developed at Stanford that produces periodic inversions of the crystallographic orientation; this material is called orientation-patterned GaAs (OP-GaAs). The material is produced through a process combining molecular beam epitaxy (MBE), lithographic patterning, wet etching and thick-film hydride vapor phase epitaxy (HVPE). OP-GaAs has been used to demonstrate second harmonic generation, difference frequency generation, and optical parametric oscillation (OPO) as well as optical parametric generation (OPG) that produced an ultra-broad mid-infrared spectrum spanning 4.5 to 10.7 μm. We have recently explored pump-polarization dependence in OPG.

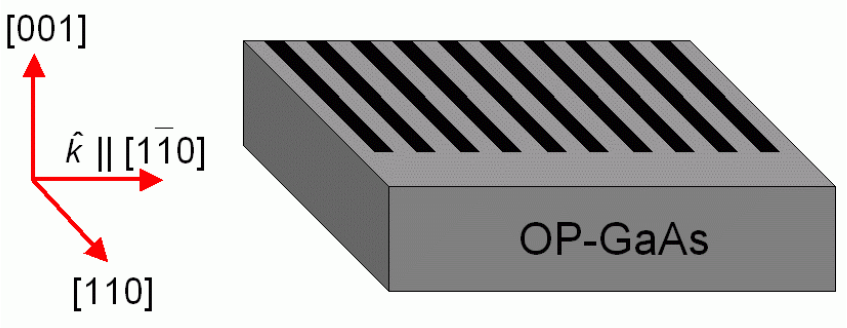

Figure 1: Geometry of optical waves propagating in an OP-GaAs crystal. The waves propagate in the $[1\bar{1}0]$ direction and have electric fields confined in the plane normal to $[1\bar{1}0]$.

Interesting polarization behavior in GaAs arises from its high symmetry. GaAs is not birefringent, and it has only one non-zero, independent, nonlinear-susceptibility coefficient, d_{14} (corresponding to d_{xyz}). The effective nonlinear coefficient, d_{eff}, for different input pump polarizations can be calculated by writing out the nonlinear polarization matrix equations and considering the propagating components. In three-wave mixing in GaAs, typically the interacting waves all propagate in the $[1\bar{1}0]$ crystal direction such that the electric fields are in the plane containing [001], [110] and [111] (see Fig. 1). We expect the effective nonlinear coefficient to be largest when all three waves are parallel to [111] with $d_{eff} = 2/\sqrt{3}\, d_{14}$. In Fig. 2a, we calculate d_{eff} as a function of pump polarization for the OPG or OPO process. One interesting observation is that d_{eff} varies from a minimum of d_{14} up to $2/\sqrt{3}\, d_{14}$, which implies that all pump polarizations can be efficiently utilized by OP-GaAs. Circularly polarized or even an unpolarized pump can be used with OP-GaAs. In contrast for periodically poled $LiNbO_3$, a pump polarized along [001] is significantly more efficient for OPG or OPO than any other incident pump polarization.

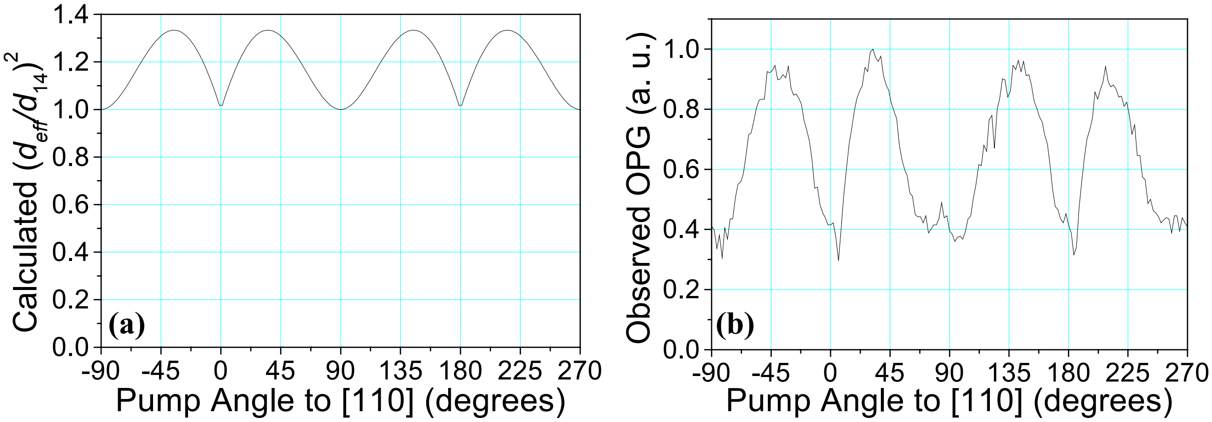

Figure 2: (a) Effective nonlinear coefficient for OPG for different pump polarization angles; (b) observed OP-GaAs optical parametric generation as a function of pump angle to [110].

In our experiment, we pumped a 17.5-mm-long, 0.5-mm thick, 166.6-μm-period OP-GaAs sample with 1-ps duration, 3.1-3.3-μm wavelength pulses with energy up to 2 μJ. The pump was focused to a 75-μm $1/e^2$-intensity-radius spot. The pump was circularly polarized using a quarter-wave plate, and then a rotating wire grid polarizer was used to select linear polarizations of different angles while maintaining the same intensity. The mid-infrared OPG output was measured with an amplified pyroelectric detector.

The observed OPG as a function of incident pump polarization is plotted in Fig. 2b. We see good qualitative agreement between the experiment and the calculated dependence of OPG on pump angle (noting that unsaturated OPG is an exponential function of d_{eff}). Maxima were observed at 35°, 145°, etc. when the pump is parallel to <111> crystal directions. Both the theory and the experiment showed differences in the shape of the minima at 0° ([110]) as compared to at 90° ([001]).

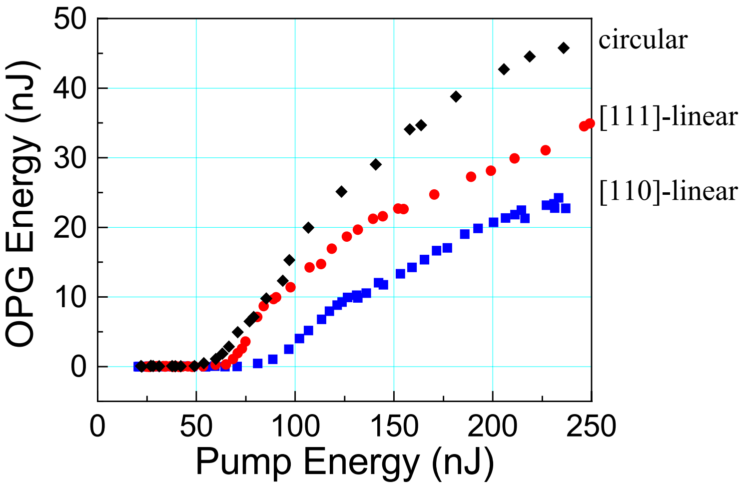

Figure 3: OPG energy curves for circular, [111]-linear and [110]-linear pump polarizations.

We also compared the OPG efficiency for linear and circular pump polarizations (see Fig. 3). We expected the circularly polarized pump to have equal efficiency as the [111] linearly polarized pump. However, the experiment showed that the circularly polarized pump had slightly lower threshold and higher efficiency than the [111] linearly polarized pump. We suspect the circularly polarized pump performed better because it suffers less from parasitic nonlinear index effects that are present at the high optical intensities of the OPG experiment.

We have observed efficient optical parametric generation for all linearly polarized pump angles, as well as for a circularly polarized pump. This result suggests that OP-GaAs can be efficiently pumped with sources of various polarizations including unpolarized sources such as some fiber lasers.

References

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