Measurement of thermal lensing in GaAs induced by 100-W Tm:fier laser

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We present the characterization of thermal distortion induced in bulk and orientation-patterned GaAs samples by a 100 W narrow linewidth, linearly polarized CW Tm:fiber laser focused to ~150 µm diameter. For a 500-µm thick bulk GaAs sample, the induced thermal distortion is measured using a probe laser beam at 1080 nm and a Shack-Hartmann wavefront sensor (SHWS). We also compare the power dependent induced divergence for 500-µm thick bulk GaAs and 10-mm thick orientation-partnered GaAs (OP-GaAs) samples as they are translated axially through the focus of a 2-µm wavelength Tm:fiber laser beam.

Introduction

Recent efforts to develop robust and efficient sources of energetic mid-IR light sources, such as the work of Creeden et al. [1], demonstrate the utility of Tm:fiber lasers as pumps for nonlinear frequency conversion. As part of our efforts in the development of Tm:fiber lasers offering high average power [2,3], high peak power [4,5] in the 2-µm wavelength regime, and high peak power mid-IR optical parametric oscillators (OPO) [6], we have found that there is a need for "new" techniques to characterize the thermo-optic properties of mid-IR materials. As discussed in [6], the OPO setup shown in Fig. 1 was sensitive to thermal lensing effects even at the relatively low pump power of ~4 W. This was primarily due to the linear absorption of the ZGP nonlinear crystal at the pump wavelength of 1979 nm [7]; however thermal-optic effects can also be significant in the 2-µm wavelength regime for other elements such as optical isolators, lenses, waveplates, mirrors, etc.

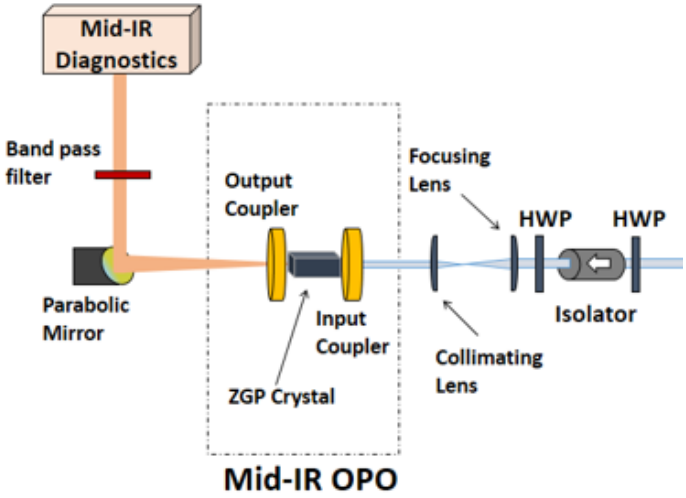

Figure 1: OPO setup from [6]

While ZGP has been the nonlinear conversion medium of choice for high energy mid-IR generation pumped by Ho-based solid-state lasers as illustrated in [8-10], orientation-patterned GaAs (OP-GaAs) is particularly well-suited for high average power energy mid-IR generation due to its high thermal conductivity [11]. However, energy scaling is limited by the ~500-µm thick aperture of the orientation patterned quasi phase-matched region. Due to the significant potential of OP-GaAs as a medium for the generation of high average power mid-IR, we sought to develop a method that would allow us to characterize the thermo-optic response of OP-GaAs "in situ" within setups for nonlinear frequency conversion.

Experimental Setup

In order to provide the greatest flexibility to characterize materials in situ, we choose to utilize a geometry in which the irradiating 2 µm laser itself provided the thermal lensing data (Fig. 2). In this case, we used a CW Tm:fiber laser with up to 100 W output power [3] to heat a 10-mm long OP-GaAs chip and a 500-µm thick GaAs wafer. For these tests, both samples had similar AR coatings in order to maximize transparency. The incident power was varied using a light valve consisting of a half waveplate and polarizing beam splitter. In order to determine the thermal response, the 2 µm laser is focused to a waist of 150 µm by a 50 mm focal length lens. The test sample acts as a thermal lens and is scanned through the 50 mm focal plane. The resultant far-field beam size was measured using a pyro-electric array camera. Thus, the beam divergence and measured diameter would vary depending on the position of the sample and the magnitude of the thermally induced gradient.

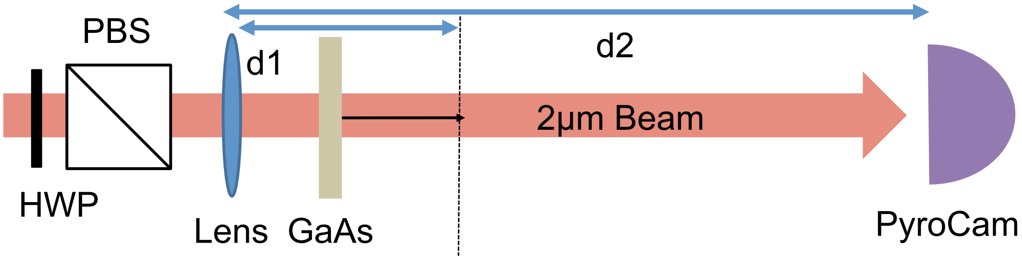

Figure 2: Thermal lens measurement setup; HWP – half waveplate, PBS – polarizing beam splitter, d1 – distance from focusing lens to beam waist with no sample, d2 – distance from focusing lens to pyro-electric array camera

The measured response results from the aggregate effect of thermally induced refractive index change (dn/dT), thermally induced end face deformation, and thermo-optic stress. Although this method does not provide the individual contributions of these effects, it does not require any a-priori assumptions regarding the material to be tested and can be performed with simple diagnostics.

Experimental Data

The raw data obtained as part of initial experiments is shown in Figures 3 and 4 for the GaAs wafer and the OP-GaAs chip respectively. Despite the significant differences in material thickness, both display a measureable deviation in beam size as the sample was translated through the beam focus. Unfortunately, the GaAs wafer could not be translated over the same range of relative positions due to differences in the sample holder. Likewise, it was not possible to conduct a full run of powers for the GaAs wafer because the Tm:fiber laser suffered a catastrophic failure during these experiments.

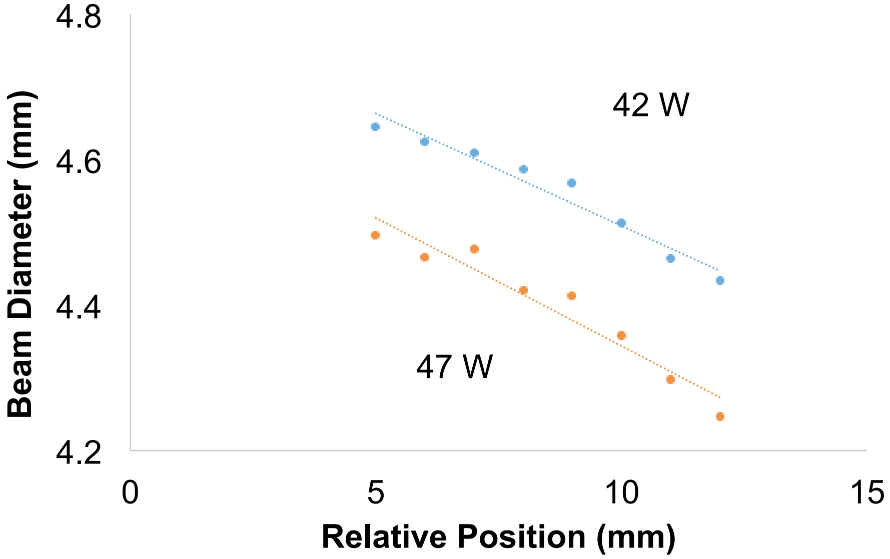

Figure 3: Raw data for the 500-µm thick GaAs wafer

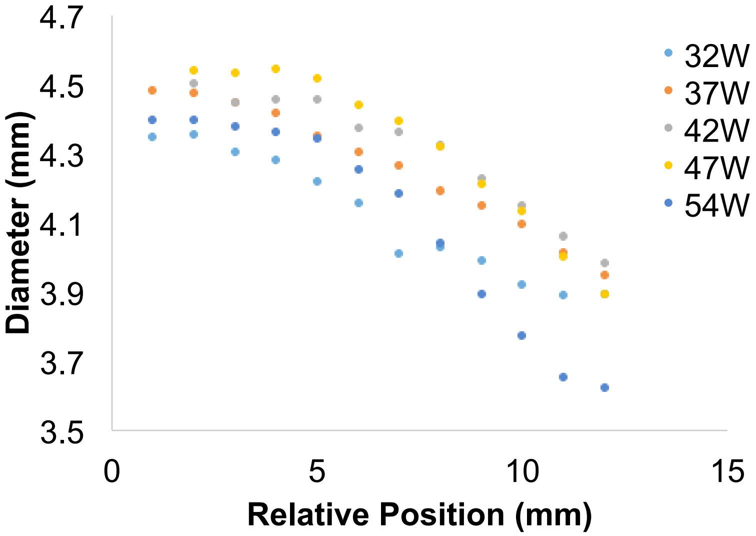

Figure 4: Raw data for the 10-mm thick OP-GaAs sample

From the data in Fig. 4, we extracted the power dependent dioptric power as shown in Fig. 5. This initial linear fit provides a rough estimate for the steady-state thermal response for OP-GaAs. However, we consider this an initial proof of concept as we have not yet had sufficient opportunity to study the data in terms of absolute accuracy. In particular, we have made several assumptions in this extraction such as approximating the sample as a thin lens. Further refinement will be required before we can compare this technique rigorously with the established "gold standard" of photo-thermal common path interferometry.

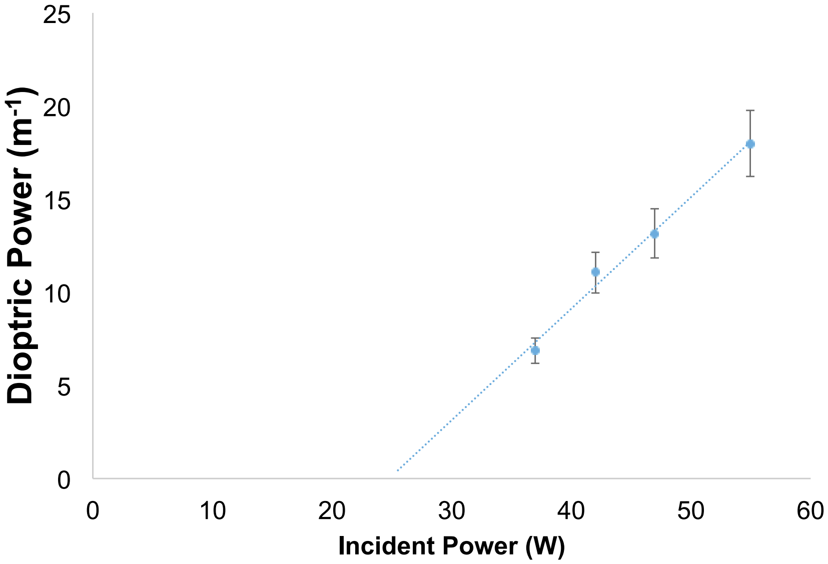

Figure 5: Dioptric power as a function of incident laser power in the 10-mm think OP-GaAs sample

As a check, we compare these results with previous data for the 500-µm thick GaAs wafer measured using an alternative technique based upon a Shack-Hartmann wavefront sensor (SHWS). In this case, the same Tm:fiber laser source was used to heat the sample and the induced wavefront deformation was measured using a 1080 nm probe beam. This data also demonstrates a linear dependence of induced dioptric power on incident Tm:fiber power.

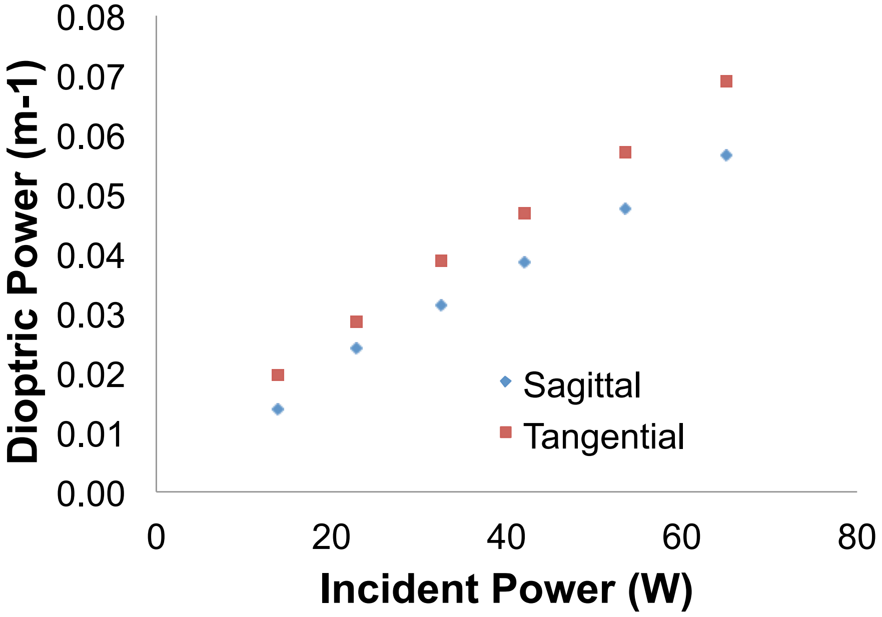

Figure 6: Dioptric power as a function of incident laser power in the 500-μm thick GaAs wafer measured with a SHWS

Discussion

This initial demonstration requires calibration and to be compared in terms of precision and sensitivity to more established analysis methods such as photo-thermal common path interferometry. The direct thermal lens measurements scheme is attractive as it does not require an external probe and can replicate the conditions required for nonlinear frequency conversion to the mid-IR.

Acknowledgements

The authors acknowledge the contribution of OP-GaAs crystals from BAE Systems, and the funding of the United State High Energy Laser Joint Technology Office (HEL JTO) and the State of Florida.

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