our future through science

Thermally induced lensing determination from the coefficient of defocus aberration

J. Bell[1,2], D. Naidoo[1,3], and A. Forbes[1,2,3]

[1]CSIR National Laser Centre, PO Box 395, Pretoria 0001, South Africa.
[2]School of Chemistry and Physics, University of KwaZulu-Natal, Durban 4000, South Africa.
[3]Laser Research Institute, University of Stellenbosch, Stellenbosch 7602 , South Africa.

ABSTRACT

The effects of a temperature gradient in a laser crystal in an end-pumped configuration in a solid-state laser resonator results in thermally induced aberrations. Of particular interest we measure the thermally induced lens from the coefficient of defocus aberration with a Shack-Hartmann wavefront sensor. As a calibration technique, we infer the focal length of standard lenses probed by a collimated Gaussian beam at 633 nm and this technique is applied to an Nd:YAG medium under active pumping. This result is compared to a typical thermal lens determination where the length of an unstable cavity is varied.

INTRODUCTION

Thermal effects, such as thermal aberrations in solid state lasers have been a subject of interest in many research areas [1]. In diode-pumped solid state lasers the gain medium absorbs the pump energy resulting in end face bulging thus creating a thermally induced lensing effect which can be described by the coefficient of defocus aberration. This effect changes the optical path length, thus altering the properties of the selected mode at the output of the laser. In this study, we investigate a calibration technique for the measurement of the defocus coefficient of known lenses and apply it to an Nd:YAG gain medium under active pumping.

CONCEPT AND CALIBRATION EXPERIMENT

In developing a calibration technique to be applied to a solid-state gain medium we measured the wavefront of a light beam with a Shack-Hartmann wavefront sensor (SHWFS). We extract the coefficient of defocus aberration, described mathematically as $C_{2,1} = a(2r^2 - 1)$ where r is the radial coordinate and a is the Zernike radius [2], and infer the focal length of a lens from $f = -a^2/C_{2,1}$. We magnified and collimated a Gaussian beam at 633 nm with a pair of lenses (L_1 and L_2) and measured the wavefront at Plane 1 as in Fig. 1(a) and (b) and relay image Plane 1 with an afocal telescope (L_3 and L_4) to Plane 2 to preserve the wavefront as in Fig. 1(c).

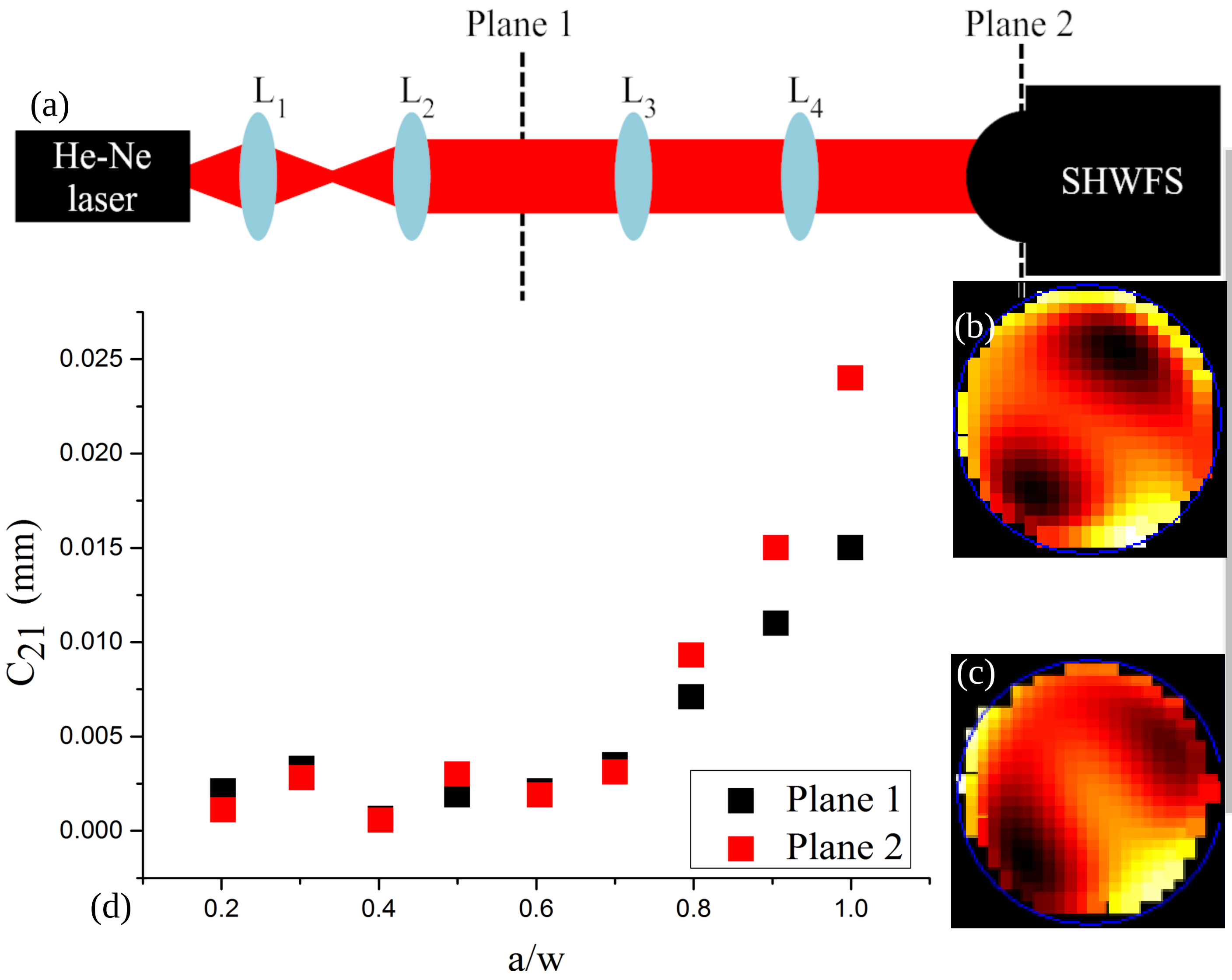

Figure 1: (a) Calibration experiment setup. Beam wavefront at (b) Plane 1 and (c) Plane 2 with its corresponding (d) graph of the defocus coefficient against the aperture-beam size ratio (a/w).

A defocus coefficient that approaches zero provides the most accurate representation of a collimated beam and we identified this operating condition by varying the Zernike radius over the incident beam. We performed this measurement at Plane 1 and Plane 2 and identified the best approximation at 40% of the size of the incident beam as illustrated in Fig. 1(d). With this, we determined at Plane 2 with high accuracy, the focal length of standard lenses positioned at Plane 1 by probing the lenses with the collimated beam as in Fig. 2(a). As an example (see Fig. 2(b)), we confirmed the 40% operating condition as the focal length determination lies within the tolerance region (dashed lines) of a standard lens.

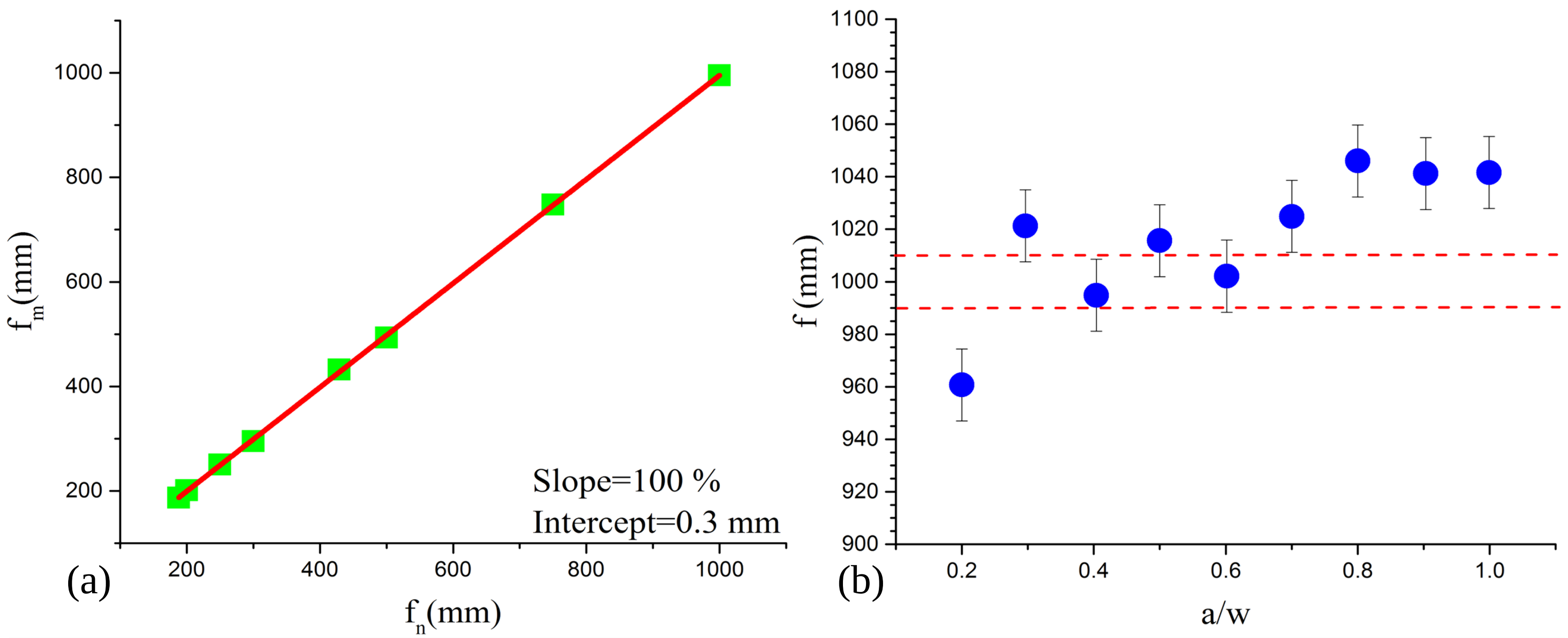

Figure 2: (a) Graph of the measured focal lengths (f_m) against the nominal focal lengths. (b) Measured focal length f against a/w ratio for a lens of focal length f = 1000 mm.

REFERENCES

[1] Farrukh, U. O., Buoncristiani, A. M. and Byvik, C. E. “An analysis of the temperature distribution in finite solidstate laser rods,” IEEE J. Quantum Electron. 24, 2253–2263 (1988).
[2] Mahajan, V. N. (1981). Zernike annular polynomials for imaging systems with annular pupils. *Journal of the Optical Society of America*, *71*(1), 75. doi:10.1364/JOSA.71.000075

THERMALLY INDUCED LENSING

We measured the thermally induced lensing effect with the calibration technique in an end-pumped solid-state configuration for an Nd:YAG gain medium pumped at 808 nm, where the pump beam was focused within the crystal as in Fig. 3(a) with its corresponding intensity distribution in Fig. 3(b). The transmitted pump power was measured to determine the gain saturation point (see Fig. 3(c)) indicating that a strong lensing effect would occur with an increase in the pump power.

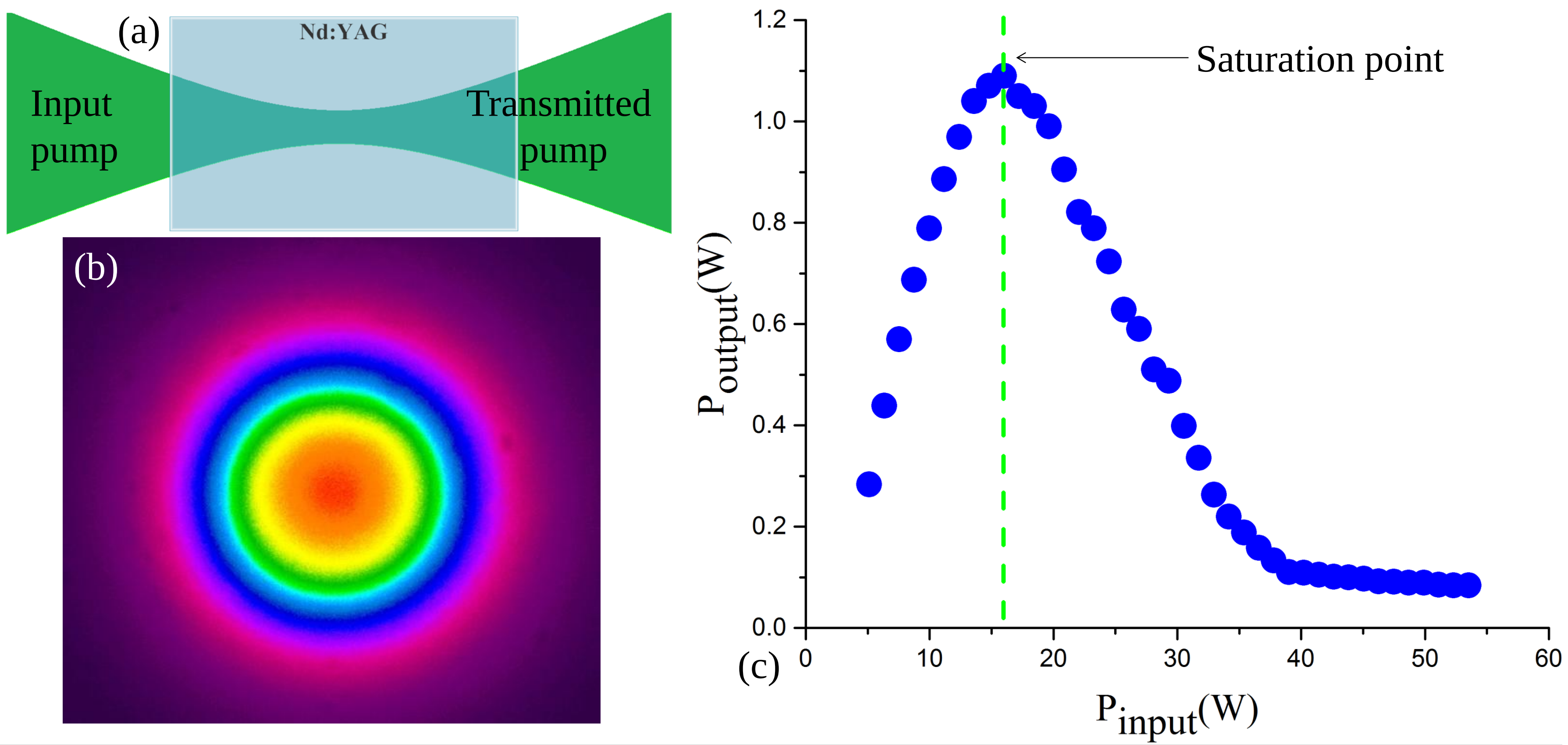

Figure 3: (a) Nd:YAG gain medium pumped at 808 nm. (b) Intensity distribution of the focused pump. (c) The transmitted power against the input pump power.

We explored a typical thermal lens measurement in an end-pumped configuration by varying the length of an unstable resonator while measuring the output power as in Fig. 4(a). A power drop is indicative that the length from the centre of the gain medium to the output coupler is equivalent to the thermally induced lens. This, however, is an unreliable measurement as a power drop may occur more than once at a specific length as in Fig. 4(b) which is not anticipated due to a uniform absorption of the pump beam.

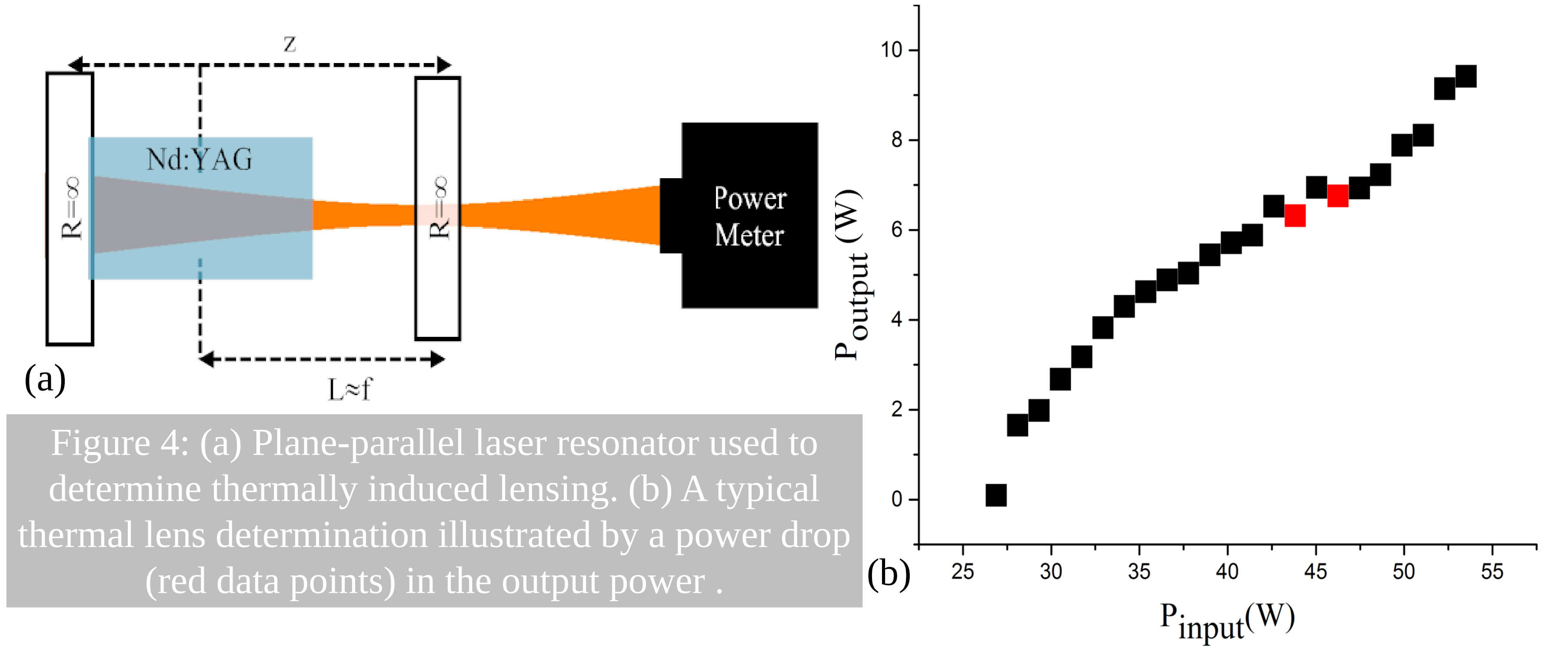

Figure 4: (a) Plane-parallel laser resonator used to determine thermally induced lensing. (b) A typical thermal lens determination illustrated by a power drop (red data points) in the output power .

We thus determined the thermally induced lens as in the calibration technique where we positioned the gain medium at Plane 1 and under active pumping we measured the effect on the collimated probe beam as illustrated in Fig. 5(a). As presented in Fig. 5(b), the focusing capacity of the thermal lens increases dramatically with an increase in pump power beyond the saturation point and is consistent with the uniformity of the pump absorption. This differs markedly from a typical measurement to infer the thermally induced lens.

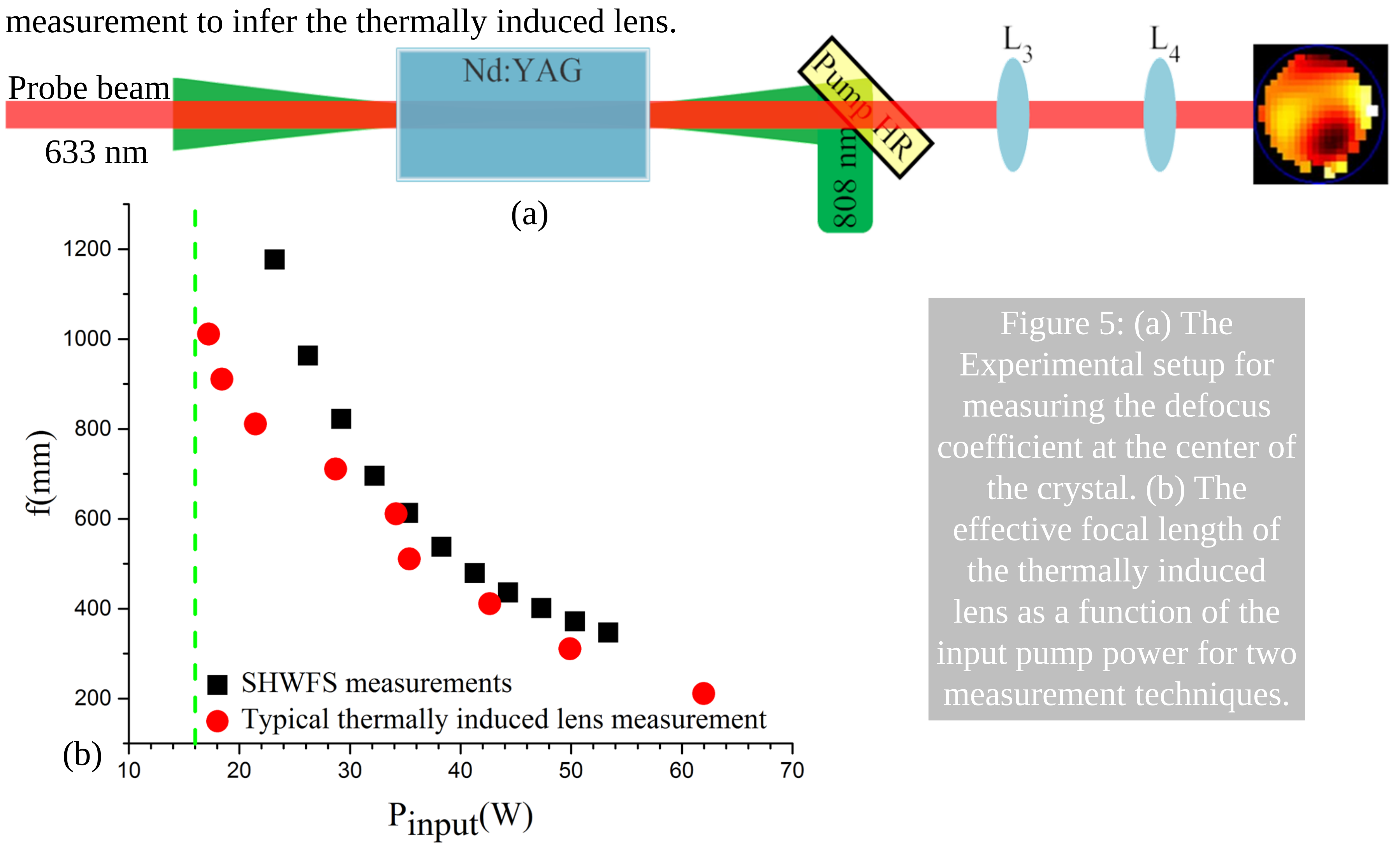

Figure 5: (a) The Experimental setup for measuring the defocus coefficient at the center of the crystal. (b) The effective focal length of the thermally induced lens as a function of the input pump power for two measurement techniques.

CONCLUSION

We have investigated the measurement of a thermally induced lensing effect with a Shack-Hartmann wavefront sensor in an end-pumped solid-state gain medium. We have considered a calibration technique that was applied to known lenses with high finesse and extended to the pumped gain medium. This method was found to be highly consistent with the pump absorption and differs substantially from a typical measurement as irregularities are alleviated.