Thermal lensing measurement from the coefficient of defocus aberration

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ABSTRACT

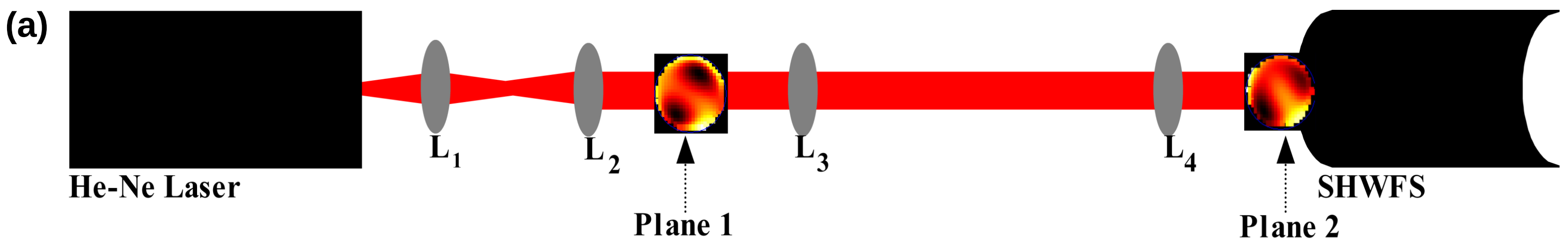
We measured the thermally induced lens from the coefficient of defocus aberration using a Shack-Hartmann wavefront sensor (SHWFS). As a calibration technique, we infer the focal length of standard lenses probed by a collimated Gaussian beam of wavelength 633 nm. The technique was applied to an Nd:YAG crystal that is actively pumped by a diode laser operating at 808 nm.

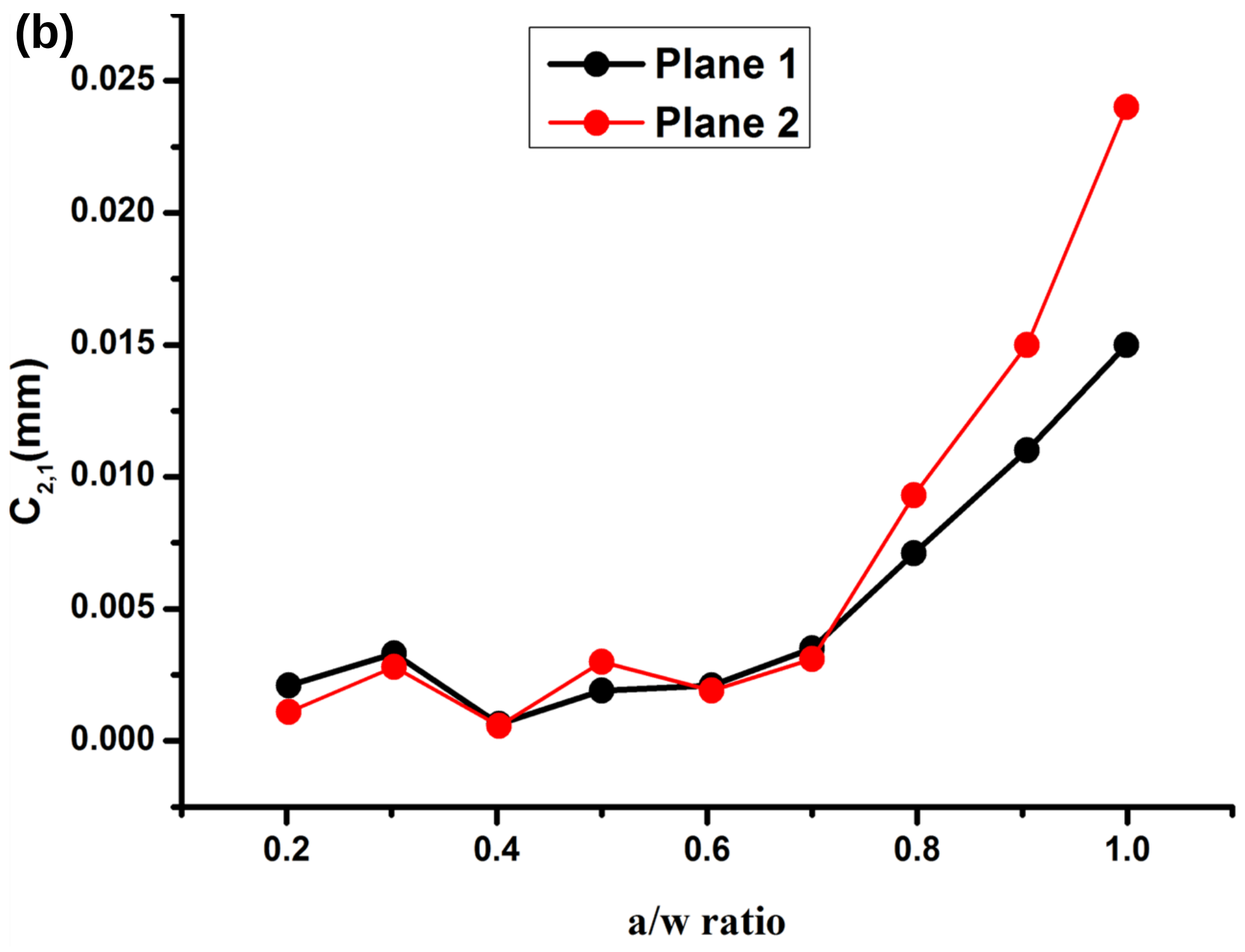
INTRODUCTION

The Solid-state lasers with a wavelength of 1064 nm based on Nd:YAG and Nd:YVO$_4$ crystals, are widely used for marking and micro-structuring processes in industry [1]. One of the limitations for these lasers to reach maximum potential is the thermal lensing effect [2]. 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 that can be described by the coefficient of defocus aberration [3].

CALIBRATION EXPERIMENT

We developed a calibration technique that was applied to a solid-state gain medium. The wavefront of a Helium-Neon light sources was measured with a SHWFS. The coefficient of defocus aberration, $Z_{2,1} = a(2r^2 - 1)$, was extracted, by where r is the radial coordinate and a is the Zernike radius [4].The wavefront was measured at the plane 1 as in Fig. (1a) and relay imaged with a telescope to plane 2 to preserve the wavefront as shown in Fig (1a). Figure .(1b) shows that at both planes it is not necessary to capture 100% of the ratio of Zernike radius (digitally changing the Zernike aperture on a Class2D software) over beam size (a/w), at 40% and /or 60% of a/w a lower defocus coefficient is determined.





The radius of curvature R can be calculated from the wavefront sensor measurement as $R = -a^2/4C_{2,1},\ (R = f)$, $C_{1,2}$ is the coefficient for the defocus term [4]. In determining the focal length of known lenses from the coefficient of defocus aberration we tested eight known lenses , which were positioned at plane 1, the results are shown in Fig. (2a). For a measured focal length of f= 250 mm, the results for varying aperture size are illustrated in Fig. (2b).

Figure 1: (a) Experimental setup for calibration. (b) The Graph of defocus coefficient versus the ratio of Zernike radius over beam size.

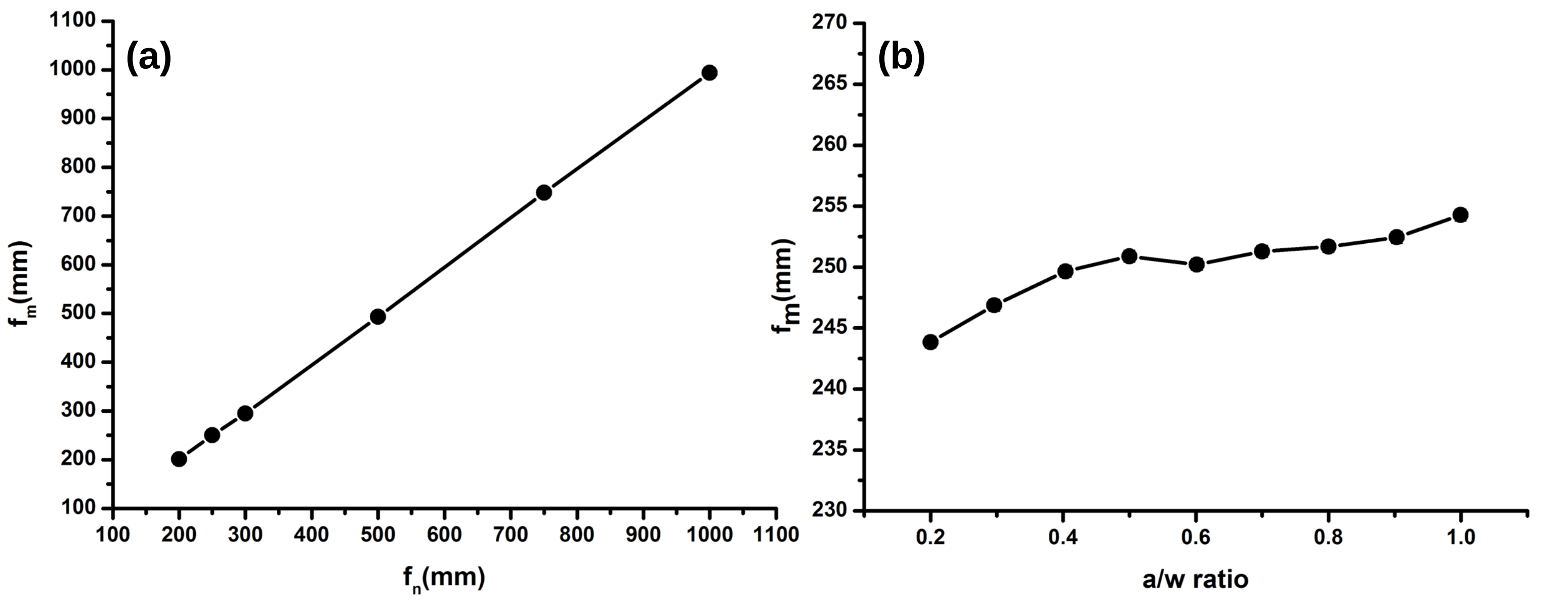
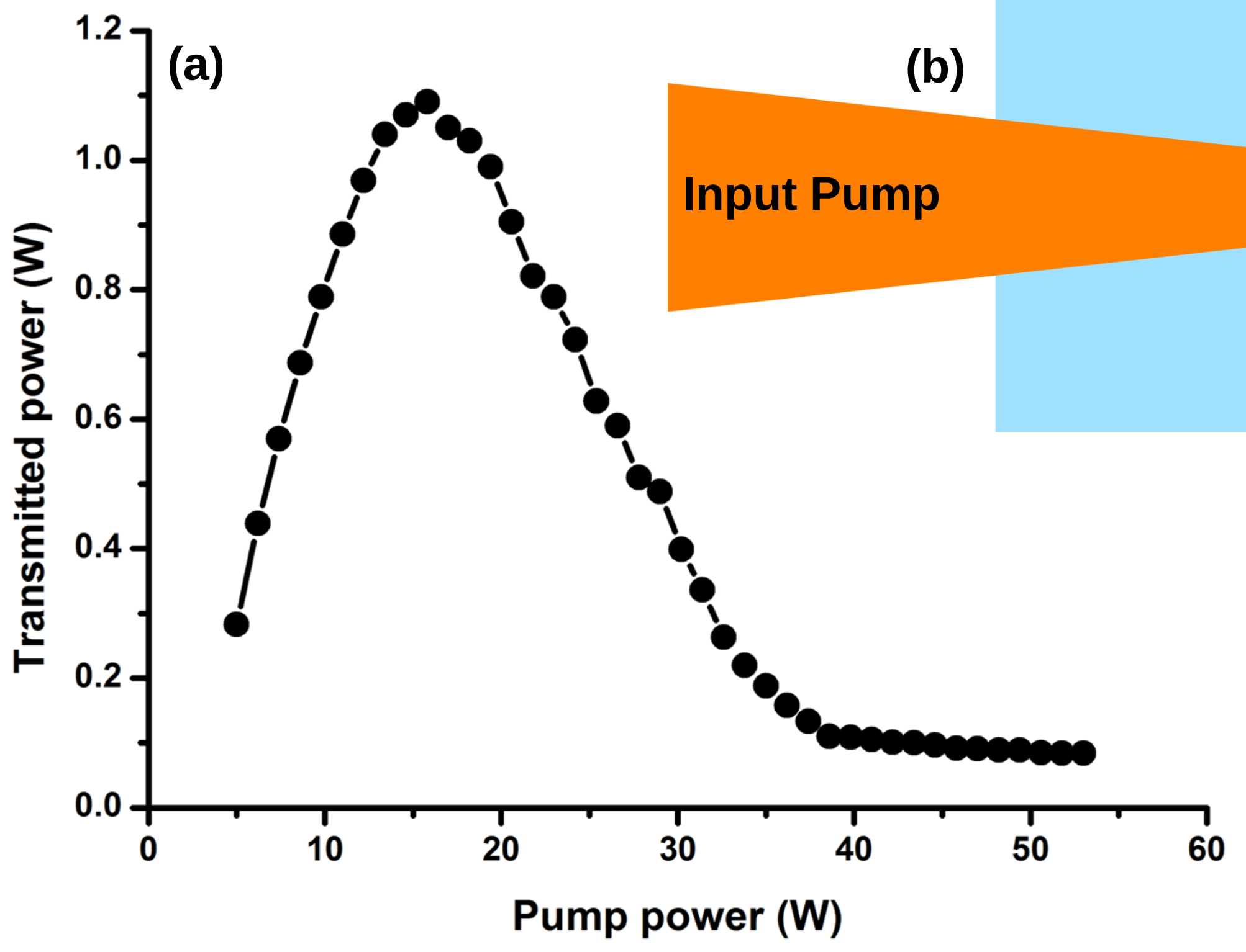


Figure 2: (a) Measured focal lengths f_m against the nominal focal lengths f_n. (b) Measured focal length for nominal focal length of f=250 mm as the ratio of radius over beam size increases.

THERMALLY INDUCED LENSING IN ND:YAG

We used a 1% doped Nd:YAG crystal that is 70 mm long and has a diameter of 4 mm, where the pump beam at 808 nm was focused within the crystal as shown by Fig. (3b). The pump power was varied from 5 W to 55 W, and the transmitted pump power was measured as shown in Fig. (3a) with its corresponding intensity profile shown in Fig. (3c). The transmitted pump power was measured to determine the gain saturation point indicating that a strong lensing effect would occur with an increase in the pump power.



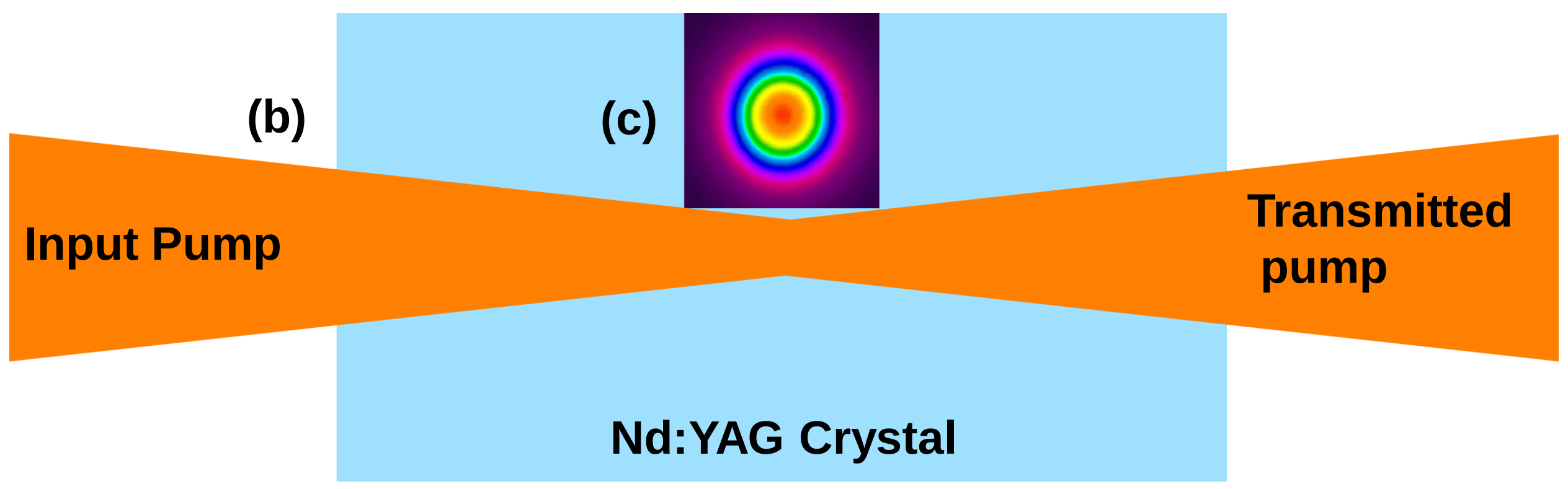


Figure 3: (a) The graph of the transmitted power against the input pump power. (b) Nd: YAG cystal pumped by a diode laser at 808 nm. (c) Intensity profile of the focus pump at the centre of the crystal.

We measured thermal lensing in an end-pumped configuration by varying the cavity length of an unstable resonator while measuring the output power as shown in Fig. (4) (We shall call this method Geometrical). The length, L, between the centre of the crystal output coupler, was varied between 200 mm to 1000 mm in steps of 100 mm.

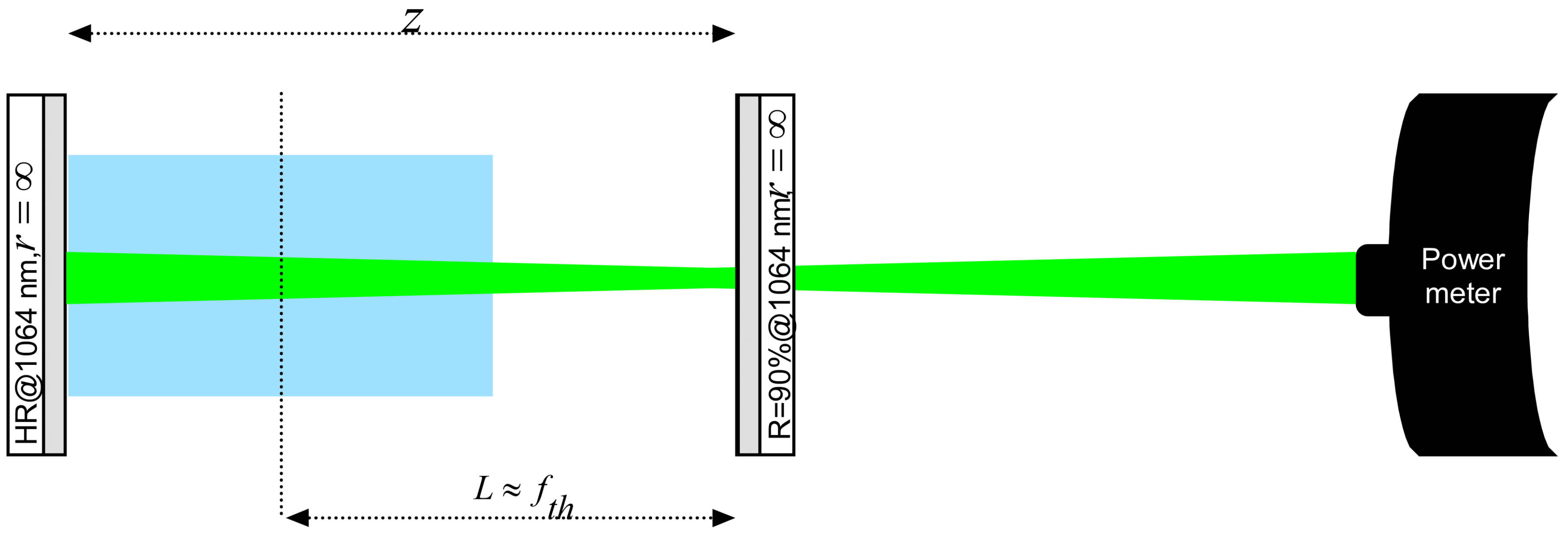


Figure 4: Unstable plano-parallel laser resonator used to determine thermally induced lensing.

For each length, the power was measured and a drop in power is experienced for all different cavity lengths. 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. However, this method is an unreliable measurement as a power drop may occur more than once as shown by Fig. (5a) at a specific length which is not anticipated due to a uniform absorption of the pump beam.

We thus determined the thermally induced lens as in the calibration technique where we positioned the centre of the gain medium at plane 1 in Fig. (1). Under active pumping, we measured the effect on the collimated probe beam as illustrated in Fig. (1). As presented by the results in Fig. (5) 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.

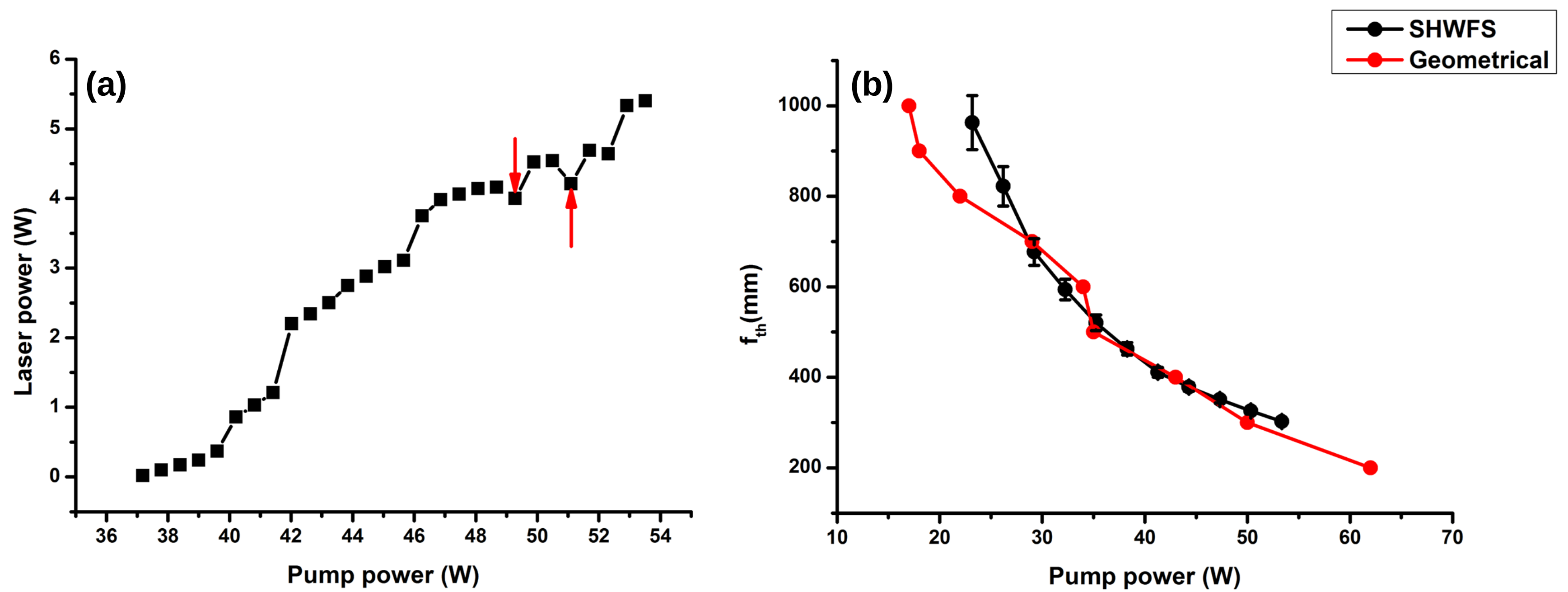


Figure 5: (a) The graph of the laser power versus pump power to determine thermal lens, illustrated by a power drop (red arrows), using Geometrical method. (b) The Graph of the effective focal length of the thermally induced lens as a function of the optical pump power.

CONCLUSION

A calibration technique was applied to known lenses with high finesse and extended to pumped solid-state gain medium. The SHWFS method was found to be highly consistent with the pump absorption, and is found to be more accurate than a geometrical method to alleviate irregularities.

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