# Thermal Properties and Wavefront Distortions of Yb:YAG Active Mirror Amplifier

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***Abstract*—Development of compact Yb:YAG active mirror amplifier is reported. Yb-doped YAG disks with different doping concentration are bonded to copper heatsink. Thermally induced refractive index change of active mirror was measured by wavefront sensor. We found the laser performance of prepared active mirror was related with the wavefront measurement result.**

## Introduction

Deep ultra violet (DUV) lasers are actively used for material micro processing and semiconductor lithography. Argon fluoride excimer laser (ArF excimer laser) is the typical light source which can generate above 100-W optical power at the wavelength of below 200-nm. Using all-solid-state DUV light source as a seed laser and amplifying by ArF excimer, both high average power and high beam quality can be realized in the DUV region [1, 2]. The solid-state DUV seed source contains Yb-doped fiber laser, Yb:YAG amplifier, Er-doped fiber laser and the frequency up-conversion chain using nonlinear crystals. To obtain the nearly 1 W output at the wavelength of 193 nm, the output pulse from Yb-doped fiber laser is amplified strongly by an Yb:YAG single crystal fiber amplifier [3]. Single crystal fiber, however, has difficulties in manufacturing. Compact and cost effective solid-state laser amplifier is favorable for industrial applications.

In case of a cavity-based laser amplifier, i.e. regenerative amplifier, Yb:YAG with thin disk configuration can realize high power and high beam quality output [4]. Because of small single-pass gain of thin disk, however, large number of optical passes is required for multi-pass amplification which requires critical alignment and stable environment. We are developing an active mirror amplifier which is suitable for a simple, compact and robust single/double pass amplifier.

## Preparation of Yb:YAG Active Mirror

We prepared 5 at.% and 15 at.% $Yb^{3+}$-ion doped YAG ceramics disks with the diameter of 10 mm. The thicknesses of 5 at.%-doped Yb:YAG and 15 at.%-doped Yb:YAG are 1 mm and 0.5 mm, respectively. These thicknesses are 5 to 10 times thicker than that of typical Yb:YAG thin disk which enables easy handling. One side of the thick disk was polished and coated with high reflection (HR) at the wavelength of both pump (940 nm) and laser (1030 nm) light. The other side was coated with anti-reflection (AR). The HR-coated side of thick disk was bonded to a water-cooled copper heatsink using a commercially available high thermal conductive adhesive. Thus, this bonded thick disk acts as an active mirror.

## Temperature and Wavefront Measurement

Pump light from a fiber-coupled laser diode emitting at 940 nm was focused on the AR-coated side of active mirror. Surface temperature of active mirror was measured by a thermal camera. Although the thickness of 15 at.%-doped Yb:YAG active mirror is half of that of 5 at.%-doped Yb:YAG active mirror, the surface temperature of 15 at.%-doped active mirror increased quickly as pump power increase as shown in Fig. 1. Since highly doped Yb:YAG has high absorption coefficient, the most part of pump light is absorbed close to the surface of AR-coated side. This localized heat made higher surface temperature of 15 at.%-doped Yb:YAG active mirror.

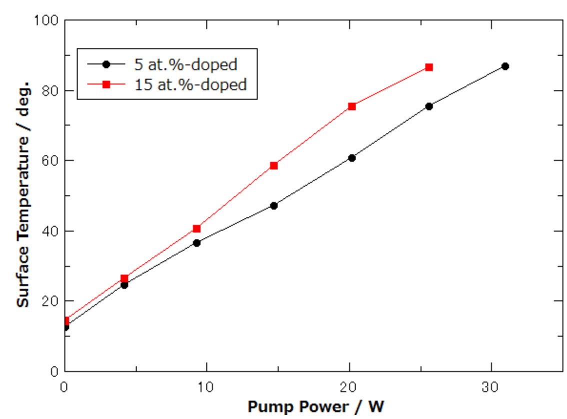


Fig. 1 Temperature measurement of 5 at.%-doped and 15 at.%-doped Yb:YAG active mirrors surface (AR-coated side)

Thermal camera has relatively low spatial resolution, and can measure only surface of heated objects. We constructed a measurement system of thermally induced refractive index change inside active mirror using a wavefront sensor [5]. Fig. 2 shows the experimental setup of wavefront measurement. Probe light generated from a He-Ne laser is irradiated to the active mirror through 4-f imaging system. The wavefront of probe light is modulated by the change in refractive index inside active mirror. The modulated wavefront of probe beam is precisely transferred to the wavefront sensor by the 4-f imaging system.

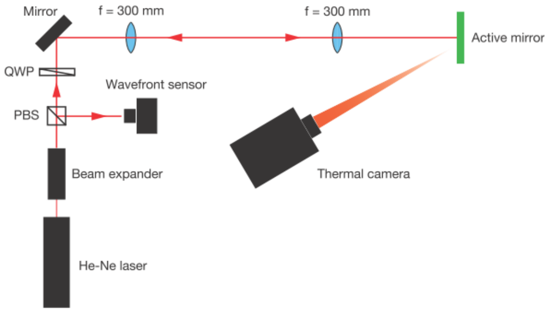

Fig. 2 Experimental setup of refractive index change of active mirror using wavefront sensor

Before the wavefront measurement of active mirror, we measured a wavefront of precise (λ/10) flat mirror as a reference. Thus, wavefront data of active mirror indicates absolute refractive index distribution of active mirror. Before the pumping, the active mirrors were relatively flat mirror with peak-to-valley (PV) wavefront error of approximately λ/5. When the 5 at.%-doped active mirror was pumped, refractive index distribution formed parabolic centering around the pump spot as shown in Fig. 3. On the other hand, saddle-shaped refractive index distribution appeared in the case of 15 at.%-doped active mirror. This asymmetric refractive index distribution would be caused by the inhomogeneous bonding to heatsink.

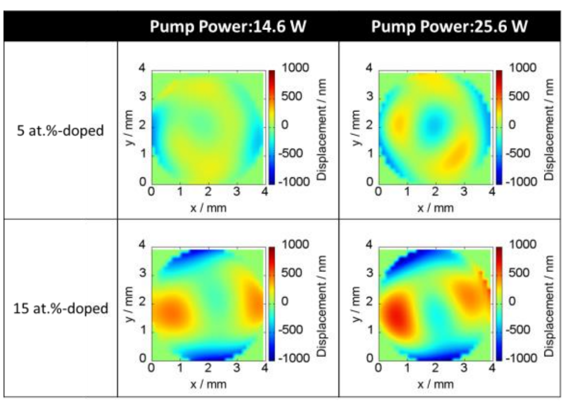

Fig. 3 Measured wavefront of pumped active mirror

## CW Laser Operation

To evaluate the amplification performance, we first constructed a W-shaped cavity and measured CW output power. We obtained 6 W output from 5 at.%-doped active mirror. Although the lasing threshold of 15 at.%-doped active mirror was similar to that of 5 at.%-doped active mirror, the output power of 15 at.%-doped active mirror was saturated around 2.5 W as shown in Fig. 4. This power saturation would be caused by the mismatching between cavity mode and pump spot due to the asymmetric thermal lens indicated in Fig. 3. Note that the laser performance can be expected from the wavefront measurement before the lasing and amplification experiment. Further thermal lens analysis based on numerical modeling of active mirror and laser amplification results will be presented.

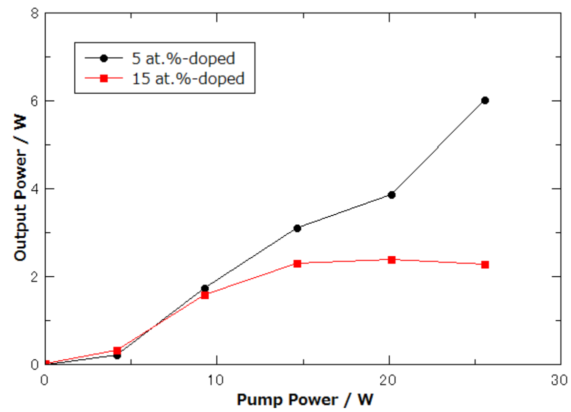

Fig. 4 CW output characteristics of W-shaped laser cavity using active mirror

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