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Efficient Tm:silica fiber laser pumped Ho:YAG lasers

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Ho:YAG lasers employing standing-wave and ring cavity configurations have yielded 6.4W of multi-axial-mode output and 3.7W of single-axial-mode output at 2.1 μm respectively for <9.6W of incident pump power at ~1.9μm from a cladding-pumped Tm:silica fiber laser.

In-band pumping of Ho:YAG lasers at ~1.9μm is an attractive route to coherent output in the ~2.1μm wavelength regime. This approach has the advantage of low quantum defect heating (~9%) with the result that very high efficiencies are attainable. Furthermore, it avoids the high upconversion losses associated with Tm co-doping as would be required for direct diode pumping at ~785nm. The standard approach for generating the 1.9μm pump wavelength at the required power levels has been via diode pumping of Tm-doped crystal lasers [1]. More recently, there has been growing interest in cladding-pumped Tm-doped silica fiber lasers as an alternative pump source. Cladding-pumped Tm fiber lasers benefit from a geometry that allows simple thermal management and hence offer the prospect of higher output power and improved beam quality compared to conventional Tm-doped crystal lasers. Furthermore, the operating wavelength can be tuned over a wide range covering many of the absorption lines of interest in Ho-doped crystals. Efficient operation of Ho:YAG lasers with multi-watt output powers pumped by Tm-doped fiber lasers has already been reported [2-4]. In these early demonstrations simple standing-wave cavity configurations were employed and optical-to-optical efficiencies were limited <57%. In this paper we report a Tm fiber laser pumped standing-wave Ho:YAG laser with a cw output power of 6.4W and improved optical-to-optical efficiency of 67%. In addition, we also report preliminary results for a single-frequency Ho:YAG ring laser pumped by a Tm fiber laser.

The Tm-doped fiber laser used in our experiments was constructed in-house and comprised ~ 4.7 m of double-clad fiber with a 20 μm diameter (0.12 NA) Tm-doped alumino-silicate core surrounded by a 200 μm diameter pure silica inner-cladding with a nominal NA of 0.49. The fiber laser was cladding-pumped through opposite ends by two beam-shaped diode-bars at ~790 nm delivering a total combined maximum pump power of 54W (corresponding to 43W launched). Wavelength tuning was achieved by employing an external cavity comprising a simple diffraction grating (600 lines/mm) in the Littrow configuration to provide wavelength selective feedback. The output power exceeded 9W over a tuning range from ~ 1860 to 2010nm.

A simple two-mirror resonator configuration was used for the Ho:YAG standing-wave laser comprising a plane input mirror with high reflectivity (>99.8%) at the lasing wavelength (2097nm) and high transmission (>95%) at the fiber pump wavelength, and a concave output coupler with a transmission of 10% at the lasing. The latter also had high reflectivity at the pump wavelength to improve the pump absorption efficiency by allowing a second pass of the laser rod for unabsorbed pump light. The Ho:YAG rod was mounted in a water-cooled copper heat-sink maintained at 15°C. The output power versus incident pump power is shown in Fig.1. At the maximum incident pump power of 9.6W, we obtained ~6.4W of TEM_{00} output (M^2<1.1) at 2097nm corresponding to an optical-to-optical efficiency of 67%, and the slope efficiency with respect to incident pump power was 80%.

To achieve single-frequency operation a simple 'bow-tie' ring resonator design was employed (see Fig.1). Unidirectional operation was achieved using a travelling-wave TeO_2 acousto-optic modulator (AOM) to provide the loss difference between counter-propagating beams required for unidirectional operation [5]. The minimum RF power (at 80MHz) required for purely unidirectional and hence single-frequency operation was found to be ~0.3W. Under these operating conditions, the Ho:YAG laser had a threshold pump power of ~0.3W and produced 3.7W of single-frequency output in a diffraction-limited TEM_{00} beam with M^2<1.1. With the RF power turned off the output power for bidirectional operation was only slightly higher (~3.9W), indicating that the diffraction loss in the lasing direction for unidirectional lasing was very small (<0.5%). Nevertheless, the slope efficiency with respect to incident pump power (~51%) and output power were somewhat lower than for the standing-wave cavity. This is believed to be due to a relatively high insertion loss for the AOM. Hence with further optimization of the cavity design and by using a lower loss AOM, a significant increase in output power and efficiency should be achievable.

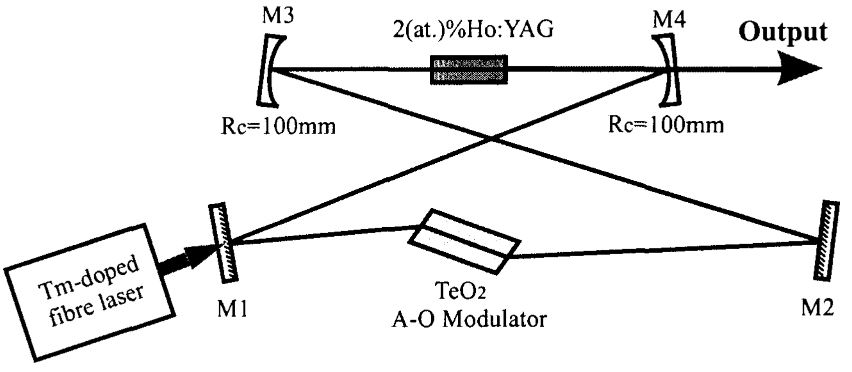

Fig.1. Ho:YAG lasers pumped by a Tm-doped silica fiber laser

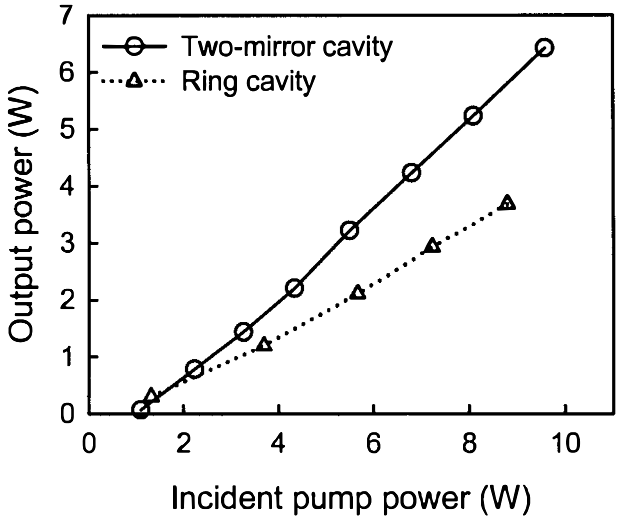

Fig.2. Output power versus incident power

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