Efficient Resonant Waveguide Grating for High-Power Lasers in the 2-µm Wavelength Range

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Abstract: We present resonant waveguide-grating (RWG) tailored for lasers operating at the 2-µm wavelength range. Utilizing the RWG as a cavity mirror, generation of tunable narrow-bandwidth and linearly-polarized radiation from a Ho:YAG thin-disk laser was demonstrated.

1. Introduction

High-power lasers operating at the 2-µm wavelength range have garnered significant interest in recent years for various scientific applications [1], such as driving of secondary sources [2] and THz spectroscopy [3], as well as industrial applications like laser-based processing of polymers [4] and semiconductors (e.g., in volume processing of silicon) [5]. Typically, the scaling of 2-µm lasers involves coherent or spectral beam combining techniques. In the latter approach, a narrow bandwidth of each emitter/port is essential. This paper utilizes a single-layer Reflective Waveguide Grating (RWG) [6], designed to enable the selection and tuning of laser wavelengths within the 2-µm spectral range, a prerequisite for spectral beam combining. The fabricated RWG was evaluated in a high-power Ho:YAG thin-disk oscillator [7], resulting in narrow bandwidth (FWHM ~ 0.5 nm) radiation with an average output power of 36 W at a central wavelength of 2090 nm. Moreover, the intracavity RWG leads to a high linear-polarization purity (with a degree of linear polarization higher than 99%) for the emitted radiation due to its polarization-dependent reflectance properties. Angular adjustment of the RWG allowed tuning the operating wavelength over a 28 nm range.

2. Design and characterization of the RWG

The RWG developed in this study comprises a structured sapphire substrate coated with a 425 nm thick Ta_2O_5 waveguide layer. The grating features a nominal period and groove depth of Λ = 980 nm and σ = 200 nm, respectively, with a duty cycle (DC) set at 50%. The design aims to achieve resonance for TE-polarization at wavelengths of 1970 nm (applicable to Tm-fibre or Tm:YAG lasers) and 2090 nm (for Tm:YAG or Ho:YAG lasers) under angles of incidence of 12.7° and 20.6°, respectively. Fig.1 illustrates the calculated and measured reflectance for TE and TM polarizations. Notably, a reflectance of $98.7 \pm 0.3\%$ is attained for both 1970 nm and 2090 nm wavelengths.

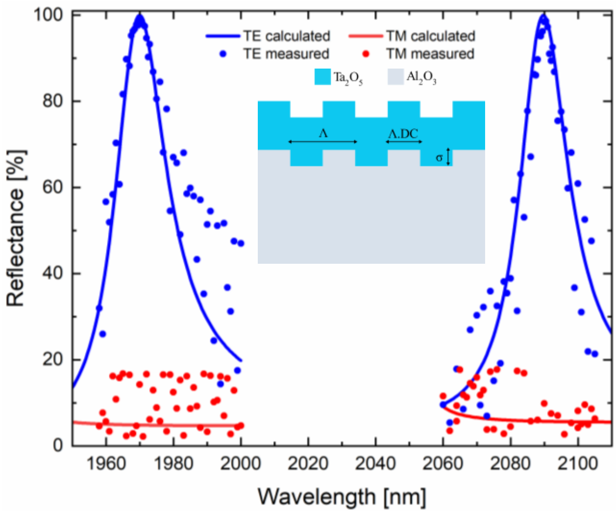

Fig.1: Calculated and measured reflectance, for TE and TM polarizations plotted against wavelength for angles of incidence (AOI) of 12.7°and 20.6°. A schematic of the RWG is depicted as an inset.

3. Qualification of the RWG in a Ho:YAG thin-disk laser

The primary resonator setup is depicted in Fig. 2a. It comprises a concave highly reflective (HR) end-mirror with a radius of curvature (RoC) of 2 m, a folding HR plane mirror, a Ho:YAG thin-disk crystal, an HR reference plane mirror or the RWG serving as the folding element, and a plane output coupler (OC) with a transmission of 3%. The Ho:YAG thin-disk with a thickness of 190 µm and a doping concentration of 2 at.%, was glued onto a water-cooled diamond heat sink with a RoC of 2 m. The mounted disk was assembled in a pumping module allowing 72-passes of the pump radiation through the laser crystal. Pumping was achieved using a commercial Tm-fiber laser, delivering a maximum output power of 209 W at 1908 nm. Prior to incorporating the RWG, the performance of the TDL oscillator was assessed with a standard HR plane folding mirror. The laser performances obtained in both configurations are shown in Fig.2b. At a pump power of 87.4 W, the HR folding mirror yielded an output power of 43 W with an optical efficiency of 49.1%. Upon replacing the HR folding mirror with the RWG, the output power decreased to 30 W, corresponding to an optical efficiency of 34.3%.This reduction in efficiency is attributed to the lower reflectance of the RWG compared to the HR folding mirror. Increasing further the pump power to 104 W led to an output power of 36 W, thus corresponding to an optical efficiency of 34.6%. Additionally, the tuning capability of the laser was demonstrated by adjusting the angle of incidence (AOI) to the RWG combined with an OC having a transmission of 1%. Consequently, the operating wavelength could be adjusted from 2080 nm to 2108 nm, providing a tuning range of $\Delta\lambda = 28$ nm. The degree of linear polarization (DOLP) was quantitatively evaluated using a Glan-Taylor polarizer, revealing a DOLP > 99%.

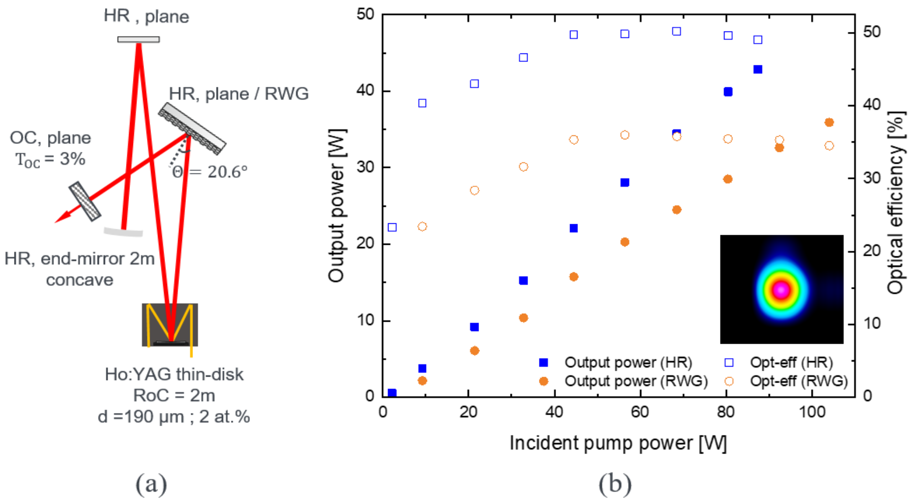

Fig.2: (a) Ho:YAG thin-disk laser resonator (b) laser performance characteristics comparing the resonator with either the plane HR mirror or the RWG. Open symbols: optical efficiency (right ordinate), filled symbols: output power (left ordinate). The inset shows the far-field intensity distribution of the laser beam with the RWG configuration.

4. Conclusion

Here we reported the first demonstration of a high-power 2-µm laser operated with an intracavity RWG, which defined the wavelength and polarization state. Efficient operation was realized with a maximum output power of 36 W and an optical efficiency of 34.6%, in addition tunable operation was shown with output wavelengths between 2080 nm - 2108 nm achieved with FWHM bandwidths of 0.5 nm.

Acknowledgments

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5. References

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