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Polarization-independent broadband dielectric bilayer gratings for spectral beam combining system

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ABSTRACT

We report on a polarization-independent all-dielectric trapezoidal bilayer grating with broadband and high diffraction efficiency. The bilayer trapezoidal grating ridge on a reflector consists of an HfO_2 layer and a SiO_2 layer. The theoretical −1st order efficiencies of the grating are more than 95% with wavelength range from 1010 nm to 1080 nm for both TE and TM polarizations. The fabrication tolerances depending on the HfO_2 and SiO_2 layer grating ridge depths are enough to obtain the designed grating using current craft. The fabricated grating with exceeding 94% efficiency from 1000 nm to 1085 nm measured by a non-polarization laser has been fabricated and applied in a spectral beam combining external cavity to combine eight beams into one beam output with 10.77 kW.

1. Introduction

The rigid demand of high average laser power in the region of material processing [1], medical therapy [2,3], and national security constantly urge scientists to develop high power continuous laser. Although fiber lasers have been developed rapidly in the past years [4], the output power of single fiber is limited by the laser damage threshold, thermal effects, and nonlinear optical effects [5]. The spectral beam combining (SBC) is a promising method to achieve high average power output without influencing the beam quality [6,7]. The SBC is an incoherent combining technique which combines the output beams of many laser arrays into a single beam by an external cavity with the laser arrays having different wavelengths [8]. A polarization-independent broadband grating (PIBG) plays a key role in the external cavity. But it is quite difficult to obtain, because of guide-mode resonance [9]. A series of structures or grating designs of PIBG have been reported [10–12]. However, they all include metal layer which has big absorption to the high power laser system. For example, a metal-dielectric PIBG is attained with >90% diffraction efficiency from 740 nm to 860 nm by simplified model analysis [10]. By rigorous couple wave analysis, Nano-periodical gratings on the gold mirror with 95% theoretical diffraction efficiency is implemented in SBC system [11]. A polarization-insensitive and broadband subwavelength grating with more than 99.5% efficiency from 750 nm to 1000 nm is reported [12]. At the same time, for the wide-used bandwidth 1020–1100 nm in SBC system, few all-dielectric PIBGs have been reported [13]. Additional, most reported surface-relief gratings are single-layer structures [10]. Although sandwiched grating is more convenient to protect the grating surface and attain high efficiency than single-layer grating [14], it is more difficult to be fabricated than bilayer grating. Comparing with single-layer gratings [15], bilayer dielectric gratings are easier to obtain the broadband property [16].

In this paper, a novel reflective PIBG is designed and fabricated with a bilayer grating ridge configuration. The −1st order efficiencies of the designed PIBG are more than 95% with wavelength range from 1010 nm to 1080 nm for both TE and TM polarizations. The −1st order efficiency of fabricated grating measured by a non-polarization laser is exceeding 94% with wavelength range from 1000 nm to 1085 nm. The eight output beams from Master Oscillator Power-Amplifiers (MOPA) are spectrally combined by this grating to form an output beam with 10.77 kW continuous-wave power.

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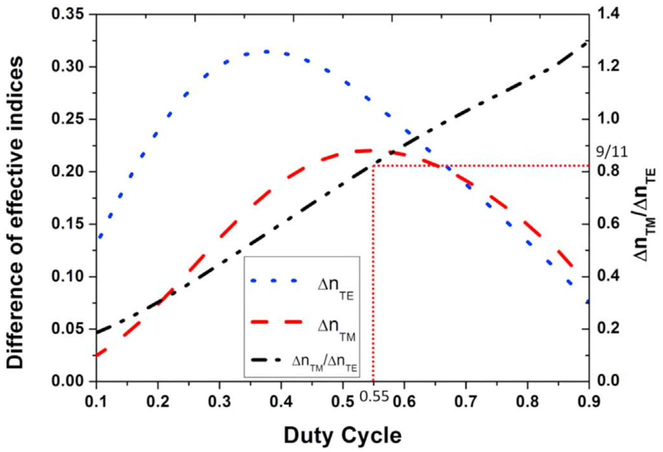

Fig. 1. Difference of effective indices for TE & TM plane waves and their ratio $\Delta n_{TM}/\Delta n_{TE}$ as functions of duty cycle. The dot line and dash line stand for difference of effective indices for TE (Δn_{TE}) and TM (Δn_{TE}) wave, respectively. The dot-dash line stands for the ratio of effective indices differences $\Delta n_{TM}/\Delta n_{TE}$.

2. Design

In process of design, our goals focus on three kernels: firstly, the bandwidth of the PIBG should be broad to contain all wavelengths of emitters in SBC whose whole range is from 1050 nm to 1085 nm in this paper. Secondly, efficiencies of the PIBG should exceed 90% for both TE and TM polarizations to decrease the power loss. Thirdly, the designed grating should have large fabrication tolerances to ensure high performance of the fabricated grating. Additional, for reducing the number of diffraction modes, the grating ridges are designed on reflectors.

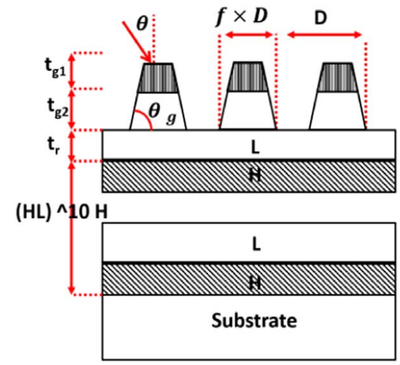

Fig. 3. The schematic of PIBG. The incident angle is θ; θ_g stands for the bottom angle; f stands for the bottom layer duty cycle; D stands for the grating period which is 1041.67 nm. The shadow areas H are Ta_2O_5 layers. Areas L are SiO_2 layers. The 1st layer grating ridge is HfO_2 which is represented by the shadow area in grating ridge. The 2nd layer grating ridge is SiO_2.

Simplified modal analysis is carried out to select grating depth and duty cycle for achieving a polarization-independent high-efficiency rectangular-ridge reflective grating [10]. According to this theory,

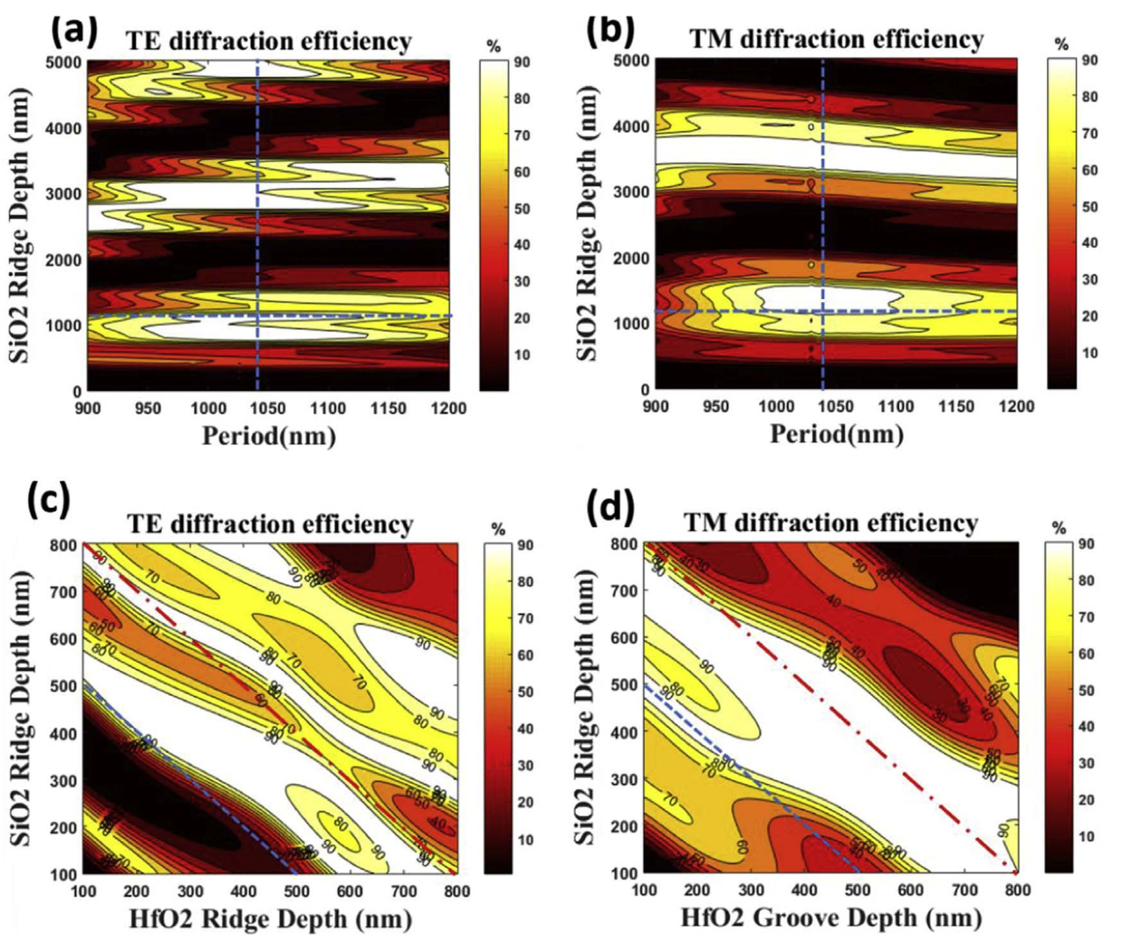

Fig. 2. (a) and (b) illustrate the −1st order efficiencies of TE and TM waves as functions of period and SiO_2 single-layer grating ridge depth, respectively. The cross of blue dashed lines is the point where period and SiO_2 grating ridge depth equal 1041.67 nm and 1100 nm, respectively. At this point, diffraction efficiencies of TE & TM are both exceeding 90%. (c) and (d) illustrate the −1st order efficiencies of TE and TM waves as functions of SiO_2 and HfO_2 bilayer grating ridge depth, respectively, when grating period equals 1041.67 nm. The dot-dashed line stands for the circumstance when the sum of SiO_2 and HfO_2 bilayer grating ridge depths equals 900 nm. The dashed line stands for the circumstance when the sum of SiO_2 and HfO_2 grating ridge depths equals 600 nm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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