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High-efficiency three-port beam splitter of reflection grating with a metal layer

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A B S T R A C T

We describe a novel reflection three-port beam splitter by a microstructure grating, which can show high efficiency for both TE and TM polarization in the 0th and the ±1st orders. The grating profile is optimized by using the rigorous coupled-wave analysis (RCWA) at telecom wavelength around 1550 nm. With the optimized grating profile, the reflection three-port beam splitter can work as a 1 × 3 beam splitter for not only TE polarization but also TM polarization. Efficiencies can reach nearly 33% in the 0th and the ±1st reflected orders. The presented reflection three-port beam splitter grating should be a useful element in numerous practical applications, and a duty of 0.5 would make it easy to be fabricated.

1. Introduction

Microstructure gratings are widely used in numerous optical systems, which have been reported in reflection and transmission [1–5], which can be designed as beam splitters. Conventional 1 × 3 beam splitters, such as the three-port beam splitters–combiner, have been designed for interferometer applications [6]. Fused silica is an ideal optical material, which can stand with high laser power [7–9]. By recording with holographic technology and etching in fused silica, such gratings can be used for the laser integrating line and laser megajoule facilities [10]. The three-port beam splitter grating is designed to separate an incident beam into three beams with equal energies. Feng et al. designed and fabricated a transmission deep-etched fused-silica three-port beam splitter grating by using rigorous

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coupled-wave analysis (RCWA) [11], where the experimental results are in good agreement with the theoretical values [12]. A double-groove fused silica three-port beam splitter grating has been designed for TE polarization light with average diffraction efficiencies more than 95% [13]. The realization of a polarization-independent wideband transmission fused-silica grating has been reported [14]. However, as far as we know, no one has reported the high-efficient reflection three-port fused-silica beam splitter grating under normal incidence. It is desirable that a fused-silica grating with a metal slab of Ag evaporated on the substrate can function as a high-efficiency reflection three-port beam splitter.

In this paper, we describe a high-efficiency three-port beam splitter of fused-silica metal-based phase grating, where energies are reflected in the 0th and the ±1st orders with different directions. Furthermore, to obtain the polarization-independent property, a perfect 1×3 beam splitter is presented for both TE and TM polarizations under normal incident. Structure parameters optimized are given based on numerical calculation by using rigorous coupled wave analysis in order to achieve three-port output with high reflection efficiency and uniformity. The wavelength range and angular bandwidth for operation are investigated with optimized results.

2. Design and optimization

Fig. 1 shows the geometrical structure of the metal-based grating as a three-port beam splitter, which consists of a phase grating etched in fused silica with the refractive index $n_2 = 1.45$ and a metal slab of Ag with the refractive index n_3 evaporated on the substrate. A plane wave with the wavelength of λ is incident upon the grating with the duty cycle of f and the period of d under normal incidence. The working wavelength is 1550 nm. After propagating through the grating depth of h_g, the wave will be reflected and transmitted back into the grating region by the Ag slab with thickness of h_m. As a three-port beam splitter, energies are reflected in the 0th and the ±1st diffracted orders, respectively.

According to the grating equation as follows:

$$n_{out} \sin \varphi_m - n_{in} \sin \varphi_{in} = m\lambda/d \quad (1)$$

where n_{in} is the refractive index of the superstrate (air); n_{out} is the refractive index of the medium of the outgoing beam (either the substrate fused-silica or the superstrate); φ_{in} and φ_{out} depict the angle of incidence and the angle of the mth diffractive order, respectively. Under normal incidence, the ratio of grating period to wave must be restricted between 1 and 2. However, efficiencies of the 1st and the -1st diffractive orders are always the same because of symmetry. So, only the 0th and the 1st diffractive efficiencies need to be considered in this paper.

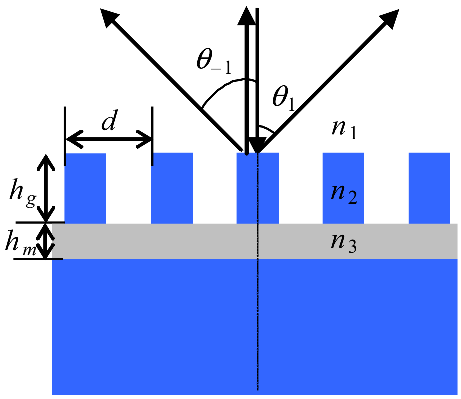

Fig. 1. Schematic illustration of a fused-silica reflection three-port beam splitter grating (refractive indices n_1: air, n_2: fused silica, n_3: Ag; d: period; h_g: grating depth; h_m: thickness of metal slab; θ_{-1} and θ_1 diffraction angles of the -1st and the 1st orders, respectively).