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Crystalline Grating-Waveguide Resonant reflectors

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The demand for reliable polarised narrow-bandwidth high-power lasers has motivated the development of innovative diffractive optics that can meet such requirements. Grating-Waveguide Structures (GWS) combining a waveguide and sub-wavelength grating can be used as a polarisation-selective high-efficiency reflector [1]. However, the maximum power (fluence) that can be used with these optics is limited by the intrinsic absorption and damage threshold of the compound materials. In this work, we report on the first resonant reflectors based on GWS made entirely of crystalline materials, which potentially offer better thermal and mechanical properties. Such crystalline GWS devices could enable operation at higher powers than conventional materials currently allow.

Two GWS designs were investigated in this study, targeting operation at 1030 nm and 1970 nm, to facilitate polarised wavelength tuning of Yb- or Tm-lasers. These devices comprise a sub-wavelength grating etched into a sapphire substrate on which an epitaxially grown waveguide layer of Sc_2O_3 is deposited (Fig.1a). In our experiments, 4-inch (0001) sapphire wafers were used as the substrate. For the respective designs, a 200-nm or 400-nm SiO_2 layer was deposited to act as hard mask to dry etch the substrate. An extra 50-nm Cr layer was deposited on top of SiO_2, which acts as conductive layer in the patterning process, but also as hard mask for the dry etching of SiO_2. E-beam lithography was used to pattern linear gratings with a 515-nm or 984-nm period at 50% duty cycle, for the 1-and 2-μm devices respectively. Inductively Coupled-Plasma (ICP) etching with Cl_2/O_2 gas chemistry was used to etch the Cr layer, followed by O_2 plasma cleaning to remove any residual resist. ICP with CHF_3/Ar was then used to etch the SiO_2 layer followed by Cl_2-based dry etching to remove the residual Cr layer. At this stage the sapphire substrate is patterned with a 200-nm or 400-nm thick SiO_2 mask. Sapphire structuring was achieved using ICP with $BCl_3/Cl_2/Ar$ or $SiCl_4/Cl_2/Ar$ gas chemistry (Fig.1b top), followed by immersion in hydrofluoric acid (7:1) to remove the residual SiO_2. Dicing out a ~1-cm^2 chip from the wafer, the final step in the waveguide reflector fabrication process is the growth of Sc_2O_3 on top of the sapphire grating using pulsed-laser deposition (PLD). The structured chip was heated to ~1100° C by a CO_2 laser, in chamber with an O_2 background gas pressure of 20 μbar. A 100-Hz KrF excimer laser ablated a ceramic Sc_2O_3 target, positioned 55mm in front of the heated substrate. Optimisation of growth conditions was made on flat sapphire substrates to determine the growth rate and film properties [2].

SEM images of the GWS are shown in Fig.1b(top) with residual SiO_2 mask before its removal and Fig.1b(bottom) after PLD. To characterise the performance of the crystalline reflectors their transmission was measured with a 1030-nm linearly polarised laser beam in function of the incident angle (Fig. 1c). For both TE- and TM-polarisations, a drop in the sample's transmission to ~40% was observed at angles of incidence of 6.1° and 7.4° respectively, demonstrating coupling of the incident beam to the waveguide mode. With a corresponding measured reflectance of 30% (TE) and 47% (TM), whereby the deficit is due to losses, either in the material or scattering. A discrimination of 5:1 for the TM-resonance was found, which could be improved with a back-surface AR coating.

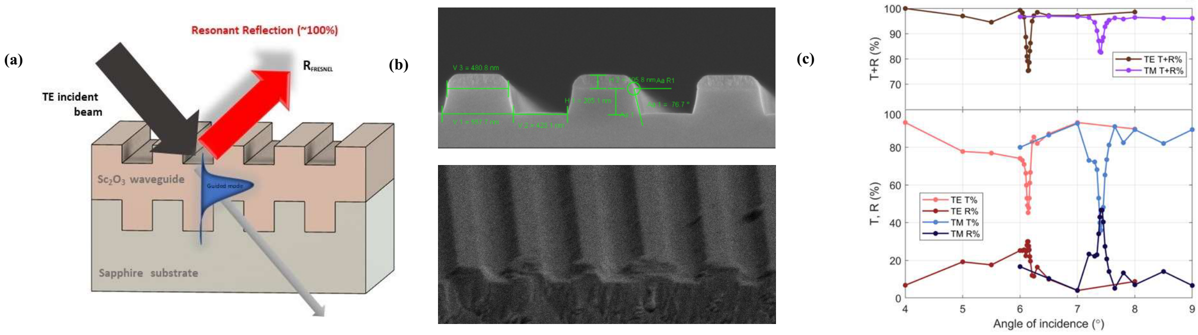

Fig. 1 (a) Grating waveguide reflector concept; **(b)** SEM images of structured SiO_2-masked sapphire (top) and after Sc_2O_3 deposition (bottom); and **(c)**TE/TM-polarised resonance characterisation at 1030 nm, dips in sum of transmittance and reflectance equates to losses.

In summary, we have fabricated and characterised the first crystalline reflectors based on GWS, with a resonant reflectivity at 1-micron of 47% achieved. Improvement in the surface quality of the crystalline GWS is required to achieve the ideal ~100% resonance reflection efficiency, as material/scattering losses appear to limit current performance. Refinement of the fabrication processes will lead to better device efficiency for these narrow-linewidth polarisation-selective reflectors.

References

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