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Superstrate Index Control of Waveguide Grating Reflectivity

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Abstract
Waveguide gratings reflecting at wavelengths near 1530nm were fabricated by laser ablation of thin Ta_2O_5 films on glass waveguides. Variation of reflectivity from 0.3dB to 34dB was achieved by alteration of the superstrate refractive index.

Introduction

Relief gratings on integrated optical waveguides have many potential applications in optical communications and sensing. Shallow gratings of submicron period may readily be achieved on waveguide surfaces by laser ablation in a single fabrication step. In this paper we describe the enhancement of grating strength using a thin high-index Ta_2O_5 film overlaid on an ion-exchanged waveguide[1], and adjustment of the strength by variation of the superstrate index. The results may have application in the selection of cladding layers for waveguides incorporating gratings and, potentially, in the realisation of gratings with adjustable strength, by the use of electro-optic overlayers.

Fabrication

Monomode waveguides at 1550nm were fabricated in BK7 glass substrates by K^+ ion exchange through an Al mask with channel openings of 3μm, at 400°C for 11 hours. The waveguide endfaces were then optically polished to yield a device nominally 45mm long. A film of tantalum pentoxide of thickness 50nm was deposited by reactive RF sputtering from a tantalum target, to cover a 25mm length of the waveguides. A 20mm long grating of 510nm period was fabricated in the Ta_2O_5 film by 248nm excimer laser ablation[2] through a phase mask in close proximity mode, using 1500 pulses of $20mJ/cm^2$ energy density. The recorded grating was made deliberately weak to provide low reflectivity in air superstrate.

Waveguide grating reflectivity results

AFM and diffraction efficiency measurements revealed that the grating depth of the 510nm structure was not greater than 2.5nm. Polarisation resolved measurements of the grating spectra

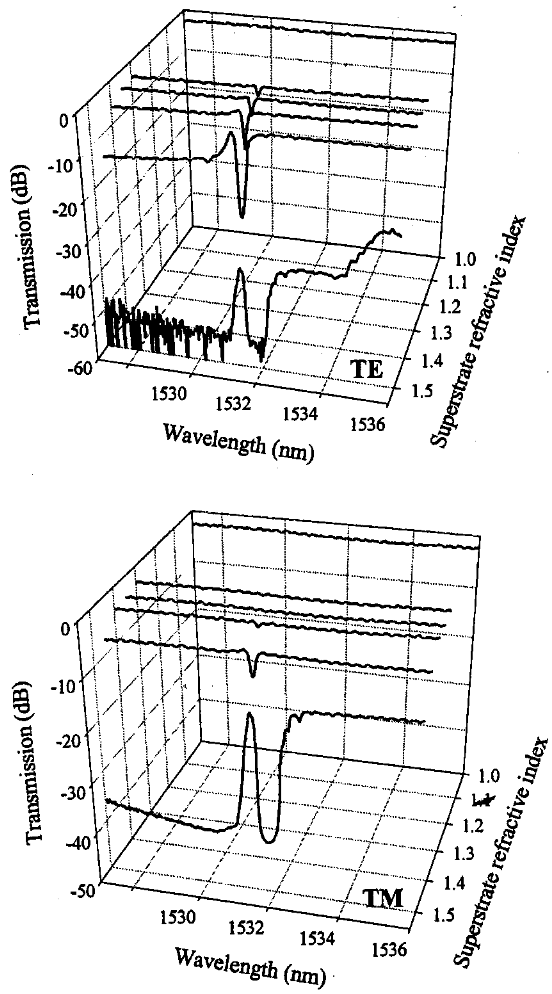

Figure 1 Waveguide transmission spectra

were obtained using an erbium-doped fibre amplifier used as a superfluorescent source, fibre-coupled to the endface of a waveguide; the spectra were measured using an optical spectrum analyser. Full details of the experimental apparatus and procedures are given in ref. 1. The results for air and five different liquids, of indices 1.30, 1.35, 1.40, 1.45 and 1.50, covering the grating are presented in Fig. 1 for both the TE and the TM polarisation. The spectra are normalized to the spectrum of the superfluorescent source measured without the waveguide in place. For the TE polarisation, the grating reflectivity in air, of 0.3dB, is increased to 20dB with the superstrate liquid of index 1.45. A grating reflectivity of 34dB is observed when the liquid of index 1.50 is applied; however for a superstrate index this high, the waveguide becomes multimode, affecting the modal intensity distribution and the grating response. Similar results are observed for the TM polarisation, where the spectral notch is unmeasurable in air but becomes greater than 27dB after application of the liquid of index 1.50.

The application of superstrate liquids to the corrugated grating also affects the broadband transmission loss of the structure. The Ta_2O_5 film is more lossy than the ion-exchanged region and the grating and waveguide surface is imperfect. The presence of the Ta_2O_5 film enhances the modal field near the waveguide surface, increasing the overlap with the Ta_2O_5 film and grating where absorption and scattering losses may be high. The fibre-to-fibre loss of the waveguide and grating in air is 2.2dB for both polarisations, including the fibre-waveguide coupling losses which have not been optimised. Application of the liquid of index 1.40 increases the loss by less than 0.9dB for both polarisations. From the experimental data of Fig. 1 it is also observed that the grating Bragg wavelength shifts to longer wavelengths for superstrates of higher refractive index. This is due to the increase of the effective index (N_{eff}) of the composite waveguide structure for higher superstrate index, in accordance with basic waveguide theory.

A commercial beam propagation method (BPM) package[3] was employed to model channel waveguides overlaid with high-index films and to estimate the grating reflectivity expected for different superstrate indices. The reflectivity was estimated from the effective indices calculated for the waveguide regions with the complete Ta_2O_5 film and those with the Ta_2O_5 film thickness reduced due to ablation. For simplicity an equivalent step-index waveguide structure was used to model the experimental ion-exchanged waveguide. The theoretical peak reflectivity for a 3μm wide and 3μm deep embedded channel waveguide, with corrugation depth of 2.5nm in a 50nm thick Ta_2O_5 film is presented in Fig. 2 as a function of superstrate index. The experimentally-determined peak reflectivities extracted from Fig. 1 are also shown for comparison. The transmission losses that emerge from the experimental data of Fig. 1 were included in calculating the grating reflectivity.

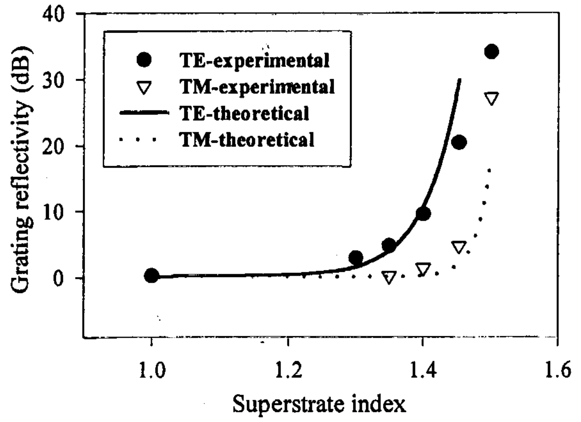

Figure 2. Peak reflectivity vs. superstrate index

There is good agreement between experimental and theoretical reflectivity data in Fig. 2, especially for lower superstrate indices. Greater deviations between experimentally and theoretically determined reflectivities are observed for higher superstrate indices, and are attributed to the step index model used and neglect of grating amplitude and phase errors in the model. Such grating imperfections can significantly degrade the reflectivity. Experimental N_{eff} values for the composite waveguide were estimated from the Bragg wavelength and the phase mask period. N_{eff} varied from near 1.501 in air to 1.504 (TE) and 1.502 (TM) for a superstrate index of 1.5, confirming the increasing overlap of the mode with the high index Ta_2O_5 film with increasing superstrate index. The BPM was also used to predict the N_{eff} of the composite waveguide structure, and showed fair agreement for both polarisations.

Conclusions

The fabrication of waveguide gratings at wavelengths near 1530nm by laser ablation in a Ta_2O_5 overlayer is reported. Control of the peak reflectivity over a range 0.3dB – 34dB by variation of superstrate index has been demonstrated. Potential improvements include the substitution of index matching liquids with solid films or liquid crystals and the reduction of the transmission losses using annealing techniques.

References

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