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STRONG PHOTO-INDUCED REFRACTIVE INDEX CHANGES IN RF-SPUTTERED TANTALUM OXIDE PLANAR WAVEGUIDES

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Abstract: Large negative UV-induced index changes (~ −0.01) have been measured in sputtered tantalum oxide planar waveguides using an optical fibre probe capable of accurately monitoring both the magnitude and the sign of the index change.

Summary:

Optical waveguide gratings have a multitude of uses in laser, communications and sensing systems, in both planar and fibre configurations. They may be fabricated holographically in materials that display high levels of photosensitivity when exposed to UV light. An example is Bragg grating formation in germanosilicate optical glass fibres [1] and planar waveguides of similar composition [2]. We report here, for the first time, strong UV-induced refractive index changes in sputtered tantalum oxide planar waveguides. In order to quantify the photo-induced changes in these films, we constructed a channel-dropping device consisting of a tantalum oxide waveguide sputtered on to a side-polished single-mode fibre with a P-doped core (known not to be photosensitive) - see Fig.1. The structure is similar to the one reported by Moodie and Johnstone [3]. At the probe wavelength of 850 nm, the single TE mode of the planar waveguide matched the fibre mode at a film thickness of approximately 65 nm. Real-time monitoring of the transmission as a function of deposition time enabled very accurate phase-matching between thin film and fibre modes to be achieved.

When phase-matching is achieved, optical power couples into the TE-mode of the planar waveguide from the appropriately polarised "TE" fibre mode; the orthogonal "TM" fibre mode remains uncoupled. If the fibre polarisation state is set to "TE", a sharp "absorption edge" occurs at a certain resonant wavelength. This wavelength, λ_p, is a sensitive function of both the film thickness and its index.

Exposure of the tantalum oxide films to UV light at 248 nm (20 nsec pulses, 20 Hz repetition rate, from a KrF excimer laser) consistently moved λ_p to shorter wavelengths. A device with

λ_p = 850 nm prior to exposure exhibited a total shift of approximately -20 nm (see Fig.2). The effect saturated: increasing the exposure produced no further shift in λ_p. After 100 hours a relaxation of +3 nm was observed.

Figure 3 shows the UV-induced absorption changes observed in three areas of a tantalum oxide film that were exposed to increasing doses of UV light. The characteristic strong absorption at 210 nm, which is of the order of 300 dB/μm, is enhanced whilst the absorption in the visible is reduced.

Modelling the coupled waveguide system we find that a large Δn_{850nm} of -0.01 will account for the -20 nm shift in λ_p. Although thinning by ablation is another potential mechanism, we may rule it for a number of reasons. Firstly, λ_p was seen to relax; secondly, there is no obvious mechanism by which the ablation could saturate, especially since the absorption at the exposing wavelength (248 nm) is seen to increase (Fig.3); and thirdly, ablation is highly unlikely to yield the uniform reduction in film thickness needed to explain the results.

In conclusion, we have measured bulk index changes of -0.01 at infra-red wavelengths in sputtered tantalum oxide films. Work continues on establishing whether these index changes can be used to form strong refractive index gratings of sub-micron pitch. Preliminary indications are that, despite a small initial relaxation, the index change is stable.

References

1. P.St.J. Russell, J.-L. Archambault and L. Reekie, "Fibre Gratings," Physics World **6** (41-46) 1993.

2. G.D. Maxwell, R. Kashyap, B.J. Ainslie, D.L. Williams and J.R. Armitage, "UV written 1500 nm reflection filters in single mode planar silica guides," Electron. Lett. **28** (2106-2107) 1992

3. D.G. Moodie and W. Johnstone, "Wavelength tunability of components based on the evanescent coupling from a side-polished fiber to a high-index-overlay waveguide," Opt. Lett. **18** (1025-1027) 1993.

Figure Captions

1. Experimental configuration of a tantalum oxide waveguide on a side-polished fibre.

2. Transmission spectrum of the coupled fibre signal normalised to the uncoupled fibre transmission spectrum: (a) spectrum of unexposed sample, (b) spectrum after saturation of $\Delta\lambda_p$.

3. UV-induced differential absorption spectrum of three areas of a tantalum oxide film subjected to decreasing UV exposures: (a) ~111 J/cm^2, (b) ~44 J/cm^2, (c) ~ 11J/cm^2, (d) 0 J/cm^2 (obtained from two subsequent measurements on the same tantalum oxide film).

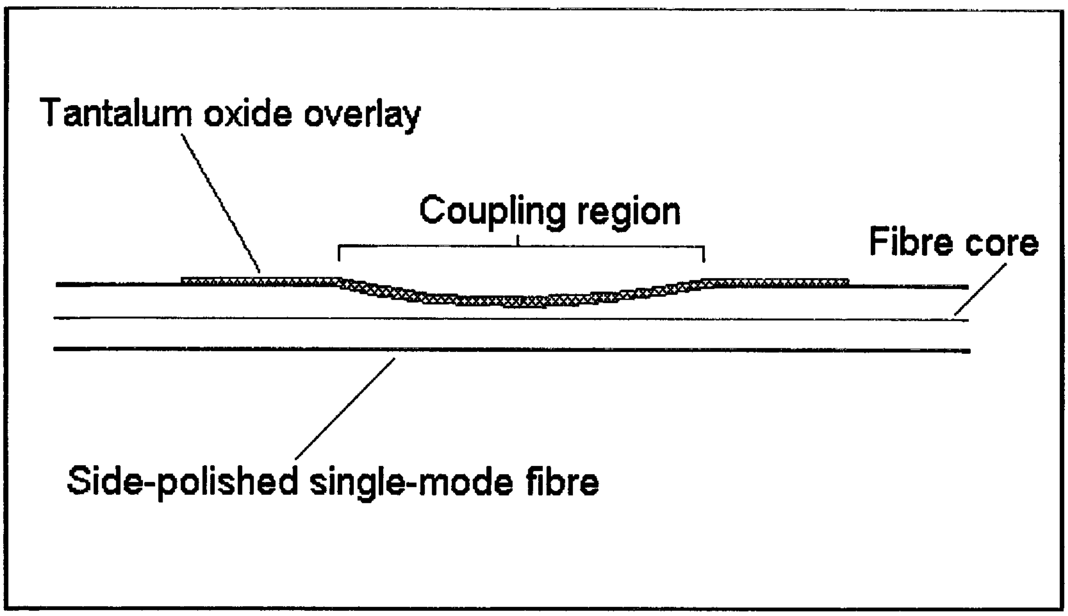
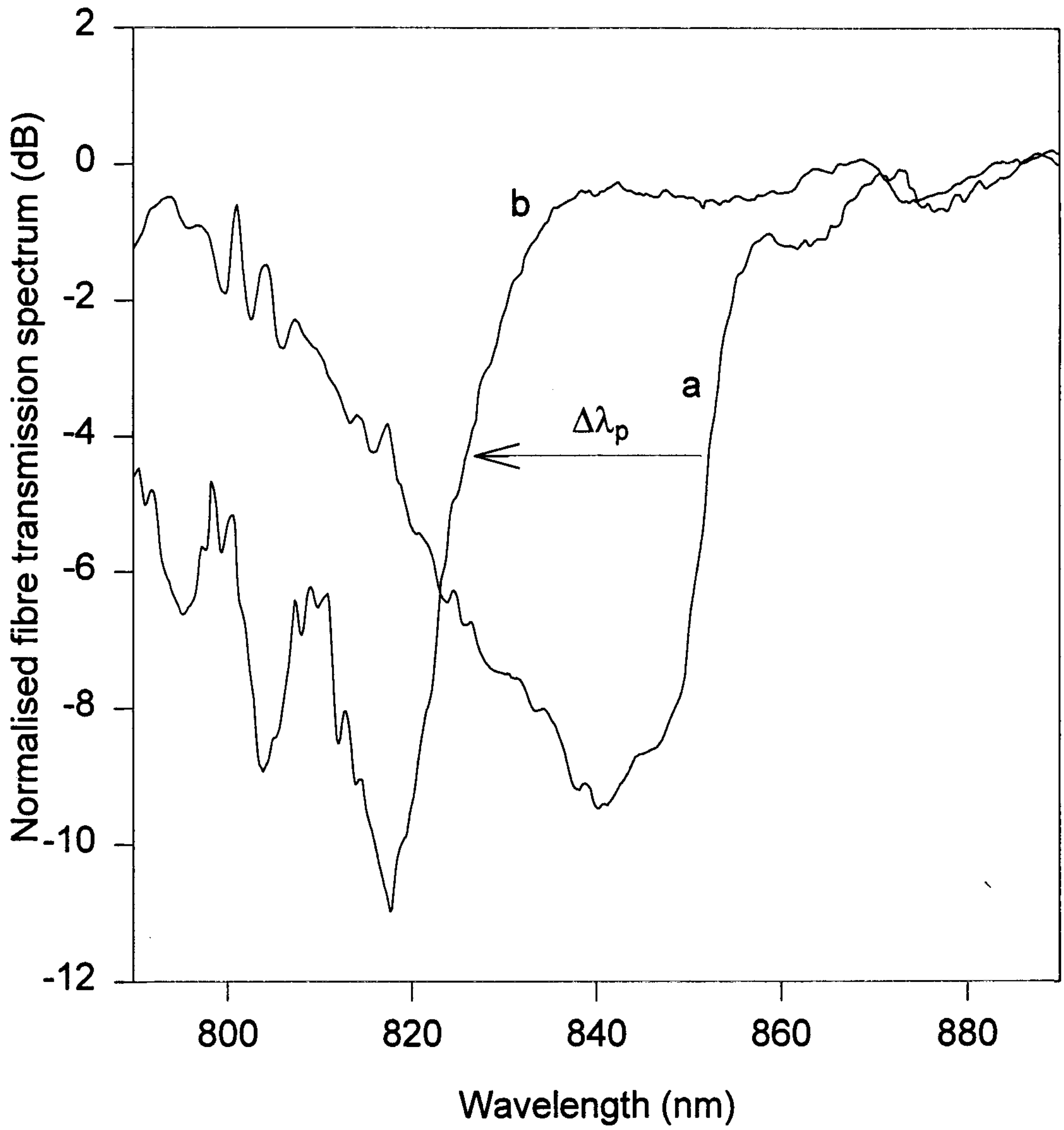
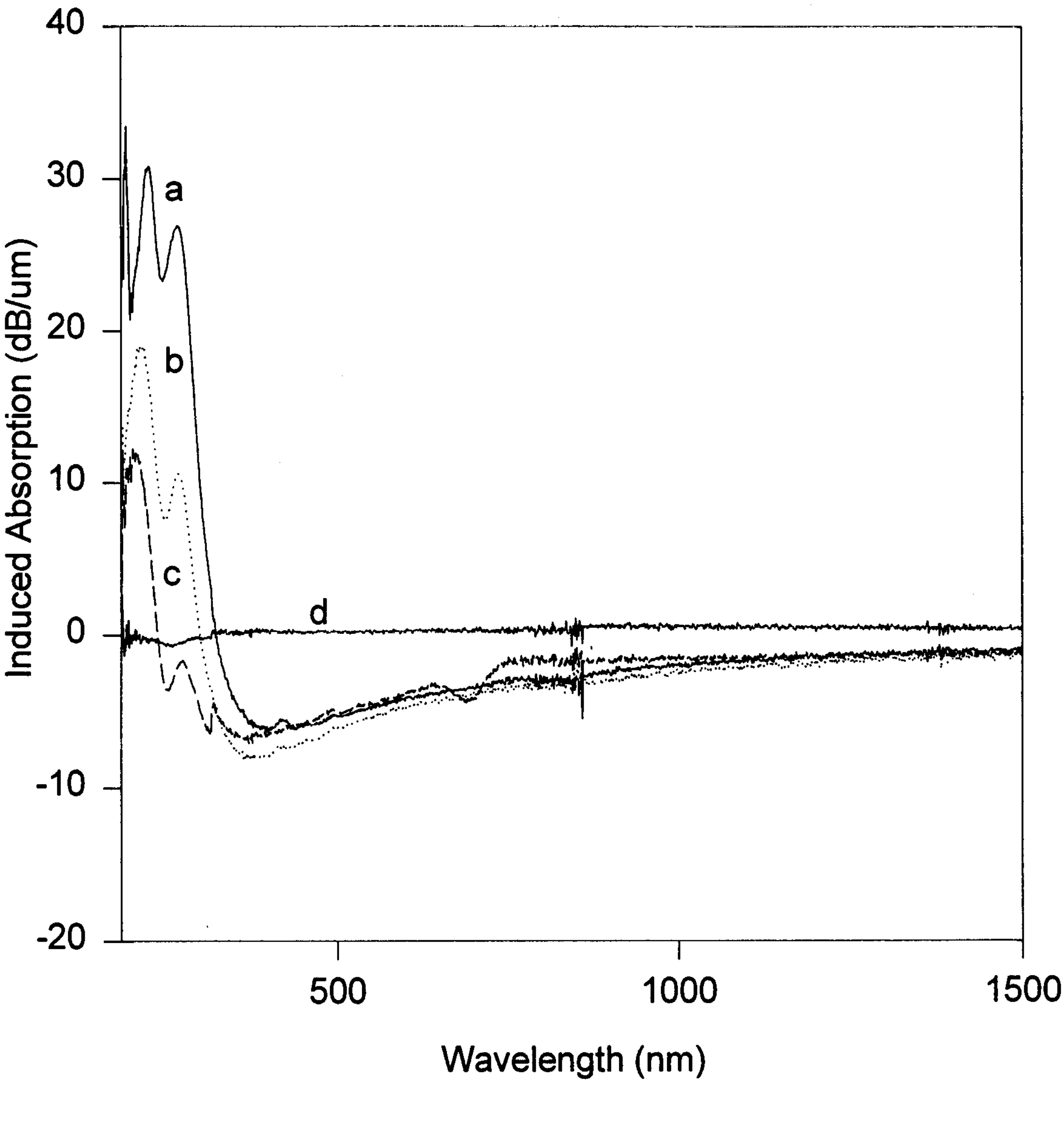

Tantalum oxide overlay
Coupling region
Fibre core
Side-polished single-mode fibre

Figure 1



2
0
-2
-4
-6
-8
-10
-12
Normalised fibre transmission spectrum (dB)
800
820
840
860
880
Wavelength (nm)
b
a
Δλp

Figure 2



40
30
20
10
0
-10
-20
Induced Absorption (dB/um)
a
b
c
d
500
1000
1500
Wavelength (nm)

Figure 3