the BER of the CR was in excess of the error correcting capability of the half rate code for more than five users.

Conclusions: We have shown by simulation that our algorithm is near–far resistant in AWGN and fast fading channels. In agreement with Turin [1], the CR is shown to be unusable in the absence of sufficiently rapid power control. The DR is hence shown to be a viable alternative to a complex closed loop power control strategy, the feasibility of which is questionable for practical vehicle speeds. We hence conclude that the sliding window algorithm has potential application to future generation point-to-point and mobile radio DS-CDMA systems.

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ELIMINATION OF PHOTOINDUCED ABSORPTION IN Ge-DOPED SILICA FIBRES BY ANNEALING OF ULTRAVIOLET COLOUR CENTRES

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Indexing terms: Optical fibres, Optical losses

Heating standard telecommunication Ge-doped silica fibres to 1200°C removes the ultraviolet absorption bands believed to be responsible for photosensitivity. Losses at 480 nm induced by exposure to 249 nm laser light are reduced from 30 dB/m to less than 0·8 dB/m in the annealed fibre.

Introduction: Standard optical fibres for telecommunications are made of silica with a germanium doped core. These fibres are opaque in the ultraviolet (UV) because of the presence of colour centres associated with Ge defects in the glass. Recently, the absorption at 240 nm was measured to be of the order of 27 dB/mm [1]. It is generally believed that photosensitivity (light-induced changes in absorption and refractive index) in such fibres is caused by absorption from these colour centres [2], either directly with UV light or with blue light at 488 nm from two-photon processes. Although these phenomena are considered useful for many purposes, there is one area where they represent a problem to be eliminated: short wavelength (blue-green) doped silica fibre lasers. The large intensities generated near 488 nm are bound to induce absorption which will prevent continuous laser operation. In fact, although upconversion lasing in the blue has been observed in suitably doped fibres, it is limited to a very short pulse before laser action stops*.

We show how a complete annealing of the fibre removes the absorption bands in the ultraviolet. We also show a strong reduction in photoinduced absorption from UV exposure. This work was stimulated by our results on implantation-induced photosensitivity in silica, in which such annealing restored the samples to their preimplantation state of transparency by completely eliminating colour centres [3].

Results and discussion: Standard Ge-doped silica fibres (Corning SMF 28) were cut to 10 m lengths, stripped of their coating, and heated in a furnace to 1200 °C, in air at atmospheric pressure. This temperature is just above the annealing point of fused silica, where residual stresses and strains are eliminated in minutes [4]. The fibres were left in the furnace throughout the heating and cooling periods, at rates from 2 to 8°C/min, with a 10 min plateau at 1200°C. The absorption spectrum of the heated fibres was measured using a monochromator/photomultiplier detection setup using a cutback method: the ratio of the transmission spectra for lengths of 10 and 1 m yields the loss spectrum shown in Fig. 1. The losses in the ultraviolet (near 240 nm) are down to 1 dB/m (compared to 27 000 dB/m in an untreated similar fibre [1]).

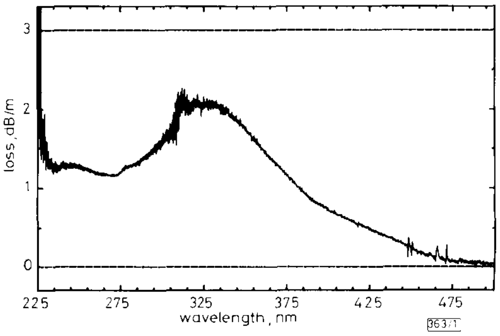

Fig. 1 *Short wavelength absorption spectrum of fibre after annealing at 1200°C*

In view of this surprising result, great care was taken to ensure that light propagates through the core by immersing the cladding in index matching oil near the input and output of the fibre being measured. Another proof of the induced UV transparency is that light from a KrF excimer laser (249 nm wavelength, average power of 5 W/cm²) can be guided in the core of a 1 m length of treated fibre, as shown in Fig. 2.

An important point to mention is that for such annealing times and temperatures, there is no significant diffusion of germanium [5], leaving the core of the fibre with almost the same concentration and distribution of dopants. Therefore, the guiding characteristics of the fibre (refractive index and

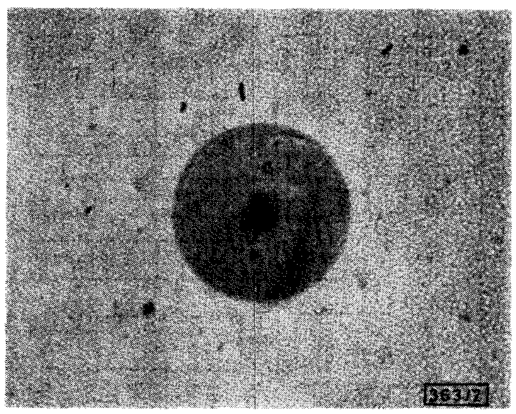

Fig. 2 *Photograph of Sensor Physics UV sensitive card exposed to end of 1 m long annealed fibre in which 249 nm KrF excimer laser light is launched*

Some stray light is seen in the cladding because no matching oil was used in this case, but this shows how UV light propagates in the fibre core

* HANNA, D. C.: Optoelectronics Research Centre, University of Southampton, personal communication

mode profile) should be nearly unchanged. Apart from the induced transparency, the only obvious change to the fibre is a reduction in strength, and more care is needed in its handling after heating (the exposed cladding was laying directly on the surface of the silica tube of the furnace during heating).

Finally, we measured the difference in UV-induced absorption changes (which are generally held to be responsible for photosensitivity) between annealed and untreated fibres. This was achieved by exposing from the side the same length (25 cm) of bare fibre to 249 nm wavelength light from a KrF excimer laser operating at 50 pulses per second with an intensity of 110 mJ/cm^2 per pulse for 5 s. The absorption changes were measured *in situ* with an optical spectrum analyser using a white light source at the input of the fibre. The results of this experiment are shown in Fig. 3. Whereas absorption at

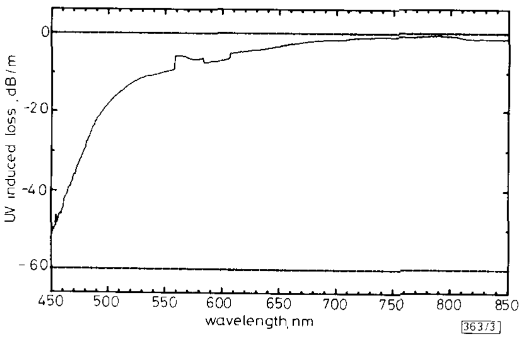

Fig. 3 *Spectrum of losses induced at visible wavelengths in untreated fibre by exposing from the side a 25 cm length to 5 W/cm^2 of KrF excimer laser light at 249 nm for 5 s*

The same experiment on the annealed fibre shows no induced loss, limited by the measurement uncertainty of 0·8 dB/m; kinks in the curve between 550–600 nm are a measurement artefact

480 nm increased to 30 dB/m in the untreated fibre, *no measurable change was observed in the heated fibre.* Given the accuracy of the measurement, the upper bound on the induced losses at 480 nm is 0·8 dB/m, still a 29 dB difference. Assuming that the presence of other dopants does not modify significantly the behaviour observed here, we see immediately why silica based blue fibre lasers would fail to operate: the onset of lasing induces high losses in the fibre and prevents further laser operation.

It is interesting to compare our results with those of Poyntz-Wright *et al.* [6], who annealed fibres in which losses had been photoinduced. They measured an increase in absorption of ~0·8 dB/m at 480 nm in a silica fibre doped with 6.5 mol% of germanium following exposure to 15 min of pulsed (30 Hz) 463 nm laser radiation propagating in the core with a peak intensity of 3 W/μm^2. Subsequent annealing at a temperature of 260°C increased losses to 2·4 dB/m, followed by a return to the as exposed loss of 0·8 dB/m when the temperature reached 750°C. No mention is made of higher annealing temperatures. The variations in losses are explained in terms of redistributions in the populations of the various types of Ge defect. In the work presented here, we show that increasing the temperature to the point where strain relaxation occurs makes a big difference in the dynamics of the defects. It is worth noting that the higher losses that we obtain in the untreated fibre with smaller light intensity from side illumination come from exposing the defects directly in a strong UV absorption band.

The effect of annealing an absorption at short wavelengths is believed to arise from the removal of Ge E′ defects, which are associated with ultraviolet colour centres. These defects are generated during preform fabrication and also fibre pulling [7]. They consist of oxygen vacancies adjacent to underco-ordinated GeO_2 molecules which have trapped an electron or a hole [8]. The annealing in air, at a temperature close to the transformation range for silica, allows some molecular rearrangement, as well as local diffusion of oxygen in the vitreous structure thereby 'repairing' the defects to some extent. EPR spectroscopy has shown that Ge E′ degects are essentially removed and cannot be reactivated after an annealing above *at least* 800°C [9]. Note that the fibre pulling process, although carried out above 2000°C, does not eliminate defects because of the rapid cooling involved.

Conclusion: We have shown how a simple annealing of standard telecommunication fibres removes ultraviolet absorption bands associated with Ge colour centres. In fact, the core of the heated fibre guides 249 nm laser light with losses of only 1 dB/m. Also, the photoinduced darkening which extends to wavelengths in the visible disappears while the other waveguiding parameters of the fibres remain relatively unchanged. We believe that this annealing process could be a solution to the selfdestructing mechanism which plagues short wavelength silica fibre lasers.

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TRUE-CW OPERATION OF GaAs BISTABLE ETALON WITH ELECTRONIC OPTICAL NONLINEARITY

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Indexing terms: Nonlinear optics, Optical bistability

An all-epitaxial GaAs/GaAlAs optically bistable Fabry-Perot etalon, designed to maximise the band-edge resonant electronic nonlinearity relative to unwanted thermal effects, has been demonstrated to be capable of being held CW in either of the bistable states. Switch times of <40 ns were recorded together with a critical switch power of <700 μW.

Optical bistability as a result of the band-edge-resonant refractive nonlinearity in a semiconductor was first demonstrated at room temperature with bulk GaAs by Ovadia *et al.* [1]. A significant problem when attempting to use such a device for optical processing applications is the presence of the competing thermal nonlinearity. This is most clearly apparent when the bistable device is held CW in its switched-on (high transmission) state when, due to the power being dissipated