

NON-LINEAR TRANSMISSION IN GERMANOSILICATE FIBRES AT BLUE/GREEN WAVELENGTHS

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Introduction

Many fibre-based devices rely on the ability to transmit light at high intensities down single-mode fibres. Examples are fibre lasers, amplifiers, second-harmonic generators and simple fibre-based high power delivery systems. It is thus important to know whether any non-linear processes exist that could restrict the usefulness of the fibres used in these applications. Brown et al have reported¹ that non-linear effects of this kind do indeed occur at Argon ion wavelengths in germanosilicate fibre, limiting the power that can be delivered to some tenths of a W over only few-metre lengths of single-mode fibre.

In this paper we report the chief results of an extensive investigation into this effect in germanosilicate HiBi fibres designed to transmit single-mode blue/green light. These observed non-linearities in the transmission of CW blue/green light cannot be attributed to conventional non-linear processes (such as stimulated Raman or Brillouin scattering) because only short (few-metre) fibre lengths are needed, the thresholds are low, and the effect is insensitive to laser line-width¹. We have indicated² that this non-linear behaviour can be explained by the creation (via two-photon absorption - TPA) and bleaching (via normal absorption) of colour-centres. TPA enables blue/green photons to reach UV energy levels that are sufficient to disrupt the glass matrix, and even though the TPA rate is very low at intensity levels where non-linear transmission is significant, the long path lengths in the fibre, added to the high likelihood of colour-centre formation by quanta at double the photon energy, mean that colour-centres created by TPA can have a dramatic effect on transmission.

Experimental procedure

High intensity pulses (6 ns FWHM, 30 Hz repetition rate) from a dye laser pumped by a frequency tripled Nd:YAG laser, at wavelengths from 420 to 540 nm, were launched into 5 metre lengths of fibre. The induced loss was measured at regular time intervals (with the laser light blocked) using a counter-propagating chopped white-light measurement system incorporating a monochromator and photomultiplier in conjunction with a phase sensitive device.

Experimental results

Upon exposure to blue/green light, the fibre attenuation increases gradually, eventually reaching a steady-state level that scales with the peak intensity in the core². If the intensity is then reduced, the transmission recovers slowly as the induced absorption approaches a new (lower) equilibrium level. If the laser is now blocked, a further increase in attenuation results, gradually approaching a new steady-state level.

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We believe that this behaviour is the result of the complex interplay of colour-centre creation by TPA, and both single-photon and spontaneous colour-centre bleaching processes.

The fibres used in our experiments were manufactured by the MCVD process with germanosilicate cores. ESR measurements on unexposed fibres show a resonance typical of oxygen-deficient germanosilicates (Figure 1), and indicate the existence of Ge(1), Ge(2) and Ge(3) colour-centres³. To establish if these colour-centres were responsible for the observed behaviour, a range of fibres with different germania concentrations was exposed to peak intensities of $10 \text{ W}/\mu\text{m}^2$ at 470 nm and the transmission allowed to stabilise. The induced attenuation at 460 nm (arbitrary choice) scaled linearly with germania concentration at 170 dB/km per mol% indicating that the colour-centres in question are indeed Ge-related. Further evidence comes from the induced absorption spectrum, which shows that the loss is strong in the UV, with a tail that covers the operating region in the blue/green. Ge(1) defects have been associated with an optical absorption band at 4.4 eV (281 nm)⁴, the shape of which resembles what we observe, being very broad and having a tail extending well into the visible.

A 5 m length of fibre was exposed to pulses of $3 \text{ W}/\mu\text{m}^2$ peak intensity at 463 nm and then thermally annealed for 15 minute periods at selected discrete temperatures. Figure 2 shows that the induced absorption increases steadily between room temperature and about 250°C, where it peaks. Then beyond 250°C it gradually returns approximately to its level prior to thermal annealing. If the initial and final loss are caused by the same colour-centres, then the TPA-induced absorption is highly temperature stable.

It is known that an absorption band exists at 240 nm in oxygen-deficient germanosilicate glass⁵. Thus it was of interest to investigate the wavelength sensitivity of the absorption creation process. To this end, pulses at wavelengths ranging from 420 to 540 nm were launched into a series of 5 m lengths of fibre for periods of 15 minutes each. As shown in Figure 3, the greatest losses were induced by a pump wavelength of 480 nm indicating that TPA does play an important role in the phenomenon.

Summary

Our physical explanation for these observations is as follows. TPA supplies enough energy to break the oxygen-deficient Ge-Ge and Ge-Si bonds, thus creating free electrons and Ge(3) centres. The released charge may then move along networks of interconnected Ge defect sites, along which the band-gap is narrower than for pure SiO_2 , until it recombines or falls into Ge-related traps to create Ge(1) or Ge(2) centres. Germania lies at the root of the observed non-linear transmission and obviously should be avoided as a dopant for high-power transmitting fibres in the blue/green spectral region.

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References

- 1 R.G.W.Brown, D.A.Jackson, J.D.C.Jones and R.K.Y.Chan, Proc ICO-13, Sapporo, Japan, August 1984
- 2 L.J.Poyntz-Wright, M.E.Fermann and P.St.J.Russell, Paper WM54, Conference on Lasers and Electro-Optics, Anaheim (1988)
- 3 E.J.Friebele, D.L.Griscom and G.H.Sigel, J Appl Phys 45 3424 (1974)
- 4 E.J.Friebele and D.L.Griscom, Mat Res Soc Symp Proc 61 319 (1986)
- 5 A.J.Cohen and H.L.Smith, J Phys Chem Solids, 7 301 (1958)

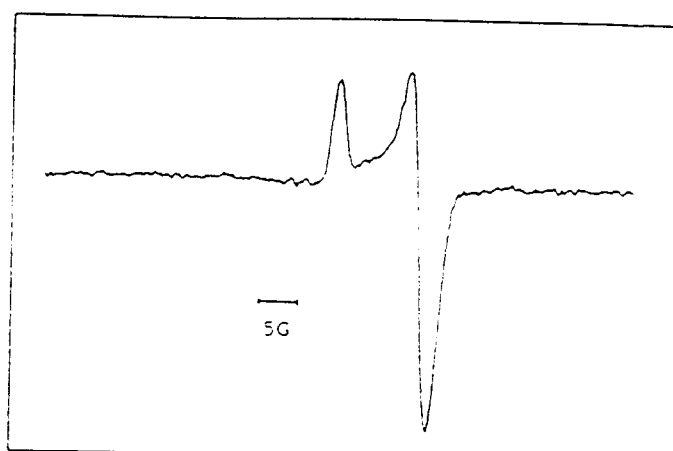


Figure 1. ESR signal observed in an untreated fibre sample.

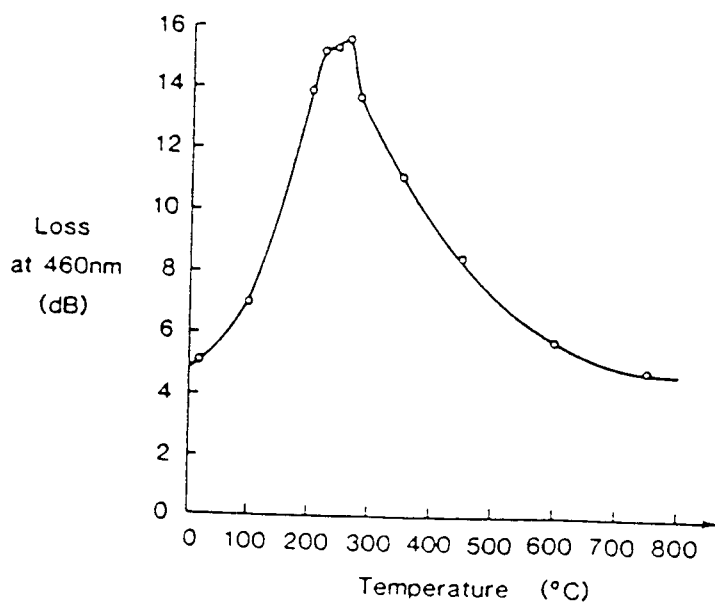


Figure 2. Effects of thermal annealing for 5m of fibre exposed to $3 \text{ W}/\mu\text{m}^2$ peak power at 463 nm.

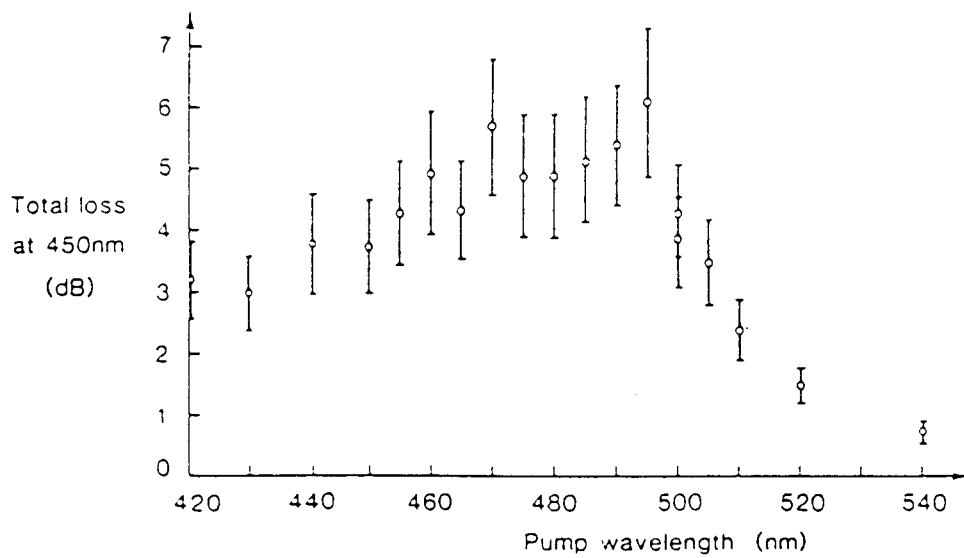


Figure 3. Attenuation at 450 nm in 5m lengths of fibre after exposure to $10 \text{ W}/\mu\text{m}^2$ at various pump wavelengths.