CLEO '88

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Optical Damage in Fibres: "The Fibre Fuse"

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Abstract

We demonstrate experimentally that catastrophic breakdown in the cores of optical fibres can be initiated thermally at modest optical intensities, forming periodic damage tracks uniform over several centimetres. The dynamics of this breakdown are investigated.

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Summary

When sufficient power is launched into an optical fibre, the fields can be high enough to cause breakdown and catastrophic destruction of the core. The consequence is an intense white spot of light travelling at speeds of 1-5 m/s along the fibre towards the laser: the Fibre-Fuse. The mechanisms behind the phenomenon are not yet fully understood; however it seems likely that run-away thermal self-focusing plays a role, leading to extremely high

local intensities that are ultimately limited by the onset of a variety of different nonlinear processes[1,2]. One might expect that very high power densities would be required to start the fibre-fuse. However, we have been able to initiate it at relatively modest power levels in a number of differently doped single and multi-mode fibres by heating the fibre locally using the flame of a match. The fibres that most readily exhibited the effect had cores which were Na-doped, CW power densities of only 50 $mW/\mu m^2$ (all lines from an Argon ion laser) being sufficient to initiate the fuse. A likely reason why heating starts the fibre-fuse is the rapid increase in attenuation with temperature that occurs above 1000°C in silica-based fibres (see Figure 1). The high ambient temperature created by the match flame raises the core temperature above 1000°C, causing increasingly strong absorption of the guided light. A nonuniform temperature profile then develops across the core, leading (since $\delta n/\delta T > 0$ for silica) to thermal self-focusing. This causes the core temperature to rise so high that the material dissociates, setting off the fuse. Evidence supporting this picture lies in the periodic damage tracks (characteristic of self-focusing phenomena[1,3]) created in the core (see Figure 2). These can be extraordinarily uniform over tens of centimetres, with periodicities of the order of a few microns. Simultaneous work at British Telecom confirms this result[4].

The linear loss in the single-mode Na-doped fibre was substantial (2 dB/m for all lines of an Argon ion laser), enabling us to chart the influence of intensity on the fuse velocity using an array of 9 photodiodes placed along a straight 1 metre length of fibre (Figure 3). From the data in Figure 3, the relationship between average core intensity I_c and fuse velocity v_f is approximately linear, with a slope of 58 ms^{-1} per $W\mu m^{-2}$. An estimate of the maximum possible core temperature T_c may be made by assuming zero dissipation at the hot-spot of the fuse:

$$T_c = T_a + I_c/v_f C_p \rho$$

where T_a is the ambient temperature, C_p the specific heat and ρ the density. This yields $T_c - T_a = 13{,}000^oC$ for $v_f = 2$ m/s and $I_c = 55\ mW/\mu m^2$.

References

[1] Y.R.Shen, "The Principles of Nonlinear Optics", ch.17 Wiley-Interscience 1984

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[3] G.M.Zverev and V.A.Pashkov; JETP lett. **9**,61 (1969)

[4] R.Kashyap and K.Blow; Postdeadline paper PD7, 8th National Quantum Electronics Conference, **QE8**, St Andrews, Scotland 1987

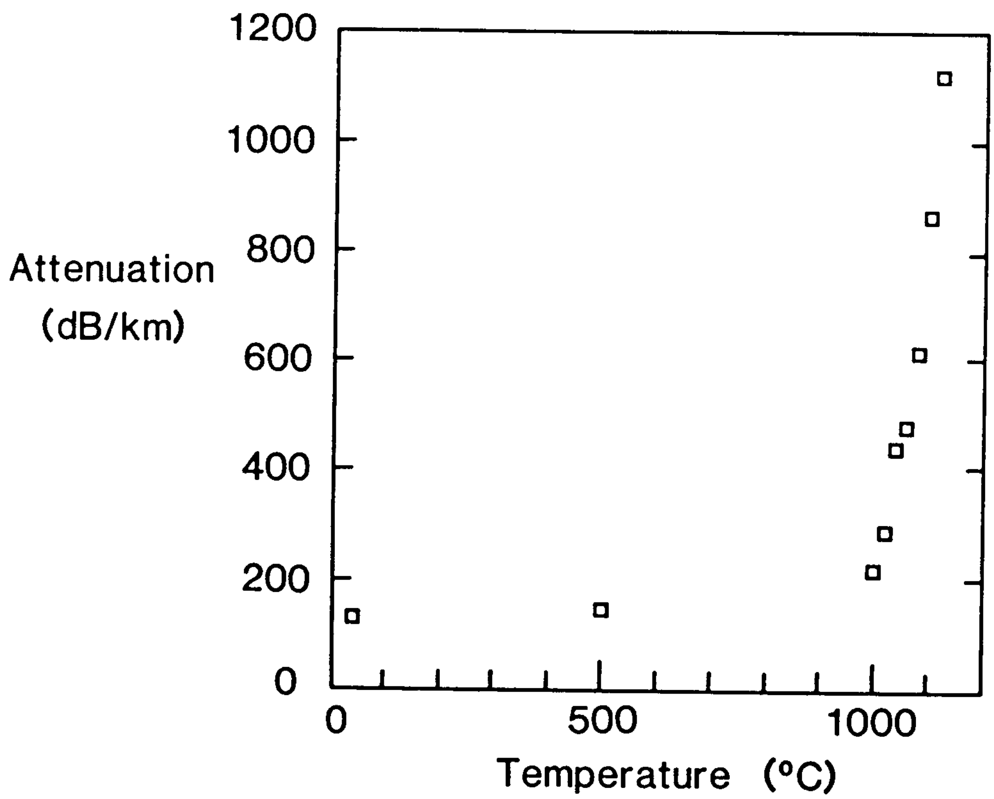
Figure Captions

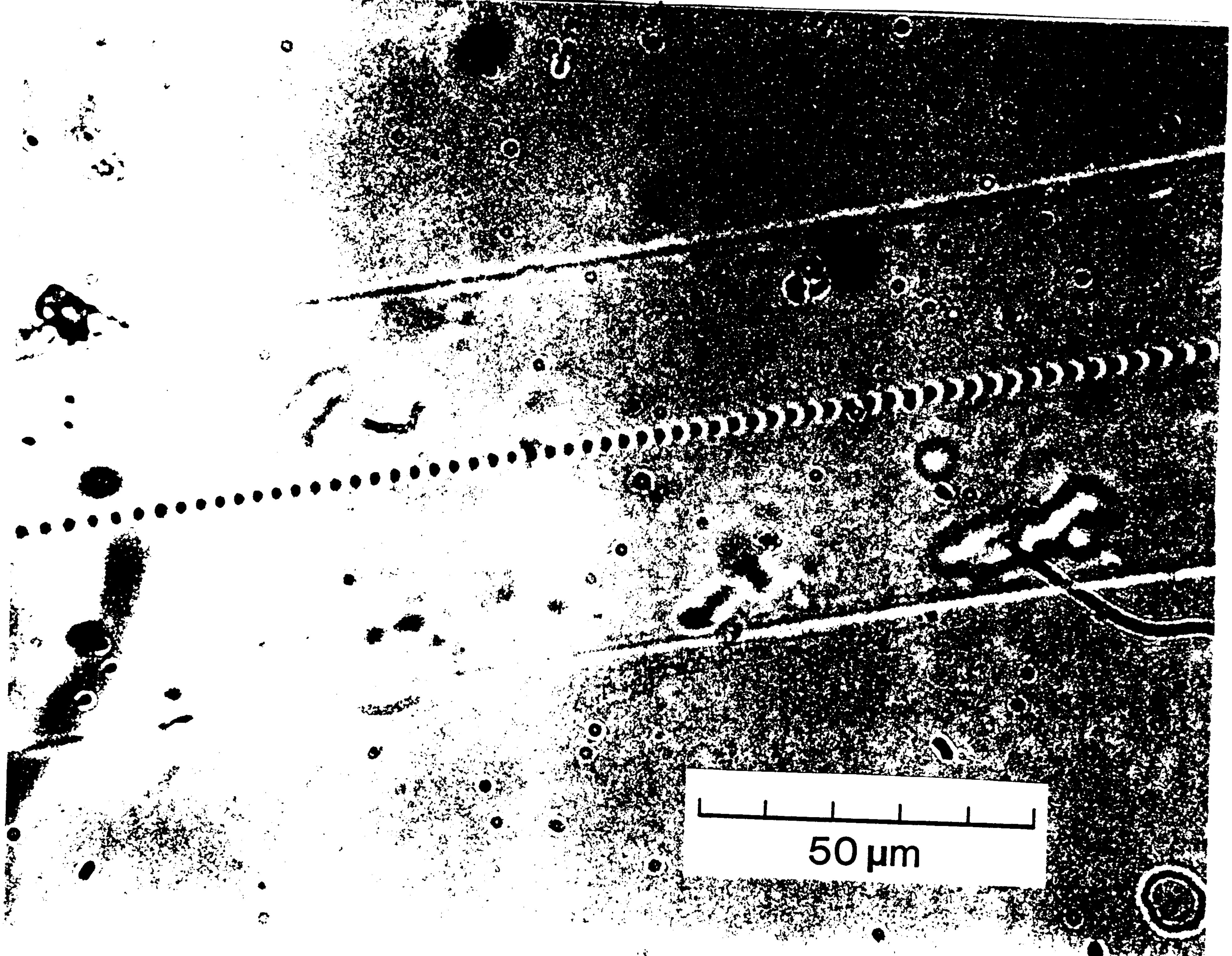
1: Temperature dependence of attenuation in a silica-based multimode fibre measured at 488nm, using a white light source and double monochromator.

2: 3μm periodic damage in a sodium-doped single-mode fibre (NA = 0.26 and core diameter = 1.4μm) viewed from the side through an optical microscope.

3: Variation of velocity with average core intensity for 4 different fibre samples; all are 1m long sodium-doped single-mode fibres. Intensity is calculated assuming a 2dB/m linear loss in the fibre.

Copy of figure 1
Optical Damage ... [illegible]




50 µm

copy of figure 3
Hand et al Optical Damage...