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Two-Photon-Induced Losses in Germanosilicate Optical Fibers: Relaxation Processes

L.J.Poyntz-Wright[1] and P.St.J.Russell[2]

[1]York Limited, York House,
School Lane, Chandlers Ford,
Hants SO5 3DG, England.

[2]Optical Fiber Group,
University of Southampton,
Southampton SO9 5NH, England.

Telephone: (0703) 559122 ext 2878

ABSTRACT

Experimental data on the spontaneous color-center relaxation processes that ensue after exposure of germanosilicate fibers to blue/green light are fitted to a three-rate analytical model.

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SUMMARY

Nonlinear transmission (NLT) at relatively modest blue/green intensity levels can limit the amount of power delivered through a few metres of single-mode fiber to some hundreds of milliwatts at 488 nm. This has severe implications in applications such as laser doppler velocimetry and dynamic light scattering[1]. We have shown that NLT is the result of color-center formation through trapping of electrons (released by two-photon absorption) at Ge sites[2,3].

An intriguing feature of the induced absorption is that it does not remain constant once the light is switched off, but continuously increases, eventually approaching a steady-state level. It is the relaxation processes behind this spontaneous evolution of the absorption that we address here.

In our experiments we monitored the loss in fresh 5m lengths of fiber, during and after exposure to 488 nm, using a counter-propagating white-light signal[1]. The results of three experimental runs are given in Fig(1). It was clear from our initial measurements that three different exponential decay rates were always present, and that once these decay rates were established for a given fiber, good fits could be obtained for that fiber in every other experimental case. This suggested that three different Ge-sites are operating in the glass, each with its own characteristic trapping and bleaching rates. Denoting the population densities of the occupied traps n_1, n_2 and n_3, the population of free (untrapped) electrons will be $n_e=N-(n_1+n_2+n_3)$, where N is the total number of electrons in the system and is assumed to be conserved. Calling γ_{ei} the rate of free-electron trapping by defects i, and γ_{ie} the rate of spontaneous release from defect i, the following set of three rate equations may be derived:

$$\begin{pmatrix} \{\gamma-(\gamma_{e1}+\gamma_{1e})\} & \gamma_{e1} & \gamma_{e1} \\ \gamma_{e2} & \{\gamma-(\gamma_{e2}+\gamma_{2e})\} & \gamma_{e2} \\ \gamma_{e3} & \gamma_{e3} & \{\gamma-(\gamma_{e3}+\gamma_{3e})\} \end{pmatrix} \begin{pmatrix} n_1 \\ n_2 \\ n_3 \end{pmatrix} = \begin{pmatrix} N\gamma_{e1} \\ N\gamma_{e2} \\ N\gamma_{e3} \end{pmatrix} \quad (1)$$

where d/dt has been replaced by γ. The three resulting normal-mode decay rates are ${}^1\gamma$, ${}^2\gamma$ and ${}^3\gamma$, where a superscript in front of a quantity denotes the mode under consideration.

Ge(1) centres are associated with a broad absorption at 281 nm with a tail extending well into the blue, and Ge(2) centres with a narrow peak at 213nm. Assuming that the experimentally measured loss arises solely from the population n_1 (i.e. the Ge(1) centers), we obtained the fits depicted in Fig(1) for $\gamma_{1e}=7.5\times10^{-5}$ s^{-1}, $\gamma_{2e}=3.6\times10^{-4}$ s^{-1}, $\gamma_{3e}=1.6\times10^{-2}$ s^{-1}, $\gamma_{e1}=0.12$ s^{-1}, $\gamma_{e2}=0.34$ s^{-1}, $\gamma_{e3}=5\times10^{-4}$ s^{-1}. The modal decay rates were 0.46 s^{-1}, 0.016 s^{-1} and 1.4×10^{-4} s^{-1}.

The model also predicts the evolution of all three color-center populations. For run (A) see Fig(2). Immediately after the laser is blocked, the free electrons rush into Ge(1) and Ge(2) traps, causing an initial surge in loss. At the same time, the electrons trapped at Ge(3) sites are spontaneously released and diffuse to nearby Ge(1) and Ge(2) sites, causing a slow further increase in loss. After n_3 has fallen to a negligible level, n_2 (which was rising) begins to fall as electrons (spontaneously released from Ge(2) sites) diffuse to neighbouring Ge(1) sites.

In the very long term (after ~11 hours), most electrons end up trapped at Ge(1) centres because they have the slowest spontaneous bleaching rate ($\gamma_{1e} = 7.5\times10^{-5}\ s^{-1}$).

REFERENCES

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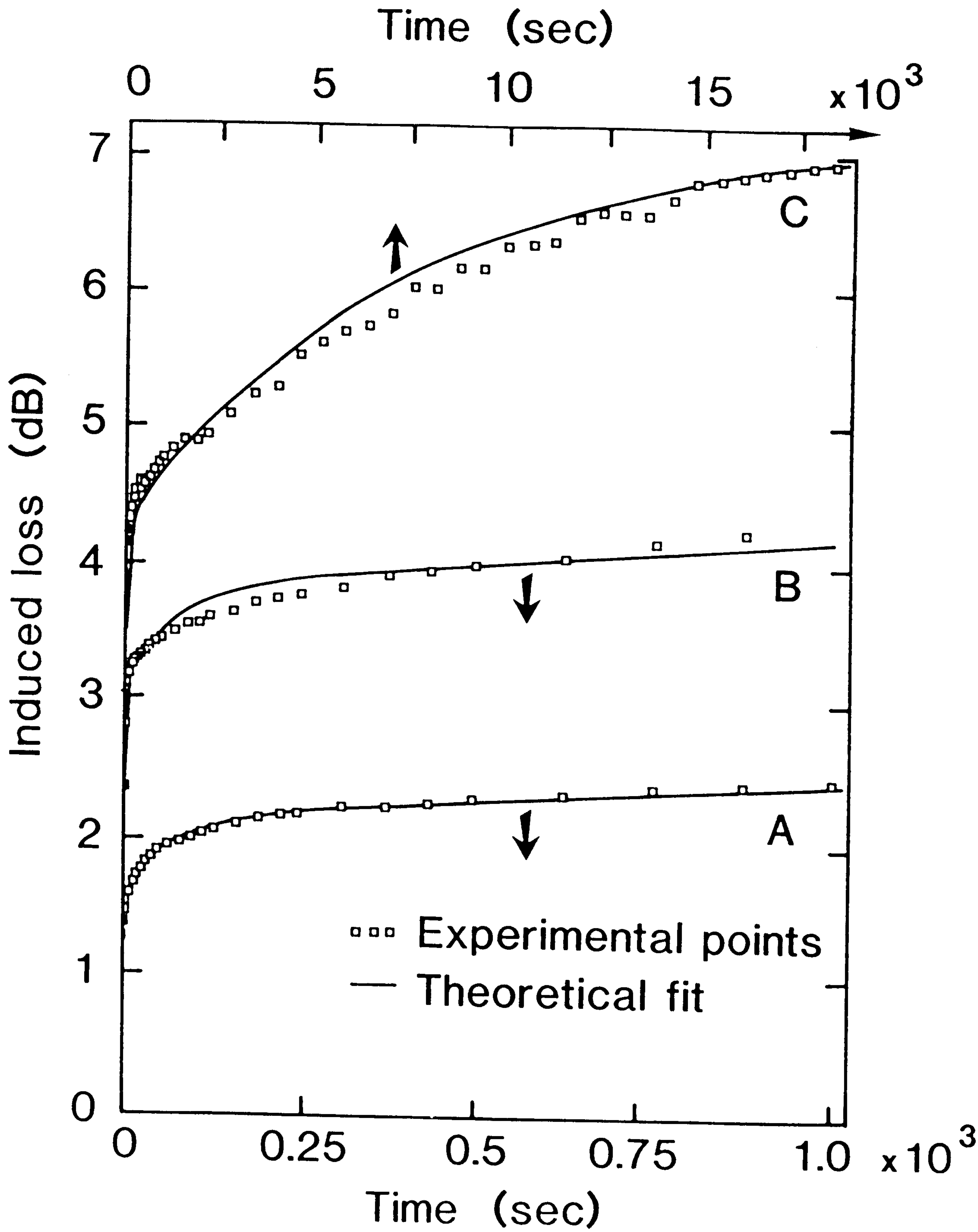
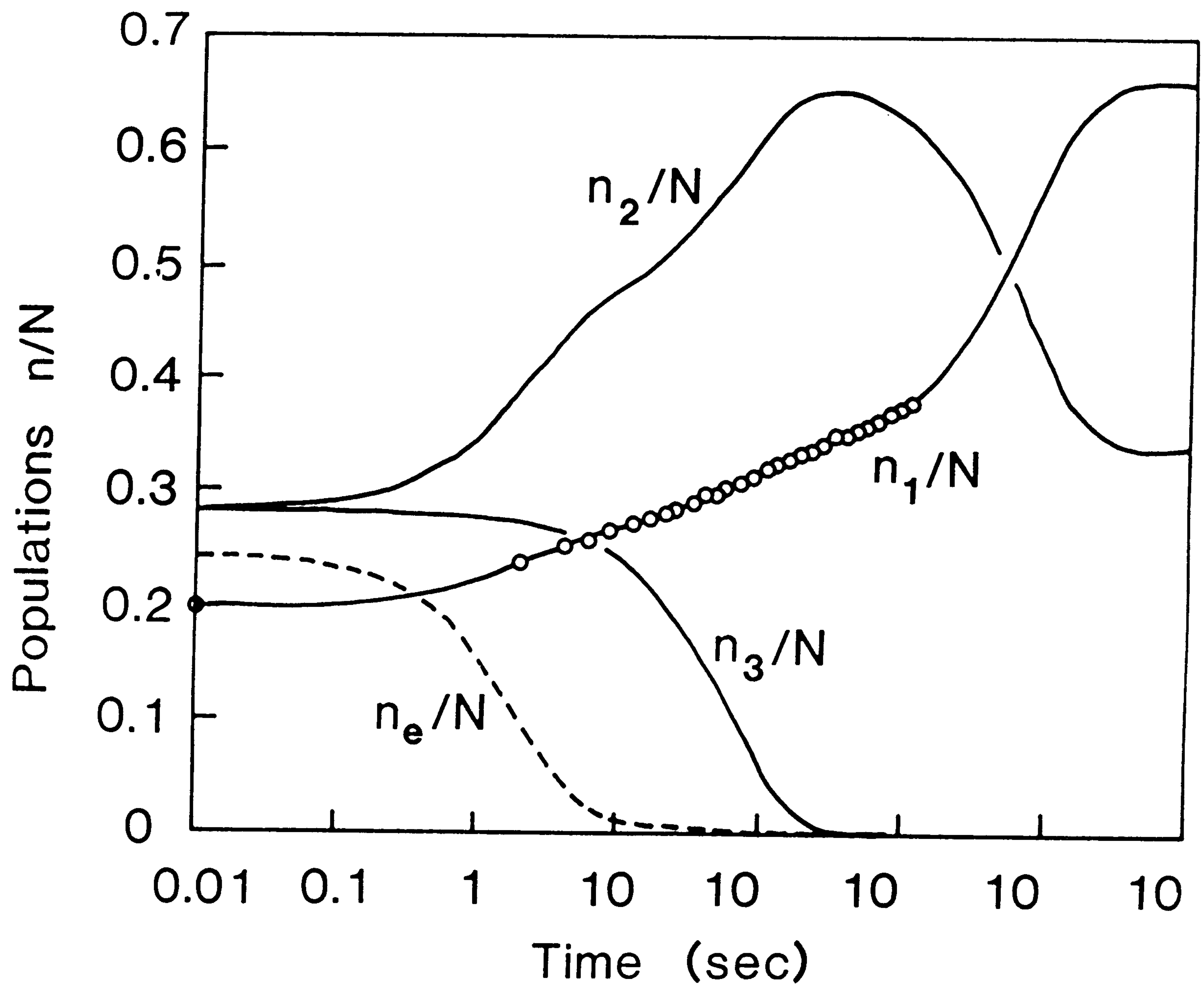
FIGURE CAPTIONS

1. Spontaneous increase in loss after exposure to A) 67 $mW/\mu m^2$, B) 114 $mW/\mu m^2$ and C) 125 $mW/\mu m^2$.

2. Evolution of the three color-center and free electron populations, together with experimental points for run (A).



Time (sec)
0
5
10
15
x10^3
7
6
5
4
3
2
1
0
Induced loss (dB)
C
B
A
Experimental points
Theoretical fit
0
0.25
0.5
0.75
1.0
x10^3
Time (sec)



0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Populations n/N
n2/N
n1/N
n3/N
ne/N
0.01
0.1
1
10
10
10
10
10
Time (sec)