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Suppression and modification of stimulated Raman scattering in optical fibres by rare-earth doping.

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Abstract

Stimulated Raman scattering (SRS) is suppressed in an optical fibre by introducing a loss equivalent to the gain at the Stokes wavelength. The required absorption profile is obtained by doping the fibre with the rare-earth holmium. Experimental measurements on these fibres demonstrate suppression of SRS and an increase in the undepleted intensity levels obtainable in an optical fibre. Moreover suppression of the main Raman band due to silica enables SRS from a weaker phosphorus line at 1.240μm emission to be observed when pumped at 1.064μm.

Summary.

The maximum power which can be transmitted in an optical fibre is limited by stimulated Raman scattering (SRS)(1). This limits the performance of many linear and nonlinear fibre devices which require high powers and long fibre lengths. Spontaneous Raman may be prevented from building up to the stimulated threshold by absorption at the Stokes wavelength. The necessary absorption profile is obtained from the spontaneous Raman cross-section of a silica fibre by calculating the net gain, which is given by:-

$$\text{Gain} = G(\lambda)\ I\ L - \alpha(\lambda)\ L \qquad 1.$$

Where G is the Raman gain coefficient, I is the pump intensity, L is the effective fibre length and α is the fibre absorption. To reduce pump depletion to below 1% the net gain must be below 11. In a long fibre with high input powers we require an absorption cross-section which matches the Raman gain cross-section. This may be realised by rare-earth-doping the fibre(2).

The suppression of SRS is demonstrated by comparative experiments on holmium-doped and undoped silica optical fibres. The stimulated Raman spectra of both fibres is presented in fig.1, which shows 3 Stokes lines from the undoped fibre and only weak first Stokes light from the doped fibre when both were pumped with equivalent powers. The output optical power at 1.064um in the undoped fibre is depleted by 50%, but in the doped fibre by only 5%.

The absorption and spontaneous Raman cross-sections of a fibre co-doped with 5% phosphorus and 0.3% holmium are shown in fig(2). It is seen that the 440 cm^{-1} Raman band at 1.100μm will be suppressed by the holmium absorption. However, the large 1340cm^{-1} shift due to P_2O_5 is in a low loss region. When this fibre was pumped with 160 W mode-locked pulses at 1.064μm, stimulated Raman was observed at 1.240μm (fig.2). Some SRS is seen at 1.100μm but this is considerably less than seen in fibres with no rare earth doping(3). The net gain at 1.240um was only 8, which gave a low conversion efficiency, due to the high residual loss (176dB/Km) in this fibre at the pump wavelength. The high loss reduces the effective fibre length. This loss may be reduced by an order of magnitude by improved fabrication technique. Moreover the phosphorus concentration can be increased to 20% which should enable a conversion efficiency of greater than 50% with only 7.5 W of input power.

References

1. Smith F.G., Appl. Opt. 1972, 11, pp2489-2494.

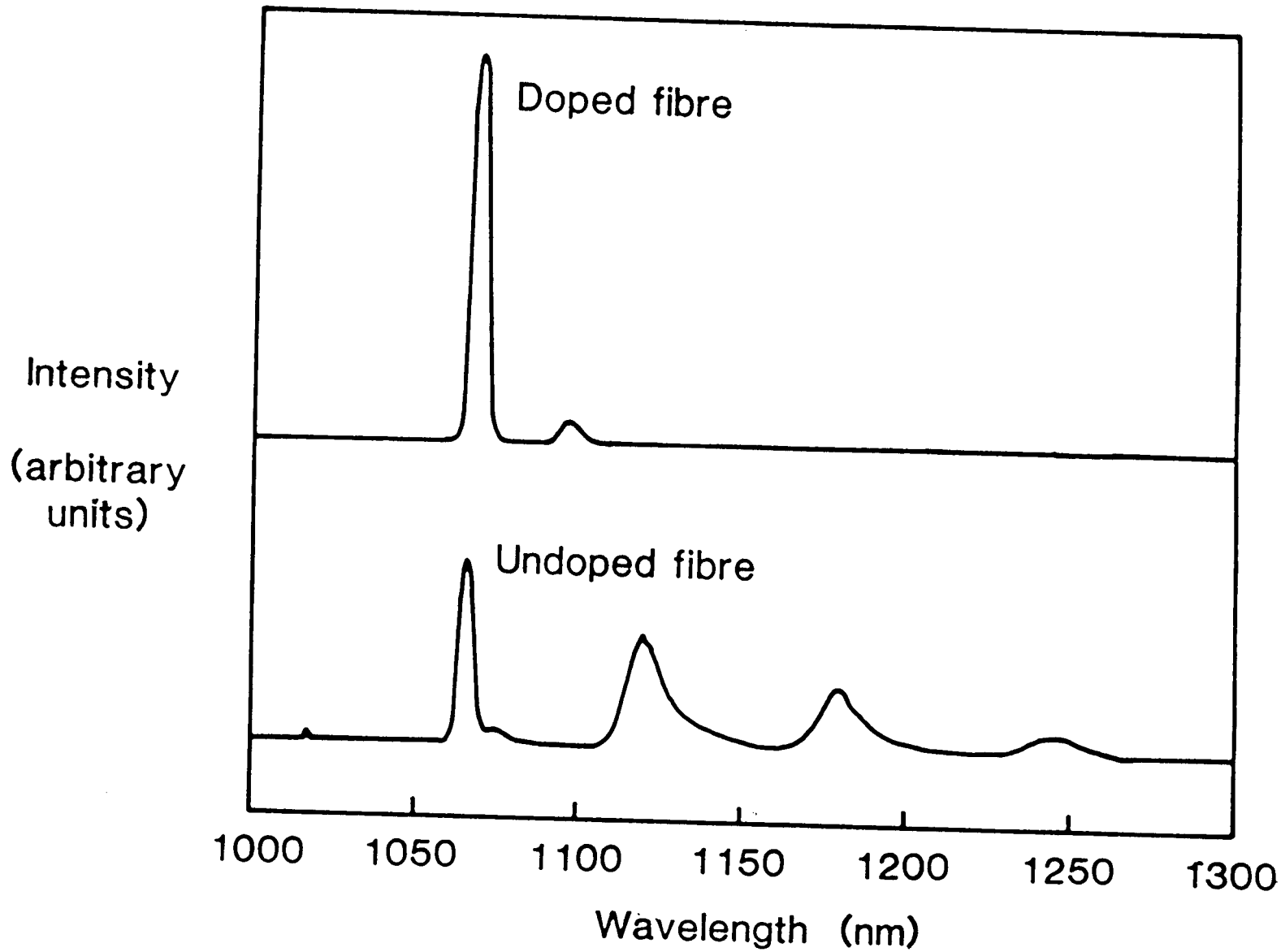
2. Farries M.C., Townsend J.E., Poole S.B. Electron. Lett 1986, 22, pp.1126-1128.

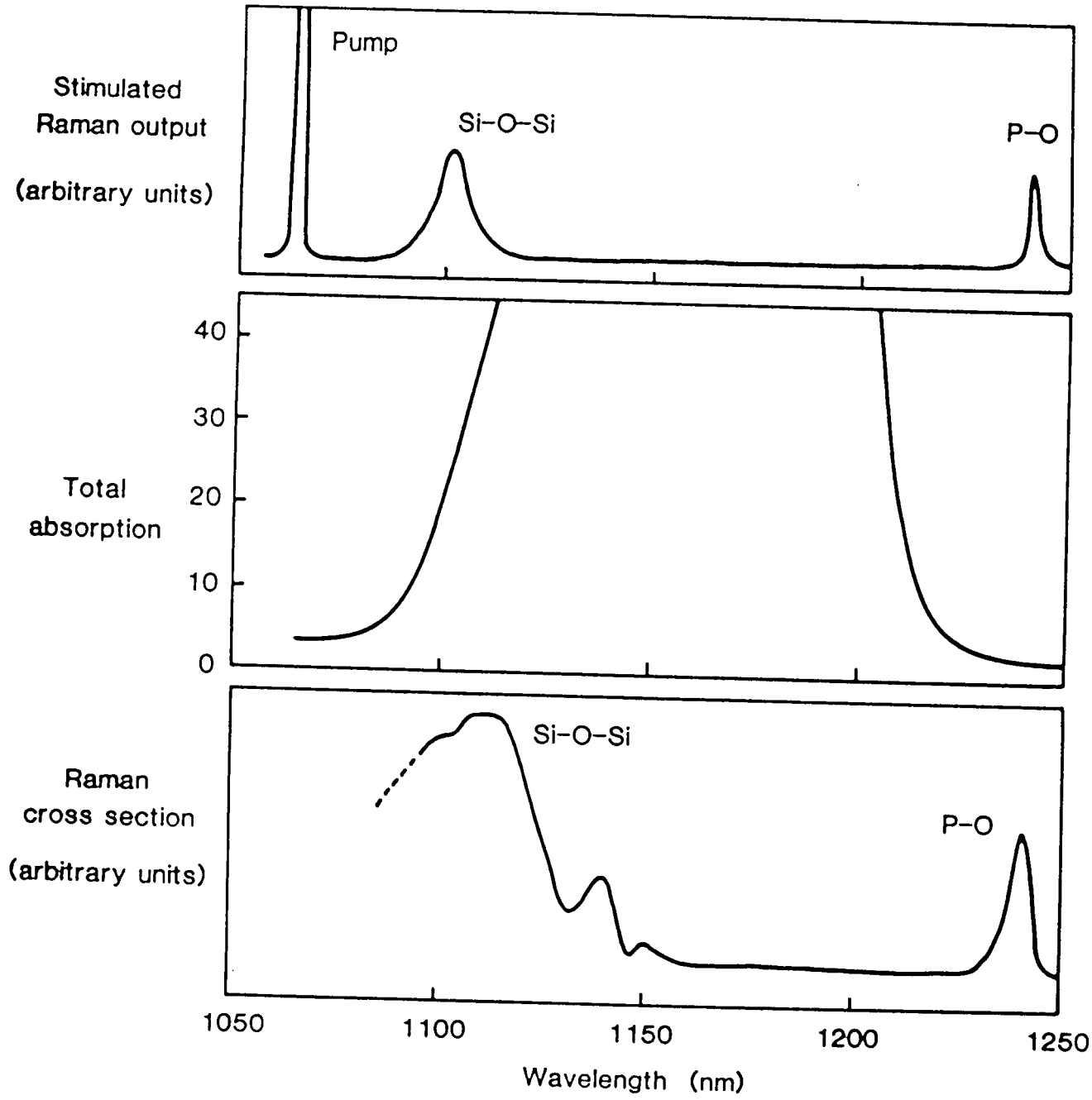
3. Shibata N., Horigudhi M., Edahiro T., J. Non-Crystaline Solids 1981, 45, pp115-126.

Figure captions

1. Stimulated Raman spectra of a holmium-doped and an undoped silica optical fibre.

2. Raman cross-section, absorption and stimulated Raman spectra of an holmium-phosphorus doped optical fibre.


Doped fibre
Undoped fibre
Intensity
(arbitrary
units)
1000
1050
1100
1150
1200
1250
1300
Wavelength (nm)


Stimulated
Raman output
(arbitrary units)
Pump
Si-O-Si
P-O
Total
absorption
40
30
20
10
0
Raman
cross section
(arbitrary units)
Si-O-Si
P-O
1050
1100
1150
1200
1250
Wavelength (nm)