Electric-field Induced Permanent Second-order Susceptibility for Second-harmonic Generation in Optical Fibres

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Introduction

Since the discovery[1] of efficient second-harmonic generation (SHG) in Ge/P-doped fibres after exposure to intense light at 1064nm, many research groups have reported the creation of a permanent second-order susceptibility ($\chi^{(2)}$) using various techniques[2,3] based on light excitation. We have discovered that a permanent $\chi^{(2)}$ for SHG in silica fibres can be induced by a strong DC electric-field without any light.

Figure 1: Time dependence of second-harmonic generation in a Ge-doped (~15 mol% GeO_2) fibre for various field intensity. The induced $\chi^{(2)}$ cannot be counteracted immediately by reversing the poling field.

Experiments

In order to study the temporal response of the electric field poling, the second harmonic (SH) was monitored during the poling process. The fundamental light at 1064nm was from a Q-switched Nd/YAG laser with 6ns pulses and a 30Hz repetition rate. The peak power from the fibre was typically 50W. Both Ge and Ge/P-doped fibres showed a permanent poling effect after the fibres were poled for several minutes with electric fields greater than 180V/μm (the SH decayed almost completely after the removal of weak poling fields). Figure 1 shows the dc-field poling effect for Ge-doped fibres. When the dc-field was switched on, there was a fast rise of the SH signal followed by slow growth. After the poling field was switched off, the SH dropped to a certain level and then appeared to remain at this level. The degree of the induced permanent effect depended on the poling field and poling time. The induced $\chi^{(2)}$ remained in both Ge-doped and Ge/P-doped fibres for at least several weeks without significant decay. The permanent effect could be due to the alignment of defect centres in both Ge and Ge/P-doped fibres. For lead glass fibres, a permanent poling effect was not evident although, as shown in Figure 2, the rising and falling times were much longer than for Ge and Ge/P-doped fibres.

Figure 2: Time dependence of second-harmonic generation in a lead glass (~35 wt% PbO) fibre for various field strengths.

The DC field poling effect was confirmed by poling Ge/P and Ge-doped fibres without any light. Figure 3(i) and (ii) show the relative SH signals from the unpoled and poled parts of the fibres respectively. The lower induced permanent $\chi^{(2)}$ in the Ge/P-doped fibre suggests that the fibre has fewer as-drawn defect centres. The effect of blue light in poled fibres was also investigated. Blue light (at 488nm) of 50mW CW power was subsequently launched into the samples without any DC field. Figure 3(iii) displays the resulting SH signals. The increase in the SH signals from both samples is probably due to gratings induced by the blue light. The greater enhancement in the Ge/P-doped fibre could be because a larger number of defect centres had been generated by the blue light.

Figure 3: Comparison of averaged SH signals from Ge/P-doped (~15 mol% GeO_2 with 0.5 mol%P_2O_5) and Ge-doped fibres (after the voltage supply had been switched off for one day): (i) the unpoled part of the fibres, (ii) the poled (by dc field only) part of the fibres, (iii) the poled part of the fibres as in (ii) but subsequently prepared with cw blue light at 488 nm (without field).

Conclusion

Electric-field poling in fibres for SHG could be useful not only in producing large $\chi^{(2)}$ but also for studying the mechanisms governing efficient SHG in optical fibres.

References

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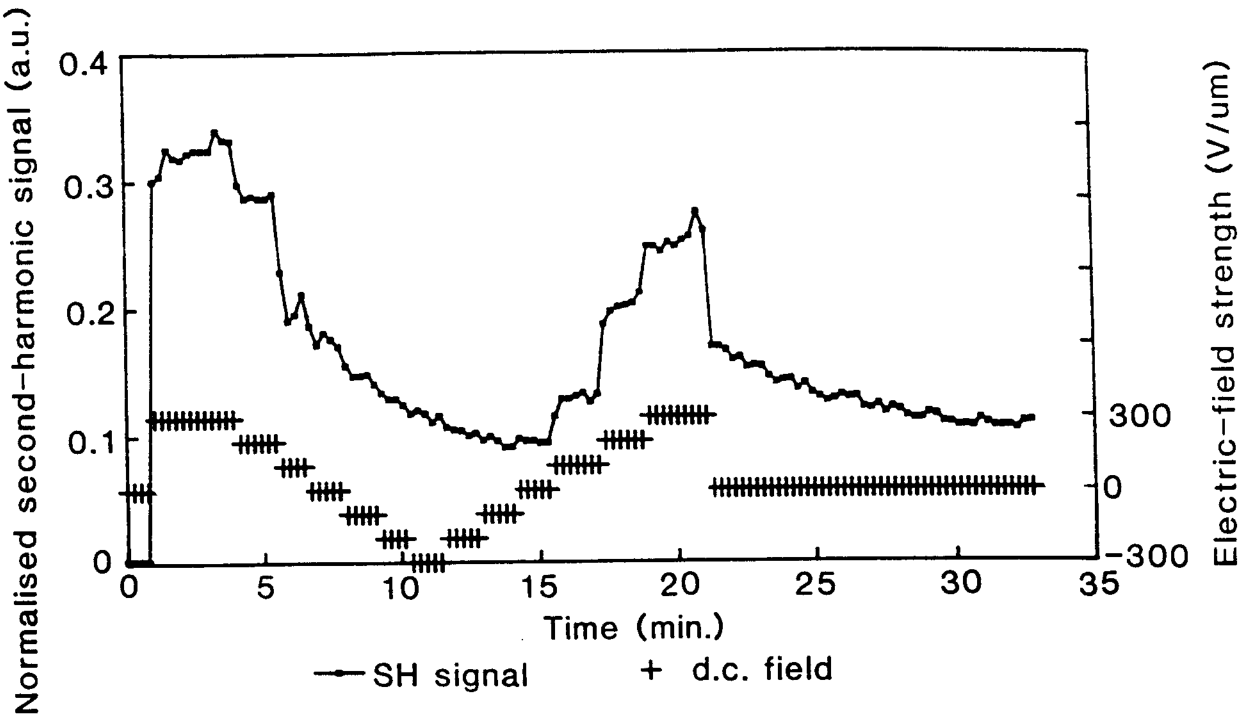
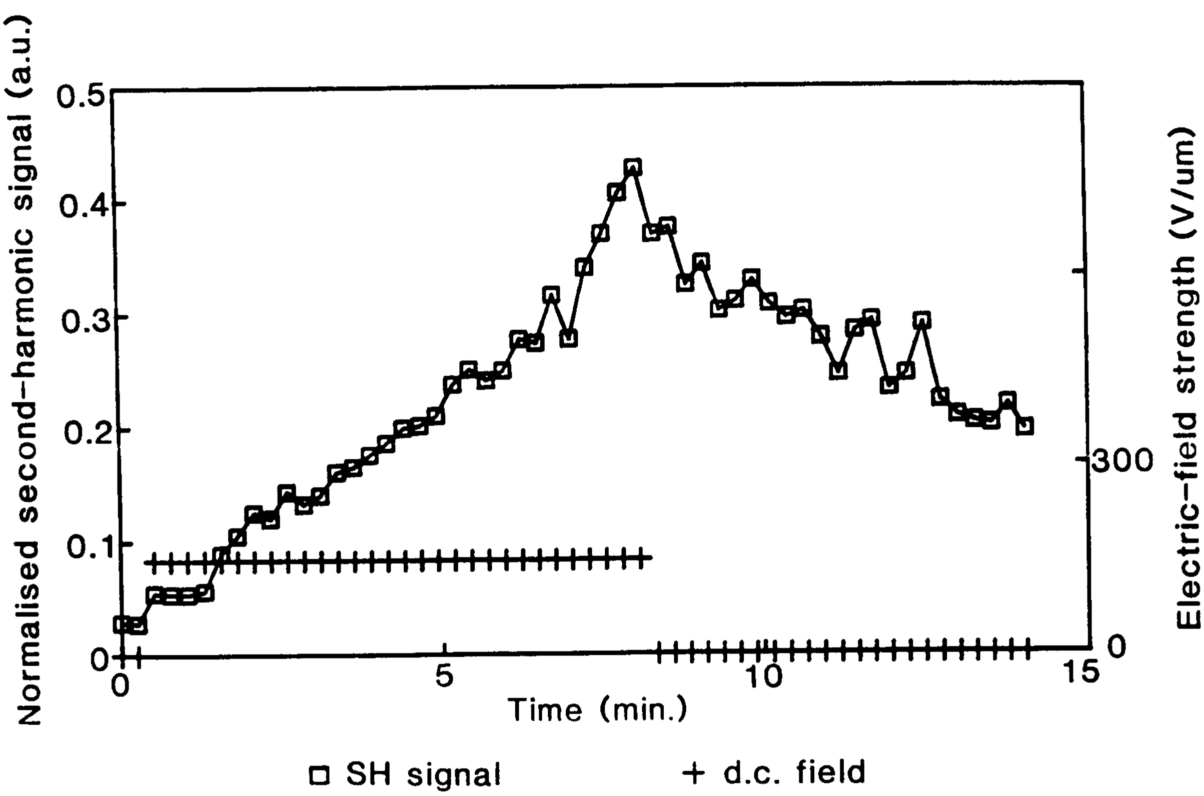
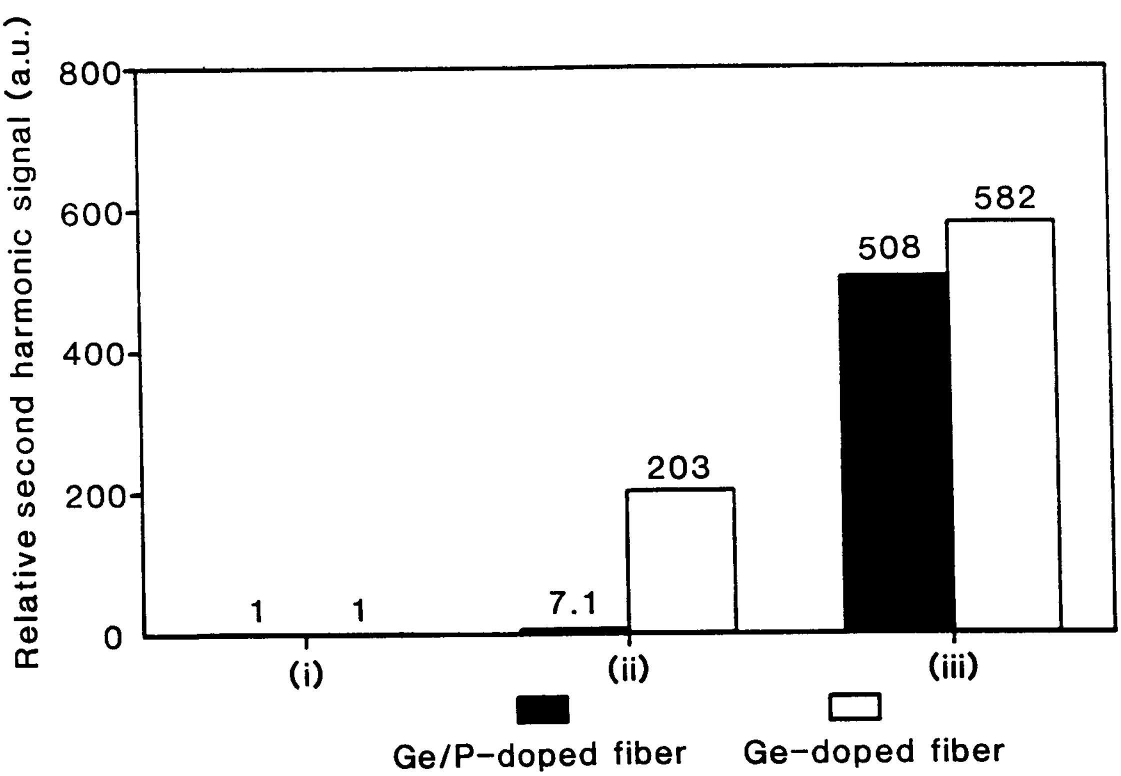


Normalised second-harmonic signal (a.u.)
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
Time (min.)
Electric-field strength (V/um)
300
0
−300
SH signal
+ d.c. field



Normalised second-harmonic signal (a.u.)
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
Time (min.)
Electric-field strength (V/um)
300
0
□ SH signal
+ d.c. field



Relative second harmonic signal (a.u.)
800
600
400
200
0
1
1
7.1
203
508
582
(i)
(ii)
(iii)
Ge/P-doped fiber
Ge-doped fiber

Fig. 3