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HIGH SECOND-ORDER NONLINEARITIES IN POLED SILICA FIBRES

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Abstract

Effective quadratic nonlinearities as high as 0.2 pm/V are obtained for the first time in poled germanosilicate fibres. This value is ~200 times higher than previously reported in fibres. The presence of Ge is found to enhance the efficacy of both thermal (in combination with OH doping) and electron beam poling in silica.

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Summary

Recently, second-order nonlinearities (SON's) of the order of 1 pm/V have been observed in bulk glasses using a variety of different poling techniques[1,2,3]. We report here the first successful poling of *optical fibre* using both thermal and electron implantation techniques. Compared to previous work in fibres [4,5], a 200 fold improvement in SON is obtained. First, the following preforms were thermally poled: MCVD preform A (starting tube: electrically fused natural quartz (GE-100, low OH ~ 1 ppm); P+F-doped silica cladding and Ge-doped core); MCVD preform B (starting tube: flame fused natural quartz (Herasil-1, OH ~ 150 ppm); P+F-doped silica cladding and Ge+Na-doped core); MCVD preform C (same starting tube as B, no cladding and Ge-doped core); MCVD preform D (same starting tube as B and C, no cladding and Ge+Na-doped core); VAD preform E with a Ge-doped core. Slices ~ 1 mm thick were poled at 2.5 kV and 280 °C for 15 min. A pump beam from a Nd:YAG mode-locked and Q-switched laser ($\lambda = 1064$ nm) crossed the

sample at the Brewster angle. The second harmonic (SH) signal was monitored while translating the sample in a direction perpendicular to the plane of incidence. No SH was detected in anywhere in preforms A and E. A strong SH signal was observed in the starting tubes in B, C and D, and no SH signal was observed in the P+F doped cladding while scanning along preform B with a *p*-polarized pump (Fig.1). We observed ~15% stronger SH signal in the Ge-doped core compared to the starting tube (Fig.2). The SH signal in the core was also found to follow the Ge concentration. The measured absorption spectrum in the core region of preforms C and D indicated an OH concentration of ~80 ppm.

These results may be explained by a high H^+ concentration in the starting tubes and preform core, where they act as positively charged carriers; interestingly, Na doping (preform D) produced no significant effect on the SH signal. In fibres B and C (pulled from preforms B and C respectively), regions ~8 mm long were side-polished to within ~1 μm of the core edge using a simple and effective wheel polishing technique. The fibre was placed on top of a 2 mm thick silica substrate and the final assembly sandwiched between two electrodes, the anodic electrode on top of the side polished surface (Fig.3). Thermal poling was carried out at 4.3 kV and 280 °C for 15 min. No SH signal was seen in fibre B. A strong non-phase-matched SH signal was observed in fibre C. The effective SON ($\chi^{(2)}_{\mathrm{eff}} = \chi^{(2)}\,\eta$, where η is the overlap integral between the SON and the modal fields) was estimated to be about 0.2 pm/V. Electron implantation was also used to pole Ge-doped fibre preforms and side-polished Ge-doped fibres. Samples were irradiated in a SEM at 0.3 nA and 40 keV. Core SON's of $\chi^{(2)} \simeq 0.2$ pm/V and $\chi^{(2)}_{eff} \simeq 0.1$ pm/V were obtained respectively in the preforms and the fibres.

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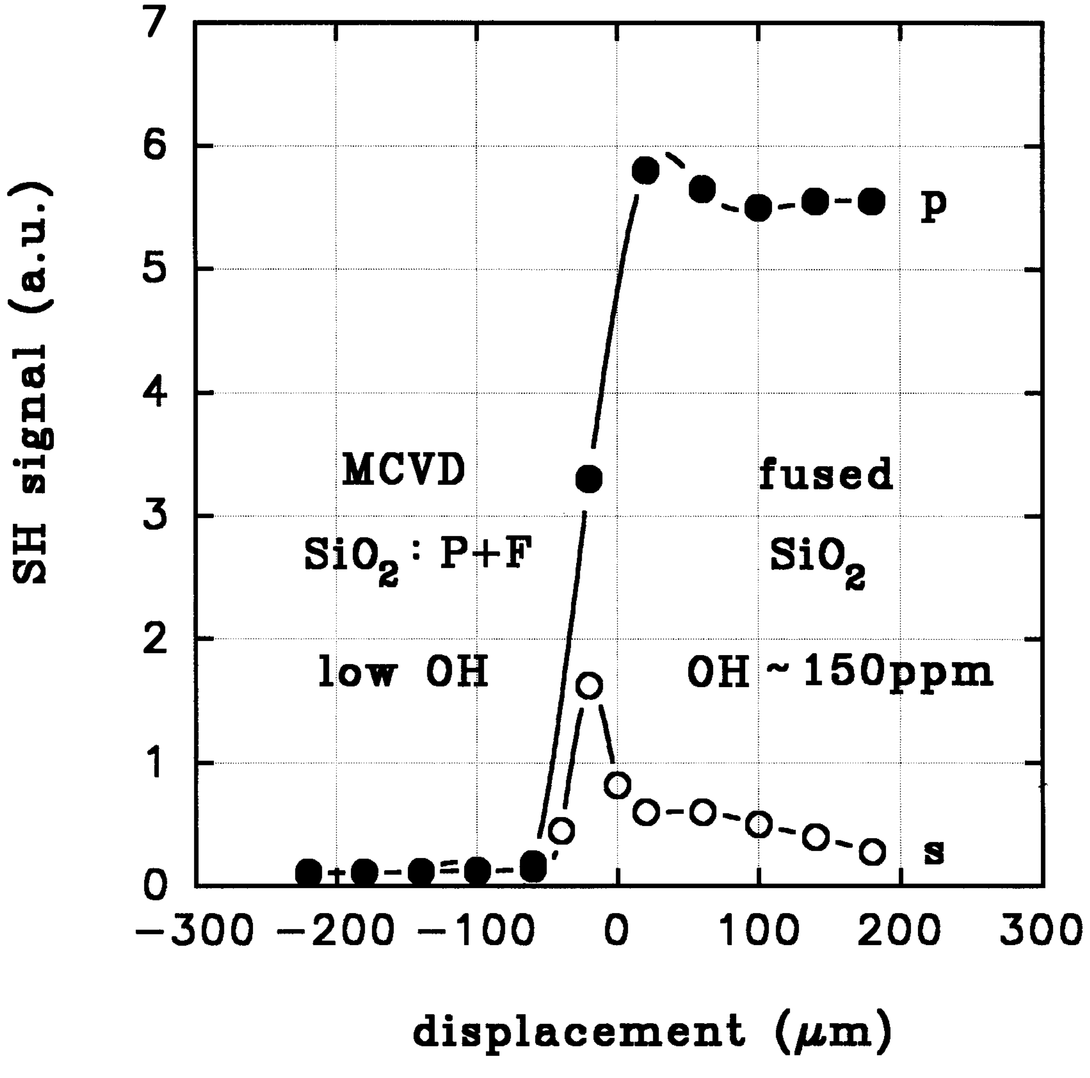
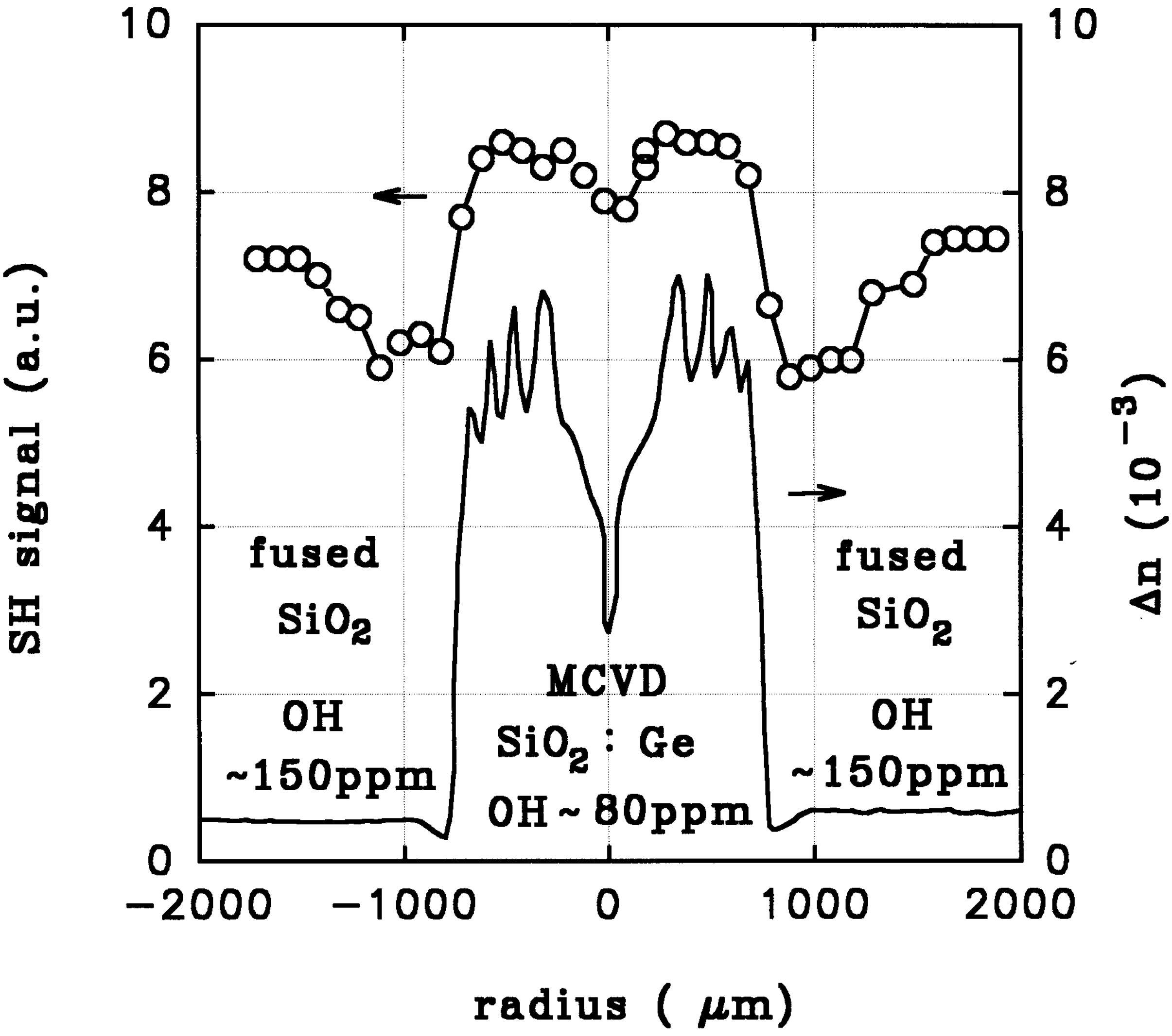
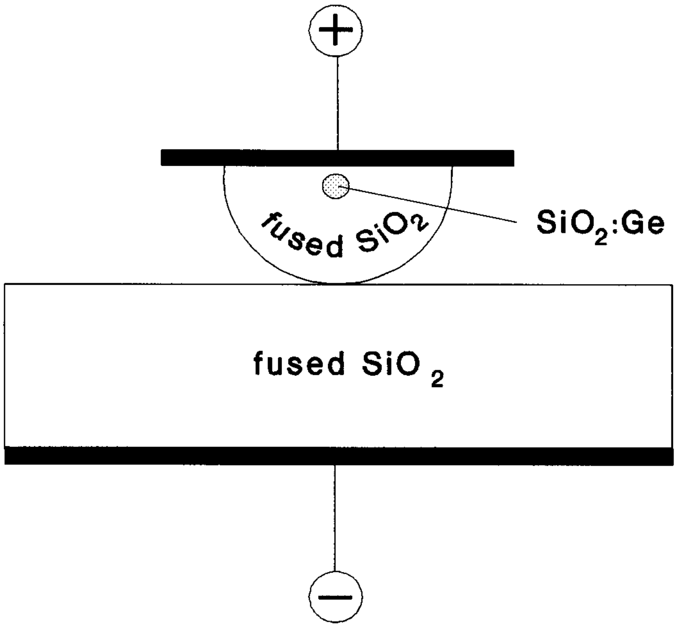
FIGURE CAPTIONS

1. SH signals for *p*-polarized pump (●) and *s*-polarized pump (○) in the cladding and starting tube in preform B. A peak in SH signal from s-polarized pump is explained by existence of a fringing electrostatic field at the boundary of two regions.
2. SH signal (○) and refractive index difference in preform C.
3. Thermal (a) and e-beam (b) poling arrangements for the fibres.


SH signal (a.u.)
0
1
2
3
4
5
6
7
−300
−200
−100
0
100
200
300
displacement (μm)
MCVD
SiO2 : P+F
low OH
fused
SiO2
OH ~ 150ppm
p
s

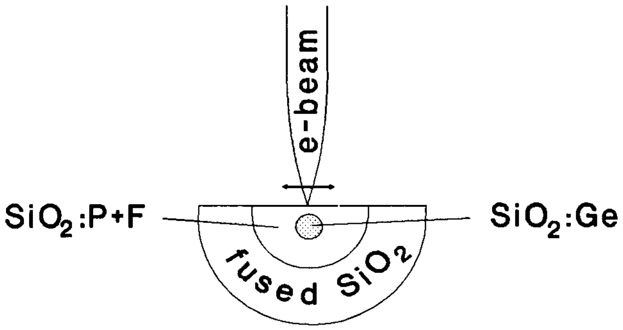

SH signal (a.u.)
Δn (10^{-3})
radius (μm)
10
8
6
4
2
0
−2000
−1000
0
1000
2000
fused SiO$_2$
OH ~150ppm
MCVD
SiO$_2$: Ge
OH ~ 80ppm
fused SiO$_2$
OH ~150ppm

a)



+
fused SiO$_2$
SiO$_2$:Ge
fused SiO$_2$
−

b)



e-beam
SiO$_2$:P+F
SiO$_2$:Ge
fused SiO$_2$