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Poling of Glass Waveguides by a Metal-Induced $\chi^{(3)}$ Enhancement.

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While the perspectives of making 2nd-order nonlinearities in optical glasses are exciting, present poling techniques are still inadequate. UV poling has proven difficult to control, and with traditional thermal poling the obtained $\chi''$ has remained $< 3 \times 10^{-14}$ pm/V. When inducing a permanent field $E_{dc}$ in the glass, the effective 2nd-order susceptibility $\chi^{(2)} = 3\chi^{(1)}E_{dc}$ has been limited by the small intrinsic value of $\chi^{(1)}$. However, an alternative method consists in utilizing indiffused metal [1]. Here we demonstrate that metal nanoclusters are an attractive means to enhance the $\chi^{(1)}$ value. In combination with a built-in dc-field in channel waveguides, effective $\chi^{(2)}$ values of more than 14 pm/V are obtained.

The channel waveguides were made by UV writing in three-layer structures [SiO$_2$ – Ge:SiON (germanium-doped silicon oxynitride) – SiO$_2$] that had been fabricated on Si substrates by plasma-enhanced chemical vapour deposition as in Ref. [1] and then loaded with deuterium. An electrode consisting of a Ag-containing paint was put on each sample and the poling was performed in air by heating the sample while applying $+1000$ V to the electrode, keeping the Si substrate on ground potential.

Optical characterisation was performed with second-harmonic scanning optical microscopy where a pump beam at the fundamental (F) wavelength is focused onto the sample and the second-harmonic (SH) signal is measured in the reflection direction while the sample is moved orthogonally to the pump beam. The SH images (examples in Fig. 1, using a 790-nm pump) show that a large $\chi^{(2)}$ nonlinearity is induced throughout the Ge:SiON core layer, peaking at the fundamental (F) wavelength is focused onto the sample and the second-harmonic reflection direction while the sample is moved orthogonally to the pump beam. The vertical polarisation (parallel to the poling field) using a 790-nm pump) show that

![FIG. 1. SHG micrographs of a channel waveguide after poling at 375 °C. Pictures (a-d) are recorded at the end facet after cleaving through the poled region. Picture (e) of pictures (a), (b), (c), and (e) are comparable; the scale of picture (d) is approximately 45% smaller.](image)

![FIG. 2. Transmission loss in a waveguide due to poling. The SPR is seen at 415 nm.](image)

an absorption peak at 415 nm (Fig. 2) which is of the width and at the peak position of the surface-plasmon resonance (SPR) of Ag nanoclusters with radius ~ 10 nm in a glass matrix [2]. Since $\chi^{(3)}$ of a metal-cluster embedded dielectric medium is strongly enhanced at the SPR it is therefore concluded that the large $\chi^{(3)}$ observed at $\lambda_{SH} = 395$ nm (near the SPR) is indeed due to a combination of a large $\chi^{(2)}$ value and a built-in field, i.e., $\chi^{(3)} = 3\chi^{(1)}E_{dc}$.

We anticipate that an improved poling scheme can be made where the loss is reduced while a large $\chi^{(2)}$ is maintained. This will require lower Ag concentrations and optimisation of $E_{dc}$ and should be combined with waveguides with especially optimised 400-nm transmission. As a further attractive perspective, the shape and dimension of the nanoclusters can potentially be varied in order to tune the width and position of the $\chi^{(3)}$ resonance.

References
