Thermal Poling of Silica

Alexander Strauß, Sven Brückner, Ulrich Röpke, Hartmut Bartelt

Institute for Physical High Technology
Albert-Einstein-Strasse 9, 07745 Jena, Germany

mailto: alexander.strauss@ipht-jena.de

Silica naturally exhibits no second-order optical susceptibility and therefore has a nonlinear coefficient $\chi^{(2)}$ of zero. During thermal poling in the material we created an anisotropy enabling an effective susceptibility $\chi^{(2)}_{eff}$. These poled samples were characterized by second-harmonic generation (SHG) measurements.

1 Introduction

Many basic functions in optical information processing like switching or modulation require nonlinear optical effects. But glasses (silica), as amorphous centrosymmetric materials, naturally exhibit no second-order optical susceptibility ($\chi^{(2)}$). Such lack of $\chi^{(2)}$ has confined glasses mainly to applications as light transmitting components in optical waveguides and fibers. For applications in optical switching, modulation and second-harmonic generation (SHG), a sufficiently large $\chi^{(2)}$ is indispensable.
An interesting way to induce an effective $\chi^{(2)}$ in silica is thermal poling of the material. Myers et al. reported such experiments for the first time [1], and further investigations have been successful [2]. Pruneri et al. also poled an optical fiber with a conversion efficiency of more than 20% [3].

2 Theory

During the poling process, a high voltage is applied to the glass of thickness l. Impurities, e.g. Na, K, H, or Al, present even in cleanest silica, cannot follow the applied electric field at room temperature. As the sample is heated, the cations become mobile and move towards the cathode. There remains a negative depletion layer near the anode (Fig.1). By means of Poisson's equation it is possible to calculate the thickness of the depletion layer:

$$l_0 = \sqrt{\frac{2 \cdot \varepsilon \cdot U_0}{\rho_0}} \quad . \qquad (1)$$

With $\varepsilon = 4 \cdot \varepsilon_0$, $U_0 = 5$ kV, $\rho_0 = N \cdot e$ where $N = 6.6 \cdot 10^{22}$ parts / m^3 (silica), e is the elementary charge and ε_0 is the permittivity in vacuum, the calculated thickness of the depletion layer $l_0 = 5.8$ µm.

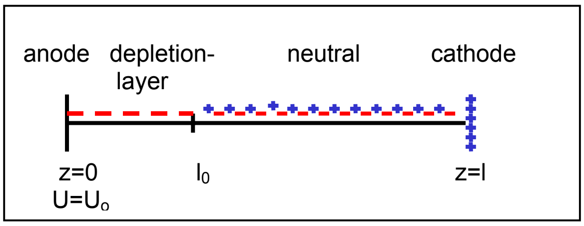

Fig.1 *Silica sample including depletion layer and neutral region after the poling process*

After the sample has been cooled back to room temperature with an applied voltage, the previously produced depletion layer is locally and temporally fixed. Then a frozen-in electric field remains in the sample even after the voltage is switched off.

3 Characterization

The characterization of the poled samples (Herasil1, 10mm x 10mm x 0.5mm) is done by SHG measurements. We used a Q-switched Nd-YAG Laser (λ = 1064 nm) with 20 kW peak power, 6 ns pulse duration and a repetition rate of 10 Hz. The focus spot radius was w_0 = 10 µm, and the corresponding Rayleigh length was 300 µm.
As a detector we used an Si photodiode. For separating the signal wave from the fundamental wave we used a combination of BG18 and KG5 Schott filters. In this way the SHG attenuation is 50%, but the fundamental wave was attenuated by 10 orders of magnitude. Thus, the limit of detection for the SHG signal is 0.5 nW.

4 Poling Conditions

The SHG signal is affected by the poling parameters.
To ensure a sufficient mobility of the cations available in silica, the sample must be heated

up to an appropriate temperature. Fig.2a depicts the SHG signal as a function of the poling temperature. An essential condition for a successful poling process is a temperature of at least 270°C.

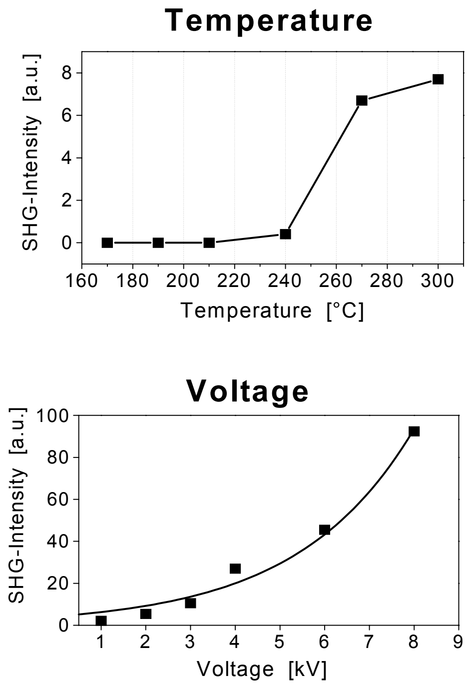

Fig. 2 *Second-harmonic signal of a poled Herasil1 sample as a function of a) poling temperature, b) poling voltage*

By heating up the poled samples without any voltage applied, the second-harmonic signal disappears, and thus the created second-order susceptibility is erased. Repoling of the same sample reproduces this susceptibility without degradation.

A second way to erase the second-order susceptibility is by UV irradiation of the sample. We irradiated the sample with a pulsed (18 ns, 55 mJ/cm^2) ArF excimer laser at 193 nm for 2 minutes. Here again, repoling the sample reproduces the susceptibility. The method has a potential to be used for the position-dependent, specific UV irradiation of poled samples for quasi-phase-matched devices [4].

Fig.2b depicts the SHG signal as a function of the poling voltage. The voltages applied are between 1 and 8 kV, and increasing the voltage causes a growth of the second-harmonic signal.

We investigated different kinds of silica and various sample thicknesses, e.g. 200, 500 and 1000 µm. SHG radiation was observed at numerous samples, whereas especially the Herasil1 samples delivered good, reproducible results. The samples, stored at room temperature, were observed for more then 14 months without showing any degradation of the SHG signal. This confirms results in the literature [5].

An important task for future applications is to identify the thickness of the nonlinear region (l_0, Fig.1) and the value of $\chi^{(2)}_{eff}$.

Equation 2 shows that the SHG signal is proportional to the product $(\chi^{(2)} \cdot l_0)^2$. Hence, in order to evaluate the value of $\chi^{(2)}$, it is necessary to know l_0 :

$$P_{2\omega} = \frac{\omega^2}{2 \cdot \varepsilon_0 \cdot c^3} \cdot \frac{(\chi^{(2)} \cdot l_0)^2}{n_\omega^2 \cdot n_{2\omega}} \cdot \mathrm{sinc}^2\left(\frac{\Delta k \cdot l_0}{2}\right) \cdot \frac{P_\omega^{\,2}}{A} \quad (2)$$

For this purpose, Maker's fringe technique is commonly used. In our case, the nonlinear layer is very small, and so we used the 'stack' version of Maker's fringe technique [6]. From the ratio of the second-harmonic power of a stack of two poled samples compared to the second-harmonic power of one poled sample (Fig.3), we obtained the thickness l_0 and then $\chi^{(2)}_{eff}$.

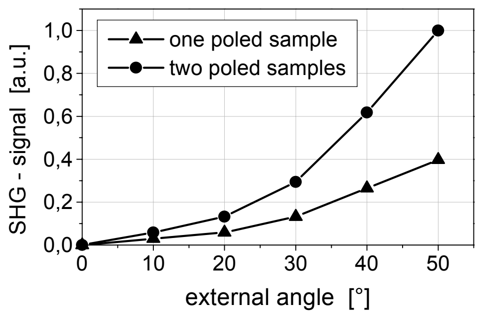

Fig. 3 *Second-harmonic signal as function of external angle for one poled Herasil1 sample and for a stack of two poled Herasil1 samples*

For example, we poled 500 µm thick Herasil1 samples at 4 kV and 270 °C for 20 minutes. Thus we experimentally obtained a nonlinear layer of 6 µm, which is in accordance with the theoretical value of 5.8 µm (eq.1). The calculated effective second-order susceptibility is 0.02 pm/V.

5 References

[1] R.A.Myers et al., Opt.Lett.16, 1731-1734 (1991)

[2] C.J.S.Matos et al., Journal of Non-Crystalline Solids, Vol.273, pp.25-29 (2000)

[3] V.Pruneri et al., Optics Letters, Vol.24, No.4, pp.208-210, 1999

[4] Huai-Yi Chen et al., Applied Physics Letters, Vol.86, 081107 pp.1-3 (2005)

[5] A. Kudlinski et al., Applied Physics Letters, Vol.86, No.161909, pp.1-3 (2005)

[6] C.Corbari et al., Electronic Letters, Vol.39, No.2, pp.197-198 (2003)