Available online at www.sciencedirect.com
ScienceDirect
Optik 121 (2010) 490–493
Optik Optics
www.elsevier.de/ijleo

Generation of green light in a thermally poled silica fiber by quasi-phase-matched second harmonic generation

A. Strauß[a,*], U. Jauernig[a], V. Reichel[a], H. Bartelt[a,b]

[a]*Institute of Photonic Technology, Albert-Einstein-Strasse 9, 07745 Jena, Germany*
[b]*Faculty for Physics and Astronomy, University of Jena, Max-Wien-Platz 1, 07743 Jena, Germany*

Received 7 April 2008; accepted 12 August 2008

Abstract

Thermal poling is an attractive method to induce a nonlinear coefficient in silica materials. We have investigated potential silica materials with respect to their suitability for thermal poling and analyzed the achievable depletion thickness in the poling process. Based on this investigation, a fiber was designed and prepared for second harmonic generation. The generation of light in the visible range at a wavelength of 532 nm was successfully demonstrated with a poled fiber and with quasi-phase matching using a pump wavelength of 1064 nm.

Keywords: Nonlinear optics; Materials; Microstructuring; D-shaped optical fibers

1. Introduction

Back in 1986 Österberg and Margulis reported on frequency doubling in optical glass fibers [1]. Later, in 1999, in a publication by Kazansky et al. [2], the concept of thermal poling was extended to quartz glass fibers. Kazansky reported on frequency doubling in a thermally poled fiber from 1532 to 766 nm with conversion efficiencies of around 20%. Although such an effect in silica fibers could be of extremely great practical importance (e.g. for visible all-fiber light sources, fiber switching, or signal modulation in fibers), rather limited additional or confirming results have been published. We have investigated the effect of thermal poling in fibers for frequency doubling in combination with quasi-phase matching, extending the wavelength range to shorter wavelengths in the visible range at 532 nm. In this context, we have also performed investigations into the appropriate choice of silica glasses for thermal poling, the achievable depletion layer thickness, periodic electrodes on D-shaped fibers for quasi-phase matching, and a specific holey cathode structure.

2. Material features

In order to specify the optimum glass material for thermal poling, we have tested different materials in a planar structure regarding thermal poling and second harmonic generation (Table 1).

These tests produced results in which glasses with cation concentration (such as Na^+, Li^+, and K^+) of around 1–10 ppm turned out to be well suited for poling. Such glasses include Herasil, Infrasil, HSQ100 (HERAEUS), and PN235 (QSIL). These cation concentrations are expected to have a thickness of some micrometers for the depletion layer (Fig. 1).

*Corresponding author. Fax: +49 3641 206399.
E-mail address: alexander.strauss@ipht-jena.de (A. Strauß).

0030-4026/$ - see front matter
doi:10.1016/j.ijleo.2008.08.008

Table 1. Second harmonic generation (SHG) signal of different glass materials depending on cation concentration

SHG signal	No	Yes	No
Cation concentration (ppm)	$\leqslant 0.02$	1–10	$\geqslant 1000$
Quartz-glass material	Suprasil (Heraeus) Lithosil Q1 (Schott)	Herasil (Heraeus) Infrasil (Heraeus) HSQ 100 (Heraeus) PN 235 (Qsil) PF1 (IPHT/Heraeus)	Vycor (Corning) coverslips (Qsil)

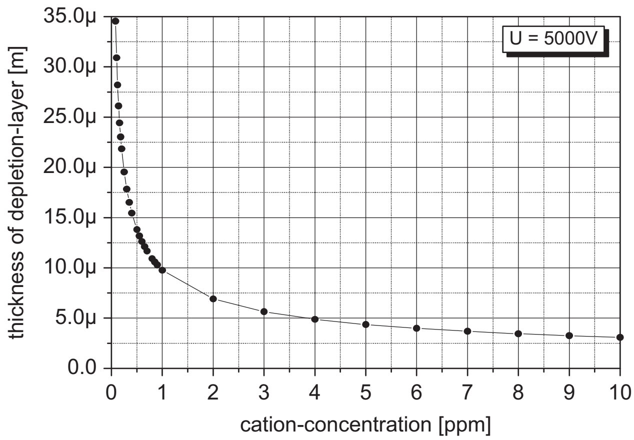

Fig. 1. Simulated thickness of the depletion layer depending on cation concentration.

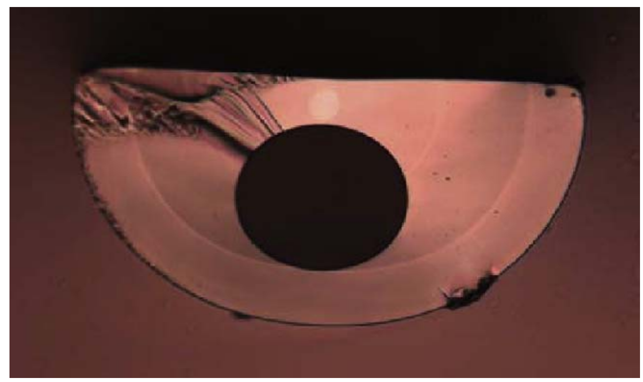

Fig. 2. Produced fiber for poling experiments. Cladding diameter: 600 µm, core diameter: 40 µm, hole diameter: 200 µm, and distance from core to side surface: 10 µm.

Glasses with considerably higher concentrations or extremely low concentrations did not exhibit any effect in thermal poling. Therefore, we used quartz glass (HSQ100) as the core material in the fiber preform. As a cladding material we used F320, a fluor-doped glass by HERAEUS with a refractive index of 1.4576 (633 nm), resulting in a refractive index difference of $\Delta n = 9 \times 10^{-4}$ between the core and the cladding.

Electrodes have to be applied for thermal poling. Therefore, a D-shaped fiber cross section was produced by polishing the preform (Fig. 2). This shape facilitates the production of a periodic electrode on the flat surface of the fiber.

3. Thickness of the depletion layer

Investigations into the thickness of the depletion layer by means of poling were first performed with planar waveguides. Here, we used two different characterization methods. The first method is referred to as the stack maker's fringe technique, first demonstrated by Kazansky et al. [3]. With this nondestructive method the thickness of the depletion layer in a poled silica sample can be determined. Even a thickness that is smaller than the coherence length ($l_c = 24\,\mu m$ in silica) can be determined. This is achieved by measuring the second harmonic power ratio of one poled silica sample and two identically poled silica samples pressed together in a stack. To perform this measurement, we used planar HERASIL samples ($10 \times 10 \times 0.2$ mm), which were poled for 20 min with 5 kV at 280 °C. The thickness of the depletion layer obtained using this method was 5.5 µm. The second method for the determination of the thickness of the depletion layer was an etching method. In this method, the same HERASIL samples, poled under the same conditions, were etched step by step in a fluorine acid (40%) solution. After each step, the second harmonic signal was measured. It was found that the second harmonic signal decreased linearly with the increase in the etching depth (Fig. 3).

After a 6 µm etching depth the second harmonic signal vanished. Hence both different characterization methods exhibit comparable results regarding the depletion layer thickness in the range from 5.5 to 6 µm. Similar values were obtained by the simulation (Fig. 1) and are also reported in other publications [4–6].

4. Electrode equipment

According to the expected small depletion layer thickness, the distance between the electrode and the fiber core in the prepared fiber had to be reduced further. We, therefore, etched the cladding on the flat surface with fluorine acid (40%) down to a distance of