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Application of highly uniform LPCVD SiO_xN_y in SHG devices

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Abstract

Silicon oxynitride layers grown by Low Pressure Chemical Vapor Deposition have been optimized towards high uniformity in thickness and refractive index. These layers have been applied as passive waveguides in phase-matched second-harmonic generating devices.

1. Introduction

In recent years, research on blue, low-cost light sources was encouraged by the need for commercial systems operating at short wavelengths for high-density data storage in the CD industry[1]. Second-harmonic generation (SHG) from AlGaAs laser diodes is one of the generation principles of blue light. In this field, planar optical waveguides are the low cost alternative for expensive frequency doubling crystals[2].

For the realization of efficient second-harmonic generating devices, material with high second-order optical non-linearity is required. Tetranitro-tetrapropoxy-calixarene (calix) fulfills this requirement and is therefore chosen for application. A second condition for efficient SHG is the phase-match (PM) between the fundamental and second-harmonic light beams. As a consequence of the PM-condition there are severe requirements for homogeneity of the relevant material properties and uniformity of the dimensions of the waveguiding structure. Of these requirements, that concerning the thickness uniformity, can be hardly obeyed by calix. The non-uniformity can be less crucial, if calix is applied as a cladding layer and the uniformity requirement is taken over by a core layer consisting of a passive material like silicon oxynitride (SiON) grown by low pressure chemical vapor deposition (LPCVD). Since this approach is based on the insensitivity of the design to layer parameters with large

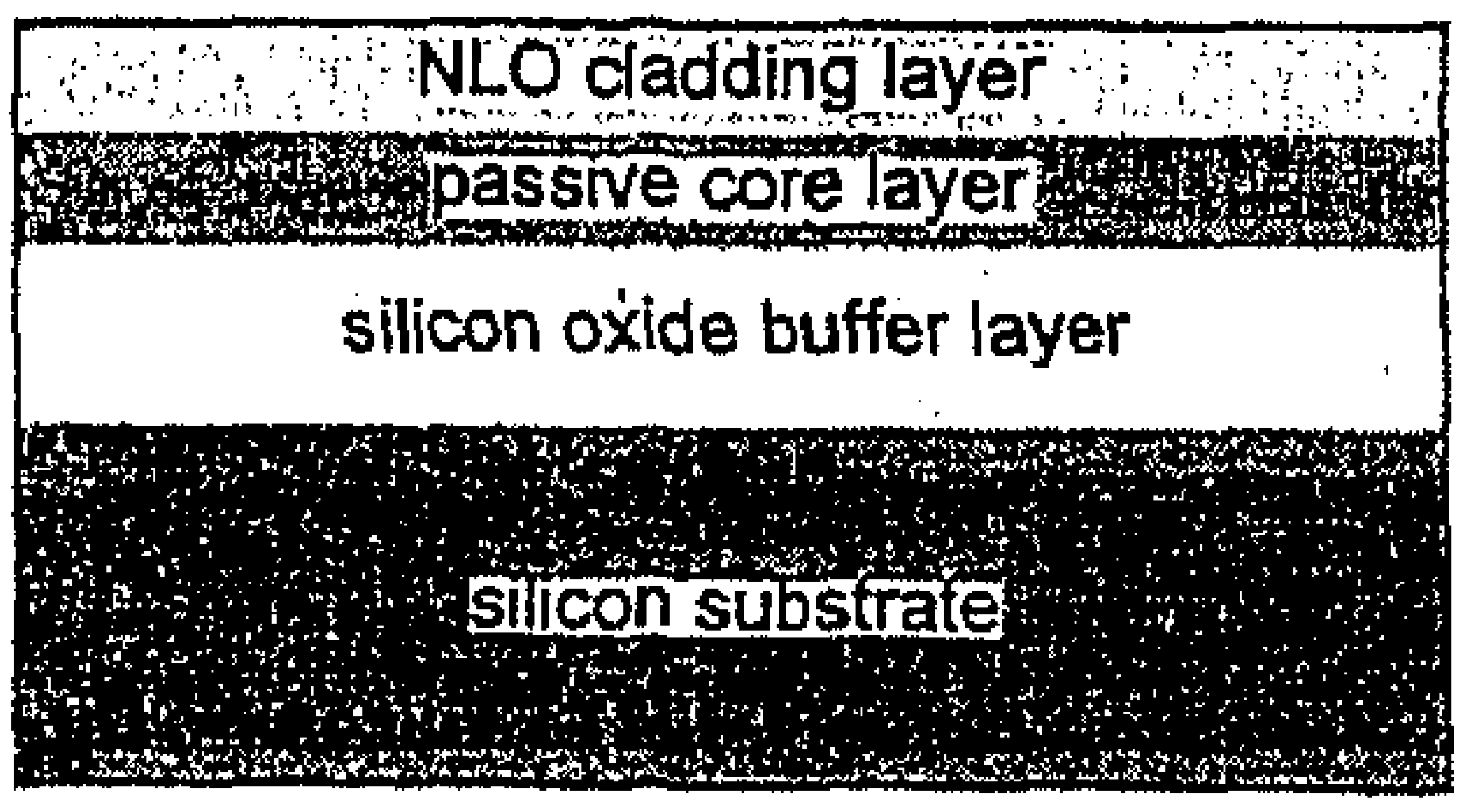

Figure 1 Schematic view of applied planar waveguide structure

technological tolerances, this type of design will be called non-critical. A schematic view of a waveguide structure suitable for non-critically PM SHG is shown in figure 1.

2. Properties of applied materials

Calixarene

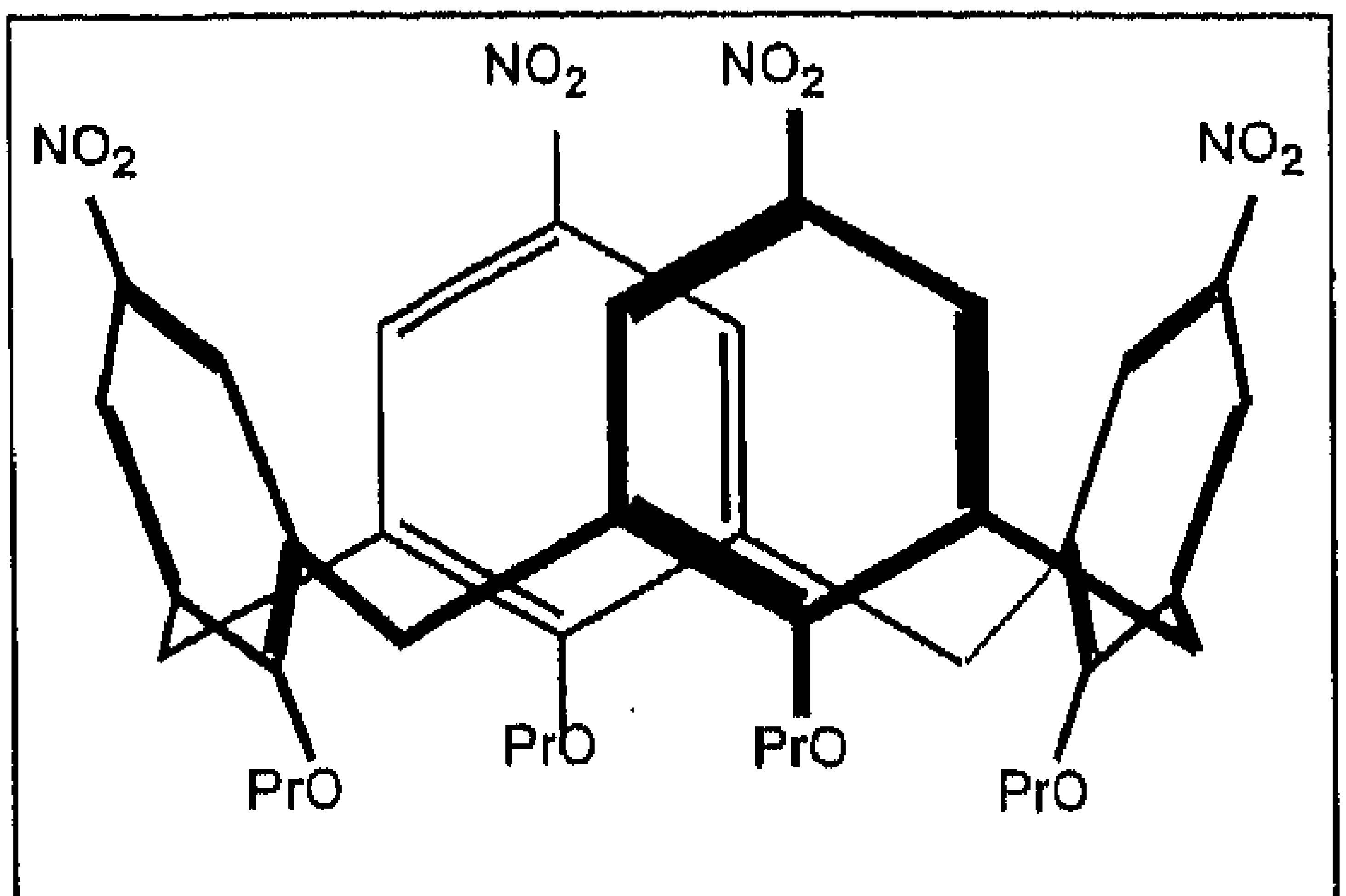

Figure 2 Structure of the tetranitro-tetrapropoxy-calixarene molecule[3]

Calix, an organic molecule with a structure as shown in figure 2, has the potential for high optical non-linearity [3],[4],[5]. For thin film preparation, 75wt% calix/PPMA is dissolved in chloroform and spin coated on a wafer. The refractive index of the layer is n_{TE} = 1.5781 and n_{TM} = 1.5795 at λ = 632.8 nm and the thickness non-uniformity is 3%, randomly distributed across the wafer. Second-order optical non-linearity is introduced by corona poling[4],[6]. Nonlinear optical (NLO) coefficients of 2±1 pm/V have been measured for calix, when corona poled on highly insulating substrates, such as SiON. Deposited on a conductive layer, NLO coefficients up to 12 pm/V can be obtained by corona poling. Furthermore, calix is transparent down to the UV[4],[7], enabling SHG of blue light down to 430 nm.

Silicon oxynitride

Silicon oxynitride layers have been grown by LPCVD from SiH_2Cl_2, NH_3 and O_2 at 900 °C and 100 mTorr[8]. The SiON layers are highly transparent down to the UV with optical losses less than 0.2 dB/cm and a high flexibility of the refractive index, ranging from 1.46 (SiO_2) to 2.0 (Si_3N_4). The wavelength dispersion of the SiON layers

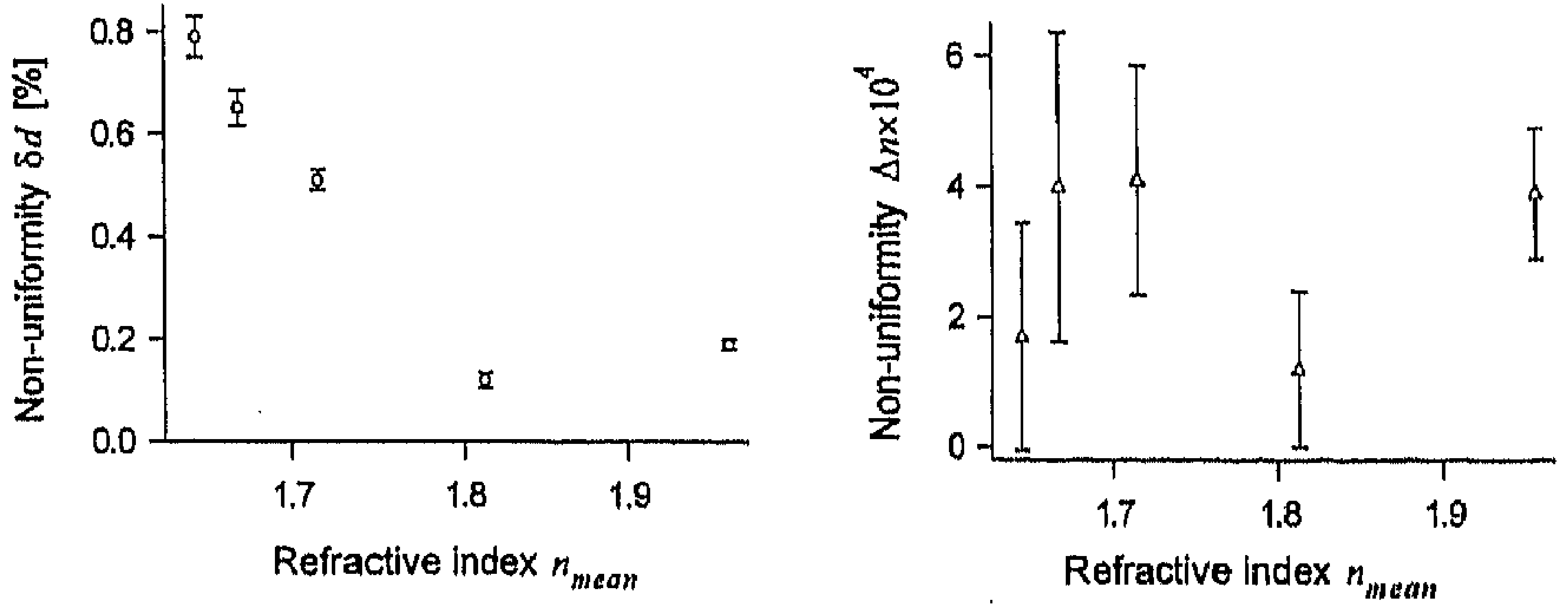

Figure 3 Thickness (left) and refractive index (right) non-uniformities of SiON with varying mean refractive indices across an area on the wafer suitable for SH-application

has been measured. Further, the uniformity and reproducibility of layer thickness and refractive index is excellent. The graphs in figure 3 give an impression about the high uniformity of SiON over an area on the wafer needed for an SHG device.

3. Device design

A device, based on non-critical phase-match between the fundamental TM_0^{ω} mode and the SH $TM_1^{2\omega}$ mode, was designed for operation at 958 nm fundamental wavelength (λ_ω). Simulation results, applying SiON with n_{TE} = 1.6852 and n_{TM} = 1.6831 at λ = 632.8 nm, is shown in figure 4. For high SH-efficiency, the overlap (i.e.: field overlap between fundamental and SH-mode in the calix layer) and the device length should be as large as possible. For realization of a device with a length of 10 mm, a $\Delta n_{eff} \leq 2\times10^{-5}$ can be tolerated[8]. From these, layer thicknesses of 645 nm and 591 nm for the calix and SiON layers, respectively, can be deduced.

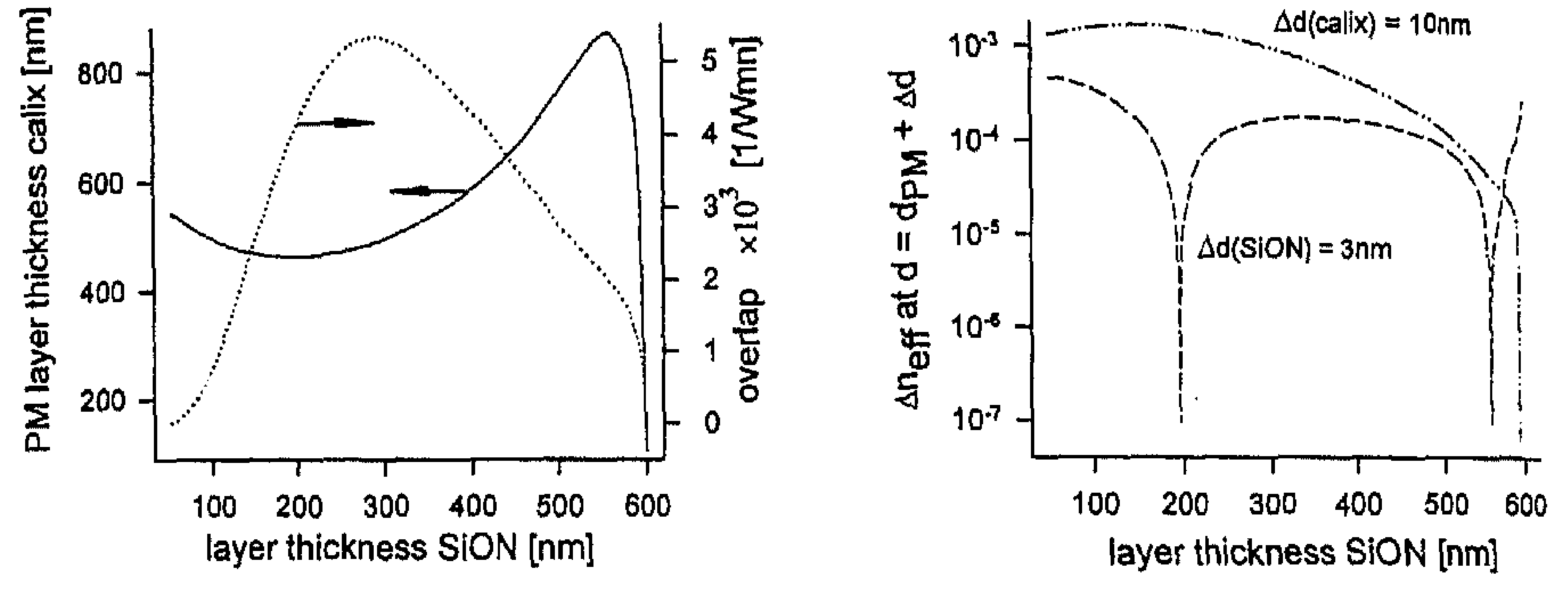

Figure 4 Simulation result of SHG device at λ_ω = 958 nm: phase-matching calix thickness and overlap vs. the SiON thickness (left) and the change of Δn_{eff} at 3 nm SiON and 10 nm calix thickness deviation away from the PM thickness (right)

4. Fabrication and results

The device was realized on thermally oxidized <100> Si wafers. At the centre of the 10 mm long device area, the deposited silicon oxynitride had a layer thickness of 589.8±0.5 nm and refractive indices of 1.686(3±1) and 1.683(4±1) (λ = 632.8 nm) for TE and TM polarized light, respectively. The thickness deviation across this area was 3 nm. A calix layer, approximately 600 nm thick, was spin coated on top and corona poled.

A frequency-doubled Q-switched Nd:YAG pumped dye laser (λ=910–970 nm) with 6 ns pulses at 10 Hz repetition rate was used for SHG. The fundamental mode with a beam width of 1 mm was coupled into the slab-type waveguide. The fundamental peak

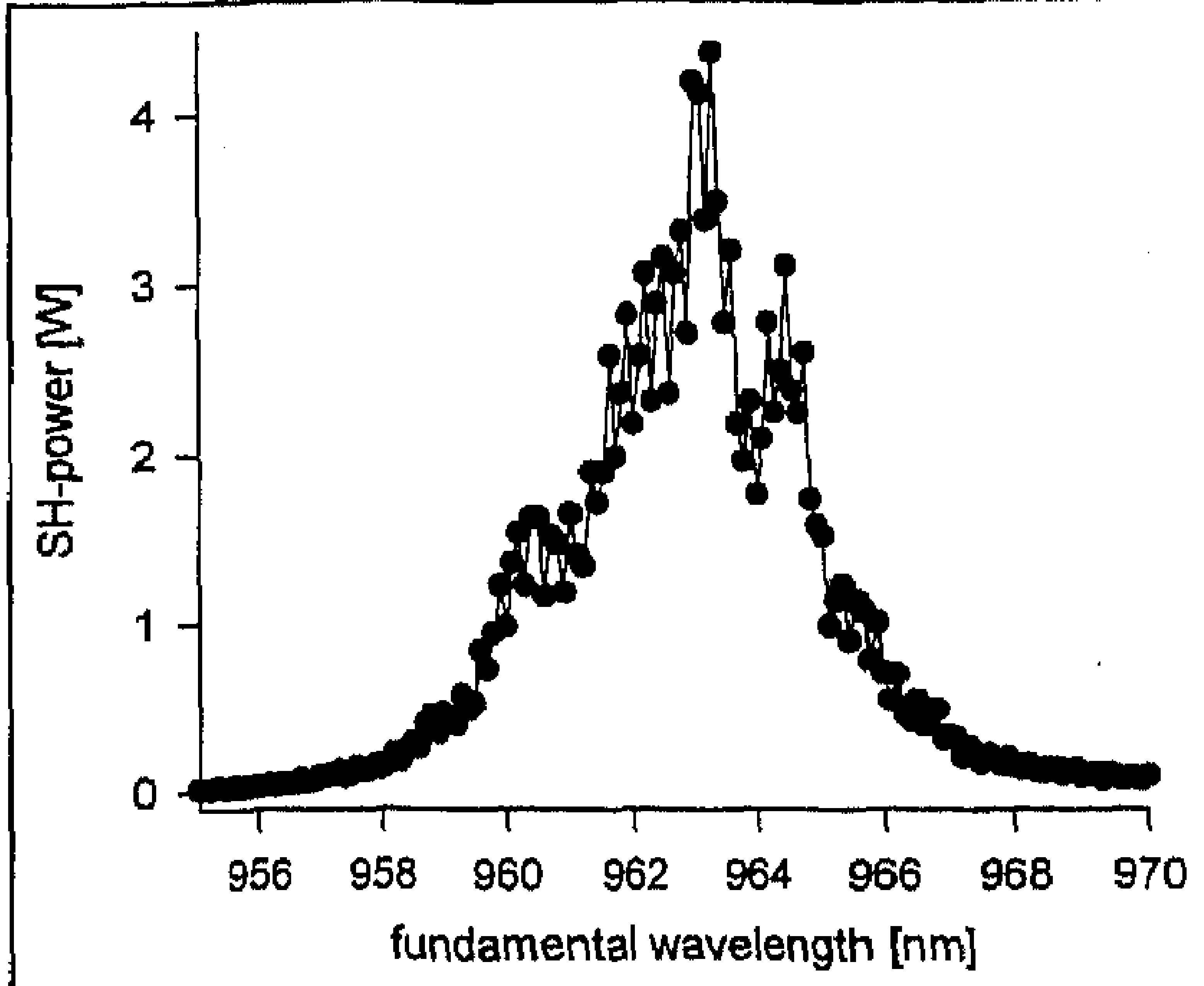

Figure 5 Measured SH-power of device

power inside the waveguide was determined to be 500 W. After 10 mm propagation, the fundamental and the generated SH-mode were coupled out. After filtering the fundamental out, the SH-intensity was measured by a photodiode. The result is shown in figure 5. The maximum of the SH-peak power, at the fundamental wavelength of 963.3 nm, is about 4.5 W. This means a conversion efficiency of $1.8\times10^{-3}\%W^{-1}$.

5. Conclusions

The suitability of silicon oxynitride for application in phase-matched SHG devices, requiring very high layer uniformity, has been shown. A device with a conversion efficiency of $1.8\times10^{-3}\%W^{-1}$ at 963.3 nm fundamental wavelength has been realized and tested. For further enhancement of the conversion efficiency, application of waveguide channels, instead of slab-type structures, and a more suitable poling method, in order reach higher optical non-linearity, are recommended.

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