FK3 Fig. 2. (a) Cross-section micrograph of the embedded waveguide, (b) Near-field pattern for TE polarized light at wavelength of 1.3 μm .

FK3 Fig. 3. Dependence of optical loss on core width for a dose of 1500 $\mu\text{C}/\text{cm}^2$.

width of less than or equal to 8 μm operate in a single mode, but the waveguides with a core width of more than 8 μm operate in multiple modes.

Figure 3 shows the dependence of optical loss on core width. The optical loss is constant for TE polarized incident light, even though the core width increases. On the other hand, the optical loss decreases with increasing core width for TM polarized incident light. The lowest optical loss at 1.3 μm among the waveguides which operate in a single mode was when the core width was 8 μm ; the values were 0.4 dB/cm for TE and 0.7 dB/cm for TM polarized incident lights.

In conclusion, we showed that embedded channel waveguides can be fabricated by direct electron beam writing. By controlling conditions appropriately, we can get single mode transmission and low optical loss.

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FK4

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Phase matched second harmonic generation in silicon [Oxy]nitride-calix[4]arene waveguides

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Within the last few years, the interest and research in compact blue lasers increased strongly. Layer structures of Silicon [Oxy]nitride (Si[O]N) and Calix[4]arenes (75 wt% Calix[4]arene in PPMA) are promising for modematching (phase matching between two guided modes) devices due to the high non-linear optical coefficients of the Calix[4]arenes and the excellent optical properties and reproducibilities of Si[O]N. The deposition process (spinning and Corona poling) of Calix[4]arenes and the optical properties have been described earlier.¹ The processing circumstances (LPCVD) and important optical parameters of Si[O]N have been shown earlier.²

Since the thickness non-uniformity of the Calix[4]arenes is about 3%, randomly distributed across the wafer, a design, insensitive towards this thickness, is required. This can be realized introducing a Si[O]N passive waveguiding layer. The sensitivity of the device towards the Si[O]N parameters is high. In Figure 1, the thickness and refractive index uniformities of the available Si[O]N layers are shown.

The SH efficiency depends proportionally on the square of the coherence length (l_c),³ and l_c is inverse proportionally dependent on the effective index mismatch (Δn_{eff}) across this length.⁴ For an l_c of 1 cm, a $\Delta n_{eff} < 2 \cdot 10^{-5}$ is required. The design of different devices based on SLAB-type waveguides and their sensitivity towards layer parameters is shown in Table 1. All devices have been designed considering mode match between the TM_0^0 and the TM_1^{20} guided modes. A pulsed Dye laser with tunable wavelength between 845–890 nm and 910–970 nm is available.

Comparing the sensitivities in Table 1 and the uniformity parameters in Fig. 1, the suitability of Si[O]N for the fabrication of devices with an l_c of approximately 1 cm can be concluded. The first two devices have been fabricated and measured using a prism coupling-photodiode set-up. The results of both measurements are shown in Fig. 2. The fundamental peak power of the first and second device was approximately 200 Watt and 500 Watt, respectively. The SH-power of both devices agree with the theoretical expectations. The broadening and shape of the SH-peak can be explained by Si[O]N layer non-uniformity across the used waveguide areas. Slight differences between the designed and measured fundamental PM-peak wavelength has been observed due to small variations in the absolute layer thickness and/or refractive index of the Si[O]N layers.

In conclusion, Si[O]N-Calix[4]arenes layer structure are well suitable for Phase Matched Second Harmonic Generation. Four devices have been designed, and two devices have been fabricated and

FK4 Fig. 1. Measurement results and accuracy (error bars) of the thickness non-uniformity δd (part a) and the refractive index non-uniformity Δn (part b) vs. the refractive index n at $\lambda = 632.8$ nm of available Si[O]N layers; the non-uniformities have been measured across an area necessary for SHG application (length 1–2 cm).

FK4 Table 1. Design of different devices for second harmonic generation using mode match between the TM_0^0 and TM_1^{20} modes (*: Δn_{eff} = sensitivity * Δd_{layer} ; unit of sensitivity $[\mu\text{m}^{-1}]$; *: field overlap of fundamental and second harmonic in calix layer).

device	λ_0 [nm]	d_{calix} [nm]	$d_{Si[O]N}$ [nm]	$n_{Si[O]N}$	sensitivity* calix	sensitivity* Si[O]N	field overlap*
1	945	700	438	2.008	$1E-4$	$2.8E-1$	0.000012
2	958	645	591	1.684	$1.4E-3$	$3.6E-2$	0.00029
3	870	700	372	2.008	$8.1E-5$	$3.8E-1$	0.000037
4	867	610	480	1.712	$3.7E-3$	$3.2E-2$	0.00047

FK4 Fig. 2. Measured SH-power of mode match ($\text{TM}_0^0 \Rightarrow \text{TM}_1^{20}$) of device 1 (part a) and device 2 (part b).

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tested, up to now. The measurement results and theoretical expectations are in good agreement.

Future research will deal with the increase of the SH-efficiency by e.g., the use of channel-type waveguides, the use of more uniform Si[O]N layers deposited by an other LPCVD process, the use of multi-layer (2 or more Si[O]N films) structure and the use of an additional cladding layer on top of the Calix[4]arenes layer.

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Er-doped silicate glass thin-film waveguide devices for integrated optics

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Stimulated by the rapid development of Er-doped fiber amplifiers, rare-earth doped glass films are drawing increasing attention for amplifiers and lasers, suitable for integrated optics. Thin-film waveguide devices, in general, require high rare-earth concentration (two or three orders of magnitude higher than that of fiber amplifiers) in order to obtain a certain amount of optical gain in a relatively short length, i.e., in centimeters as opposed to meters for Er-doped fibers. In highly Er-doped waveguides, however, a series of undesirable effects have been observed, such as reduction in fluorescence decay lifetime, multiexponential decay in fluorescence, and fluorescence emission at visible wavelengths for infrared pump. These effects usually degrade amplifier performance by reducing efficiency and gain. Therefore, developing highly Er-doped materials that are free from (or less affected by) the concentration-dependent effect would be crucial to obtaining high performance devices. We have deposited highly Er-doped (~1 mole %) silicate glass films using rf-magnetron sputtering. Erbium was doped into the host material by co-sputtering a silicon target and an elemental erbium in reactive ambient. Erbium-doped silicate glass targets were also prepared with various compositions and sputtered to deposit Er-doped glass films. Er-doped films show a strong, room-temperature luminescence at 1.54 μm wavelength, corre-

sponding to the $^4I_{13/2} \rightarrow ^4I_{15/2}$ transition of Er^{3+} ions (Fig. 1). Fluorescence decay lifetime is a function of various parameters, not only an Er concentration, but also a host composition and a target preparation method used. The highly Er-doped silicate glass films prepared by rf-sputtering show a lifetime over 9 msec (Fig. 2). Using the Er-doped silicate glass films as an active guiding layer, we have developed waveguide structures with various different geometries, which are suitable for amplifiers or lasers. Figure 3 shows one of the devices fabricated as a waveguide ring laser. The ring resonator

FK5 Fig. 1. Room-temperature photoluminescence spectrum of an Er-doped silicate glass film deposited by rf-magnetron sputtering.

FK5 Fig. 2. Fluorescence decay profile of an Er-doped silicate glass film measured at 1.54 μm .

FK5 Fig. 3. A waveguide ring laser structure. The photo shows a plan view of the fabricated structure (a Y-junction part). The stripe width is 8 μm and the ring radius is 5 mm.

structure offers a number of advantages over other cavity structure such as a Fabry Perot resonator. First, the ring laser allows easy integration with other components on the same substrate, simply due to the fact that it does not require any cleaved facet. Second the cavity lengths are defined precisely, which is important for advanced operation of lasers such as mode locking or Q-switching. Third, the topology allows for efficient use of area. The device shown in Fig. 3 incorporates two different couplers. A pump beam is coupled into the ring through a Y-branch coupler, and 1.54 μm laser light in the right is out-coupled into a linear waveguide spaced closely to the ring. A coupling ratio is determined by the proximity of the two waveguides, interaction length, and wavelength of the light. Utilizing the rather big difference in wavelength of the two lights (i.e., 1.54 μm versus 0.98 μm), the laser light can be selectively out-coupled, while the pump beam remains in the cavity. The inner S-shape path returns a counter-clockwise oscillating signal into a clockwise oscillation. This unidirectional oscillation would enhance the output power, but also eliminate spatial hole burning effect. Details of the amplifiers and ring lasers characteristics will be reported.

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Room 301 B

Laser Spectroscopy I

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Suppression of amplified spontaneous emission from twisted intra-molecular charge transfer state of diethyl amino methyl coumarin laser dye under picosecond pumping

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The decrease in the quantum yield of 7-diethyl amino-4-methyl coumarin (DAMC) dye with increasing polarity of solvents, is due to their crossover from the intra molecular charge transfer (ICT) state to the twisted intramolecular charge transfer (TICT) state, which radiates extremely weakly.¹ Unlike dialkyl amino benzotriazoles which exhibit well resolved ICT and TICT fluorescence in polar solvents,² DAMC exhibits only a single fluorescence band in conventional fluorescence spectroscopy. But under intense pulsed excitation two fully resolved peaks appear in its amplified spontaneous emission (ASE) spectra.³ This paper describes the effect of the pumping rate on the relative intensities of these two ASE peaks, using nanosecond and picosecond pump pulses. A nitrogen laser producing 300