Optimization of hydrogen silsesquioxane films for photonic applications

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Fabrication techniques for strong-confinement photonic devices are progressing rapidly, enabling increasingly complex electronic-photonic integrated circuits (EPIC) to be fabricated. Many of these EPIC systems contain photonic devices with sub-wavelength dimensions, high-aspect ratio gaps, micro-heaters, and integrated electronic controls. This has increased the requirements of the low-index overcladding material that must now be able to fill in high-aspect-ratio gaps, withstand high temperatures, provide good thermal conductivity, and optically insolate the photonic structures. Such overcladdings are usually obtained via TEOS (tetraethylorthosilicate) based deposition of SiO_2. Here, we show that hydrogen silsesquioxane (HSQ) can be used as a lower-cost alternative to TEOS with superior gap-filling and self-planarization properties

HSQ is an inorganic polymer with the chemical structure $[HSiO_{3/2}]_n$ [1]. It was designed as a low-k dielectric and is also used today as an electron-beam resist. The standard thermal cure for HSQ is based on a N_2 anneal at 400ºC resulting in a porous hydrogenated silicon oxide with low k, low thermal conductivity, a refractive index of 1.37 at 1550 nm, and negligible optical loss. The cured film also has a high intrinsic tensile stress that limits the thickness of the HSQ layer to 1.2 μm. For photonic applications, thicker films with higher thermal conductivity are desired. Hence, the tensile stress and porosity of the film must be reduced while maintaining the excellent optical properties.

In this study we explored the effects of high temperature anneals on HSQ films using a quartz tube furnace and a rapid-thermal-processing (RTP) chamber. It was found that by annealing the HSQ films at 650ºC the Si-H bonds were fully removed, as shown by the FTIR results (Fig. 1). The FTIR spectra also show that it is possible to fully convert the film to SiO_2 using RTP above 1100ºC in an O_2 atmosphere; this is further supported by measurements of the refractive index via spectroscopic ellipsometry (Table I). The tensile stress is believed to be eliminated through viscous flow at these high temperature anneals, allowing film thicknesses in excess of 2 μm to be achieved with multiple spins [Fig. 2(a)]. Furthermore, it was confirmed that these anneals do not degrade the excellent gap-filling (better than 6:1 aspect ratio), planarization, and optical properties of HSQ [Fig. 2(b)]. As a proof of principle, a microring resonator was fabricated out of Si_3N_4 using HSQ as the overcladding material. The measured loss Q of this ring is 240 000 which is the same as the best published results using the same core material with a TEOS overcladding [2].

[1] H.C. Liou and J. Prestzer, “Effect of curing temperature on the mechanical properties of hydrogen silsesquioxane thin films,” Thin Solid Films, **335**, 186 (1998).
[2] J. Guo, M.J. Shaw, G.A. Vawter, P. Esherick, G.R. Hadley, C.T. Sullivan, "High-Q integrated on-chip micro-ring resonator," LEOS 2004, **2**, 745 (2004).

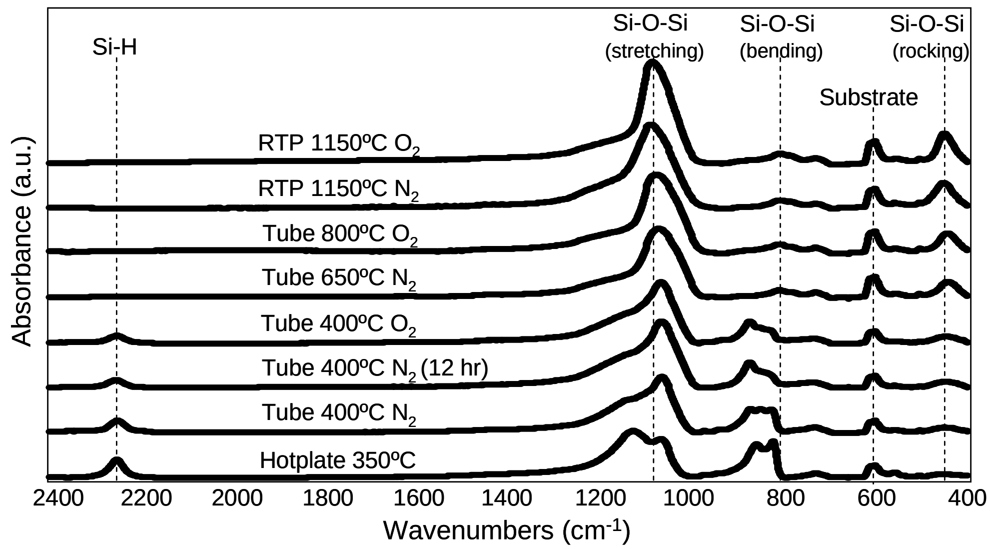

Figure 1: FTIR spectra for HSQ films annealed under various conditions. All data is normalized to a film thickness of 1 μm and the scans are vertically offset for ease of comparison.

Table I: Measured refractive index and percent film shrinkage

Temperature (°C)	Ambient	Anneal Type	Shrinkage (%)	Refractive Index[1]
350	Air	Hot Plate (1 min)	0.0	1.362
400	N_2	Tube (1 hr)	3.6	1.370
400	N_2	Tube (12 hr)	11.3	1.414
400	O_2	Tube (1 hr)	7.9	1.386
650	N_2	Tube (1 hr)	19.4	1.432
800	O_2	Tube (1 hr)	21.7	1.419
1150	N_2	RTP (1 min)	37.9	1.585
1150	O_2	RTP (1min)	23.7	1.442

[1]All refractive indexes were measured with a Sopra spectroscopic ellipsometer and quoted at λ=1550 nm.

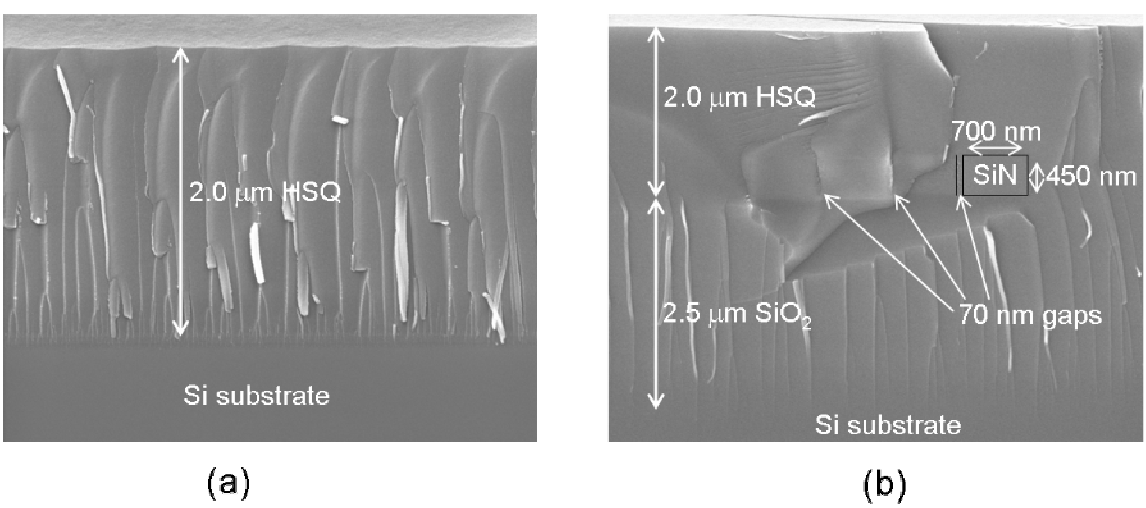

Figure 2: (a) 2 μm thick layer of HSQ formed using four sequential layers cured using RTP in an O_2 atmosphere. (b) Cross-section of four closely spaced SiN waveguides with HSQ overcladding. The filled aspect ratio of the gaps is greater than 6:1.