Material Consideration for Integrated Optics in Silica-on-Silicon Technology.

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All optical networking demands an integration of passive waveguiding, wavelength selectibility, light generation and detection, as well as active signal treatment in form of modulation, amplification, regeneration and switching. There are several materials platforms that can be suitable for large-scale optical integration. Among others, silicon based Planar Lightwave Circuits (PLCs) are of special interest because, in addition to optical function, they can combine electronic control units on the same silicon platform and the silicon substrate guarantee good thermal conductivity, chemical stability, high surface quality and low cost even for large area substrates.
For active devices such as lasers, modulators and detectors based on III-V semiconductor materials, hybrid integration on the common PLC is the technology of today although recently GaAs material grown on silicon wafer by using a novel concept with intermediate buffer oxide has been demonstrated, which may soon lead to totally monolithic integration.
Silica-based channel waveguides and waveguide devices are main candidates for inter chip communication, wavelength multi/demultiplexing, filtering and routing. These components need to be compatible with optical fibers, exhibit low losses for the whole optical communication window around 1.55 μm and be fabricated with help of low temperature processing.
Most deposition techniques for low index material for integrated optics involve subjecting the wafers to high temperatures. This limits considerably the concept of monolithic integration with all the temperature sensitive devices.
Plasma Enhanced Chemical Vapor Deposition (PECVD) technique is of great interest for microelectronic applications as low temperature processing for fabrication of dielectric coatings and insulating materials. Recently low temperature deposition of silicon oxide and oxynitride by PECVD has also been identified as very attractive technology for optical devices and as an alternative to high temperature Flame Hydrolysis.
PECVD fabricated films can easily match the refractive index profile of optical fiber by changing process parameters or doping. Usually light confinement in the core of the channel waveguide (and fiber) is realized by increasing the refractive index of the core in relation to the surrounding cladding material, which most often remains the undoped silica. The geometry of channel waveguides and components can be easily formed by patterning and plasma etching and whole process is similar and compatible to microelectronic fabrication, which potentially can result in high throughput production.
In the PECVD process, the precursors used and the deposition parameters strongly influence the optical properties and quality of the deposited films. In most PECVD processes for waveguide fabrication, nitrous oxide (N_2O) and silane (SiH_4) are used as main precursors for fabrication of pure silica. For core material phosphorous (P), nitrogen (N) or germanium (Ge) in form of suitable compounds are added to the precursors to increase the refractive index of the deposited material. Ge is most common used dopant, both for planar waveguides and fibers, due to its chemical similarity with silicon that makes it possible to keep the material losses on low level. Moreover, Ge-doped silica core exhibits UV photosensitivity, i.e., a permanent change in the refractive index of the material when it is exposed to UV-light of specific wavelength. High photosensitivity allows the fabrication of Bragg gratings in fibers or waveguides, the induced periodic modulation of refractive index inside the waveguide core allowing selective reflection of only one wavelength whereas the rest of light can pass through unperturbed. Such Bragg gratings are very versatile building blocks in different wavelength selective devices.

Unfortunately, PECVD deposited films suffer from two strong absorption peaks in the most interesting for optical communication 1.5 μm window at 1.48 μm and 1.51 μm due to N-H and Si-H bonds respectively. These absorption peaks were considered as intrinsic to the deposition method and post deposition annealing at around 1000 ^{o}C has been reported by several authors as a necessary processing step to improve the optical quality of deposited films but this treatment is not acceptable for the described monolithic integration. Alternatively, a special construction of high-plasma-density hollow cathode deposition system has been proposed for the processing, where nitrous oxide was replaced by oxygen.
This paper analyses material properties depending on different deposition parameters and discusses some of the important modifications that allow the fabrication of unannealed low-loss channel waveguide devices formed by the low temperature deposition of SiO_2 on Si using standard PECVD processing. Simultaneously the optimized material exhibits high UV sensitivity without high-pressure hydrogen loading or any other kind of sensitization. Such process would probably destroy sensitive active components integrated on the same PLC platform.
Our optimized low temperature PECVD deposition technique without annealing can contribute to increased photosensitivity due to presence of residual OH-end groups. Similarly, during hydrogen loading oxygen reacts with hydrogen to form OH groups and Ge/Si-OH formation has been implicated with the index change.
A spectrum of the fabricated in channel waveguide 25 mm long grating is shown in Fig. 1. The grating was recorded during 5 min exposure with 193 nm excimer laser with pulse energy of 2.3 mJ and pulse repetition 200Hz. The grating shows an extinction ratio of 47 dB, which to authors knowledge is the strongest grating written in channel waveguide without hydrogen loading reported to date.

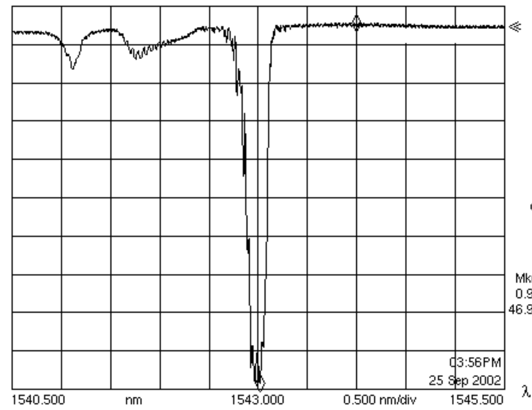

Fig. 1. Measured normalized transmission spectra through a 25 mm long grating (TE polarization)