Polycrystalline silicon as waveguide material for advanced photonic applications

Shankar Kumar Selvaraja[1], Marc Schaekers[2], Wim Bogaerts[1], Dries Van Thourhout[1], Roel Baets[1]

[1] INTEC-IMEC, University of Gent, Gent, Belgium,
[2] IMEC, Leuven, Belgium

We report single mode polycrystalline silicon-on-insulator photonic wire fabricated in a CMOS fabrication facility. The optical quality and the material aspects of the polycrystalline-silicon for photonic application were studied. We report an optical propagation loss of 13.4dB/cm, which is the lowest loss reported for a 500nm wide photonic wire.

Introduction

With ever increasing complexity and density of photonic integrated circuits the need for multilayer functionality is arising for next generation photonic circuitry. Even though monocrystalline silicon-on-insulator exhibits superior optical quality it is difficult to realize multilayer circuitry based on this material, however, deposited Si is a very good candidate for such application. The deposited material can be amorphous or polycrystalline (poly) depending on the deposition technique and parameters. An optical loss of 9dB/cm has been demonstrated for broad (1-7μm) multimode photonic wires [1] fabricated in poly-silicon. In this work we have fabricated single mode photonic wires of 220nm thick and 500nm wide on poly-silicon deposited by a low pressure chemical vapor deposition (LPCVD) process. The effect of the material properties on the optical propagation loss was studied.

Design and Fabrication

Poly-silicon waveguides were fabricated on 200mm silicon handle wafers with 1μm of high density plasma (HDP) oxide as the bottom cladding/isolation followed by a chemical mechanical polish (CMP). Successively, a 220nm amorphous silicon layer was deposited by an LPCVD process at 560^{o}C. Single mode photonic wires were then patterned by DUV lithography and etched using a $HBr/Cl_2/O_2$ gas chemistry. To reduce the rough sidewalls formed during the dry etch process, we grow a thin oxide layer. The oxide is grown at 900^{o}C in an oxygen atmosphere. The photonic wires are then covered with HDP oxide as the top cladding followed by a CMP step. The oxide cladding serves as the isolation layer for any higher level circuitry. The oxide covered wafers are then annealed at 600^{o}C for 30min to crystallize the amorphous silicon deposited by LPCVD. Unlike the work reported in [1] we use a short time and low thermal budget, which is important for fabrication in a production environment. The resulting poly-silicon is then hydrogenated in forming gas at 450^{o}C to passivate the defects in the poly-silicon photonic wires.

Results and Discussion

Fig. 1 depicts the fabricated 500nm wide poly-silicon photonic wire. The photonic wires are fabricated with different length by spirals [2]. Light from a broad band source is

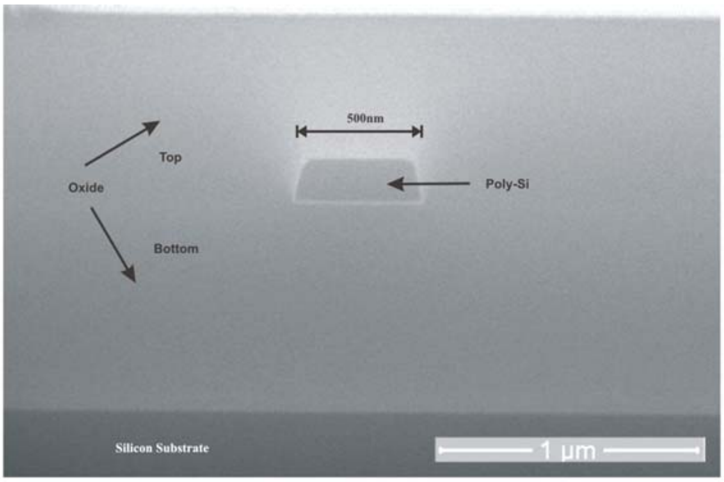

Figure 1Poly-silicon photonic wire with oxide as top and bottom clad

coupled into the photonic wire and the output at the other end is measured by a spectrum analyzer. Grating couplers were used at the input and output of the wires to couple light [2]. Samples were prepared with different process conditions to study the effect of the process on the optical loss. The effect of annealing, the oxide growth and hydrogenation were studied. The results show that high temperature annealing and hydrogenation are very important to make a photonic wire with decent propagation loss. The annealed and hydrogenated samples show a propagation loss of 13.4dB/cm. The losses for the samples without annealing or hydrogenation where too high to measure using our loss measurement technique. It was observed that growing a thin oxide of 2.5nm after etching decreases the loss by 3dB/cm; however, further oxidation increased the losses again. Various material analyses were done on the poly-silicon: atomic force microscopy, transmission electron microscopy and X-ray diffraction to study the roughness, grains and crystallinity respectively. The material analysis correlates with the optical loss mechanism.

Conclusion

Single mode poly-silicon photonic wires were fabricated. A propagation loss of 13.4dB/cm was measured, which is the lowest loss reported to our knowledge for a single mode poly-silicon photonic wire and which is acceptable for several photonic applications with micrometer scale footprint. The loss mechanism was analyzed through extensive material characterization. The results show the possibility for further reducing the loss below 13.4dB/cm.

Reference

[1] L. Liao, D. R. Lim, A. M. Agarwal, X. Duan, K. K. Lee and L. C.Kimerling, “Optical transmission losses in polycrystalline silicon strip waveguides: Effects of waveguide dimensions thermal treatment hydrogen passivation and wavelength”, *J. Electron. Mater*. Vol. 29, no. 12, pp1380-1386, 2000.

[2] W. Bogaerts, P. Dumon, D. Van Thourhout, D. Taillaert, P. Jaenen, J. Wouters, S. Beckx, R. Baets, “Compact Wavelength-Selective Functions in Silicon-on-Insulator Photonic Wires”, *IEEE J. Sel. Topics Quantum Electron.*, vol. 12, no. 6, pp. 1394-1401, 2006.