Student Paper

Free Carrier Absorption Loss of p-i-n Silicon-On-Insulator (SOI) Phase Modulator

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Silicon high-speed waveguide-integrated electro-optic modulator is one of the critical devices for on-chip optical networks. The device converts data from electrical domain to the optical domain. Most studies for high speed modulation method in Si or Si based device are based on free carrier concentration variations (injection or depletion of free carriers) which are responsible for local refractive index variations and then phase modulation of a guided wave traveling through the active region. A change in the refractive index/absorption can be achieved by injection or depletion of both electron and holes into the intrinsic region of a silicon p-i-n diode.

The paper reports on the free carrier absorption (FCA) loss associated with p-i-n silicon-on-insulator (SOI) phase modulator at $\lambda = 1.55$ µm. The analyses include the effect of various doping concentration and injected free carrier concentration on the FCA. The simulations are realized utilizing the 2-D semiconductor simulation package SILVACO.

We studied the micrometer scale silicon modulator based on the p-i-n diode structure to be operated at 1.55µm optical wavelength as depicted in Fig. 1. The P^+ type region is implanted with $5x10^{19}$ cm^3 Boron concentrations while the N^+ type region is the phosphorus implanted region with a concentration of $5x10^{19}$ cm^3. The structures have the background doping concentrations of 1x 10^{14}. The depth of the implanted region is about 1.8 µm for N^+ region and 1.6 µm for P^+ region. The rib height and width of the structure is chosen in order to have a single mode behaviour. The rib structure is designed to have 4 µm in height and 4 µm in width. With the chosen doping concentrations for the structure, the distance of the doped regions to the rib sidewalls turns to be 1.4 µm.The optical power of 1mW is applied to our design of phase modulator and the effect of the refractive index at 1.55µm optical wavelength is investigated. The important parameters used in the simulations are shown in Table 1.

Simulations predict that the FCA is directly proportional to both various doping concentration and injected free carrier concentration as depicted in Fig.2 and Table 2. The change of refractive index increases as the doping concentration and injected free carrier concentration are enhanced. Nevertheless, the FCA is also increased. Thus, it can be concluded that there is a trade-off between the change of refractive index and FCA of the modulator.

References

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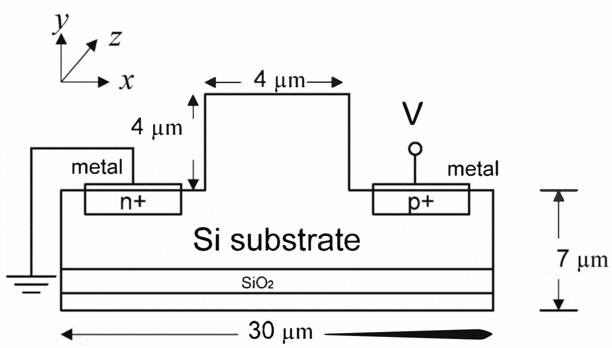

Fig. 1 Cross section of the p-i-n phase modulator.

TABLE I
SIMULATION PARAMETERS

Si refractive index	3.475
Si background carrier conc. (cm^3)	$1x10^{14}$
τ_p (s)	$2x10^{-6}$
T_n (s)	$2x10^{-6}$
Temperature (K)	300

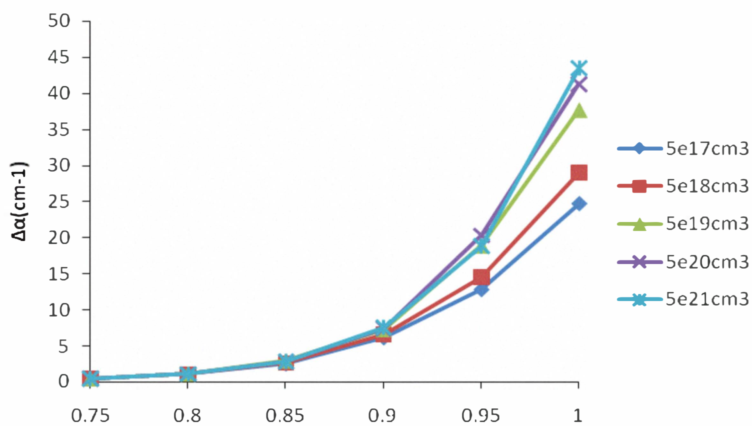

Fig. 2 Change of absorption for various doping concentration.

TABLE II
FREE CARRIER ABSORPTION LOSS FOR VARIOUS CONCENTRATION

Doping Concentration (cm^3)	**Δα (cm^{-1})**	**$L\pi$ (m)**	**α_π (dB)**	**α (dB/cm)**
5e17	6.09	5.39e-4	1.427	26.45
5e18	6.53	5.09e-4	1.442	28.34
5e19	7.25	4.65e-4	1.464	31.49
5e20	7.40	4.57e-4	1.468	32.12
5e21	7.54	4.49e-4	1.472	32.75