

Simulating Voltage-Dependent Index Changes in Silicon-on-Insulator Waveguides

Introduction

Tool used: LaserMOD

Silicon is the desired material system for integrated electro-optical devices due to its mature fabrication technology. However, not all the desired optical functionality has yet been achieved. One recent advance has been in the area of high-speed optical modulation in silicon-on-insulator (SOI) waveguides [1]. These devices rely on carrier dependent absorption/index effects [2] to modulate the propagating light. Until now, such devices have generally been slow, but an innovation that yields improved frequency response is the use of a metal oxide semiconductor (MOS) configuration. This creates a carrier accumulation channel near a thin buried oxide layer that can be controlled much faster than charge injected everywhere in the waveguide.

The model for charge-dependent absorption/index changes is given by Soref [2], and a self-consistent solution of Poisson's equation and the carrier continuity equations is used to determine the carrier densities everywhere in the device as a function of applied voltage. These models are all contained in the active device simulator, [LaserMOD](#).

SOI MOS Waveguide Structure

The waveguide structure used in the present example is very closely related to the structure disclosed in [1]. It is a 2.5-micron-wide by 0.9-micron-thick polysilicon ridge waveguide on silicon substrate. The ridge and substrate are separated by a thin (120 Angstrom) SiO₂ layer, which prevents current from flowing between the contacts. It instead permits charge to accumulate on either side, which in turn creates a strong index perturbation. The device is designed to operate at 1.55 microns and can achieve modulation at several GHz.

A highly doped region, $1e19$, resides beneath each contact, while the doping elsewhere is $3e16$ (p-type) in the ridge and $1.7e16$ (n-type) in the silicon. The cross-sectional geometry of the Polysilicon waveguide in MOS configuration is:

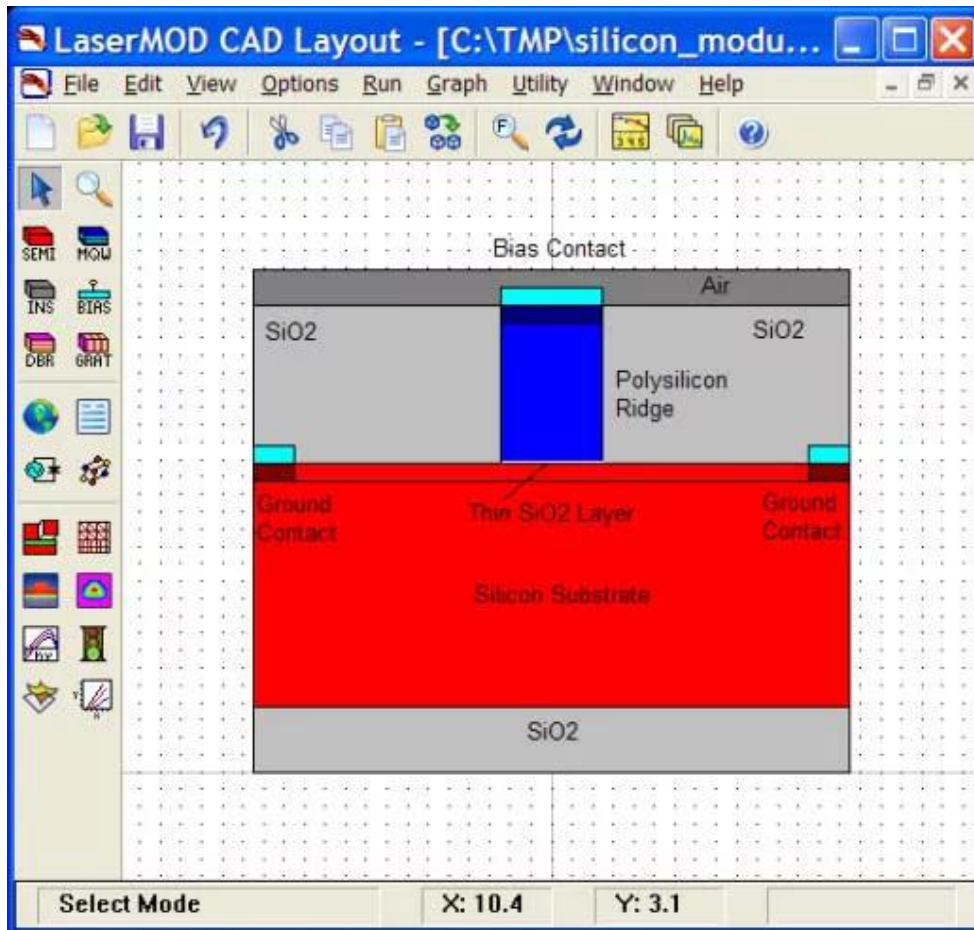


Figure 1. Cross-sectional geometry of the Polysilicon waveguide in MOS configuration

Steady-State Results

As the waveguide is driven to higher voltages, the carrier accumulation can be seen in near the buried oxide layer beneath the ridge:

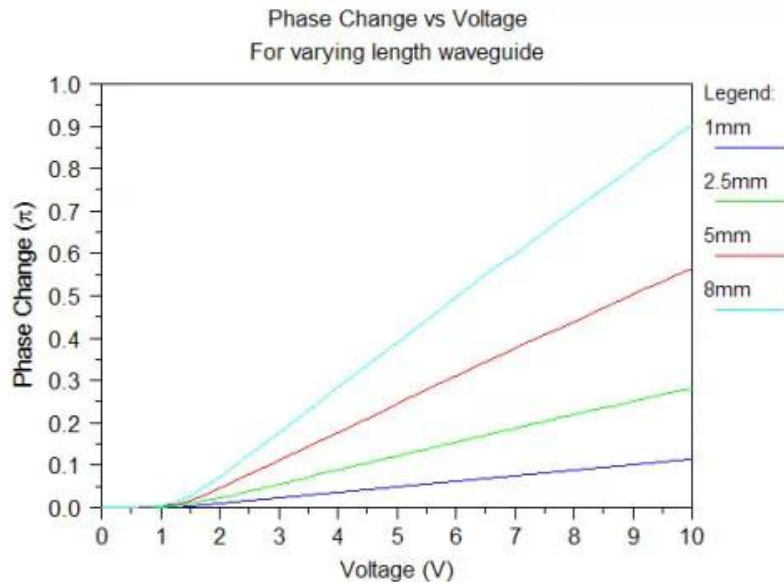


Figure 2. Phase change vs. voltage for varying length waveguide

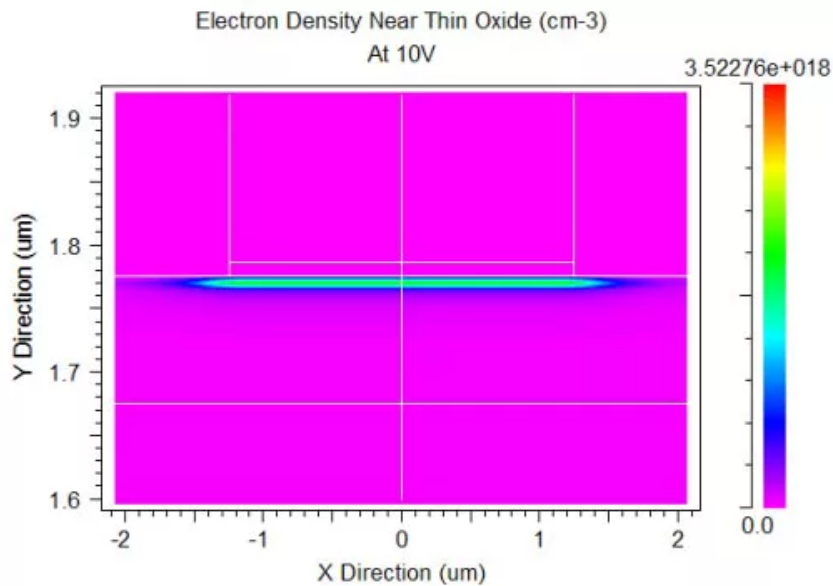


Figure 3. The electron density is on the left; hole density is on the right

The resulting index change due to these carriers causes an effective index change for the waveguide mode. This change is directly related to the optical path length change. This phase change is shown for several lengths:

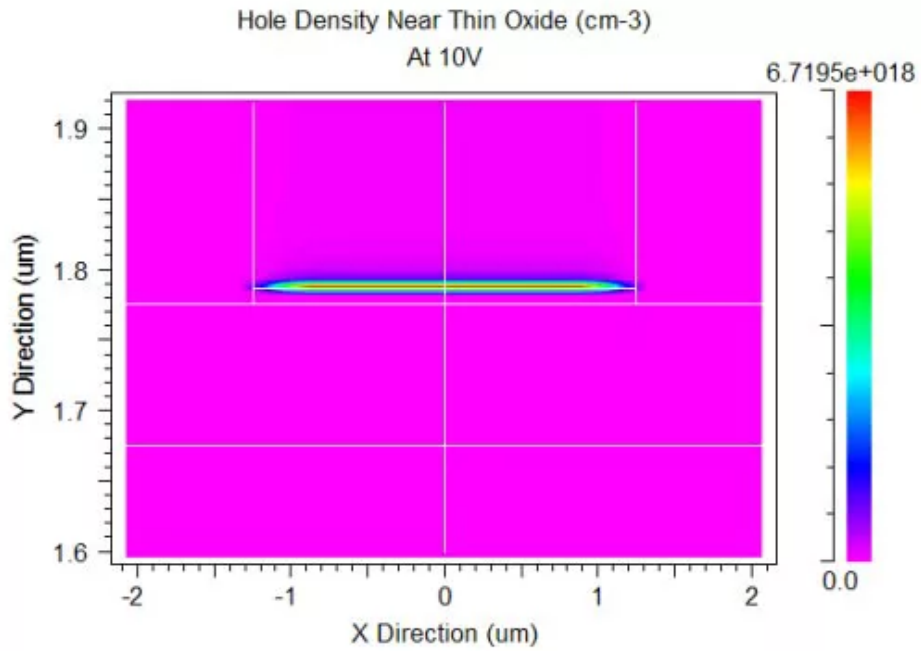


Figure 4. Hole density near thin oxide

Transient Results

Devices comprised of these waveguides stand to benefit from enhanced speed due to the rapid response of the accumulation layer. The waveguide's response to a square pulse is shown here at an operating point of 3V:

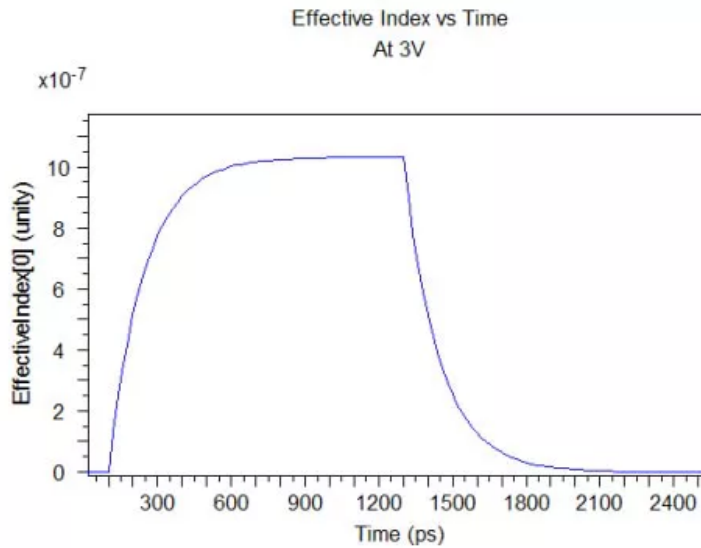


Figure 5. Waveguide's response to a square pulse at an operating point of 3V

The corresponding frequency response showing a -3dB point of more than 2 GHz:

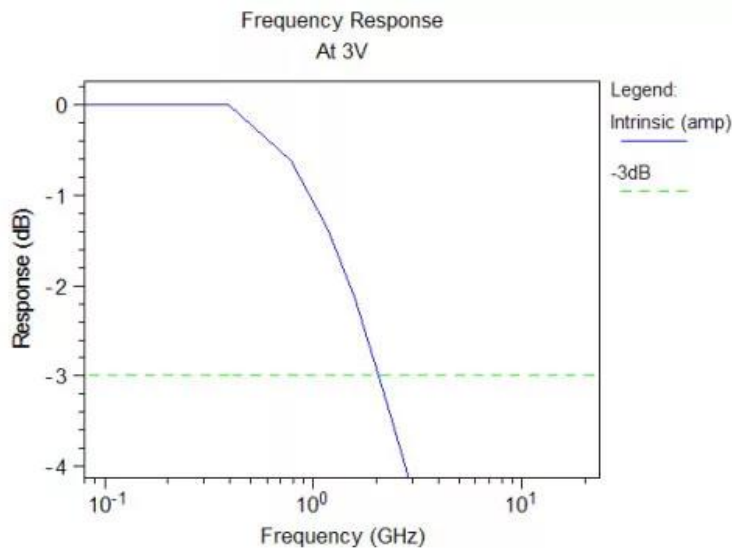


Figure 6. A -3dB point of more than 2 GHz

Such devices can respond in the several GHz range.

References

- [1] A. Liu, R. Jones, L. Liao, D. Samara-Rubio, D. Rubin, O. Cohen, R. Nicolaescu, and M. Paniccia, A high-speed silicon optical modulator based on a metal-oxide-semiconductor capacitor, *Nature*, 427, pp. 615-618, 2004.
- [2] R. Soref and B. Bennett, Electrooptical Effects in Silicon, *IEEE Journal of Quantum Electronics*, 23, pp. 123-129, 1987.



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