Optical waveguides in oxygen-implanted buried-oxide silicon-on-insulator structures

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Contents

Abstract

- **Analysis the waveguiding properties of oxygen-implanted, buried-oxide, silicon-on-insulator structures**

- **Can support TE_0 guided-wave propagation, at sub-bandgap wavelengths (λ = 1.3um), with losses 1dB/cm**

Current Interest (1)

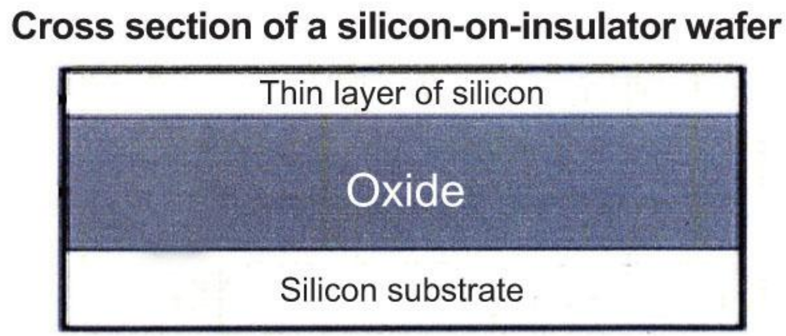
- **Important motivation :**
  - Compatibility with silicon-based integrated circuits
- **Silicon-based optical system**
  - Waveguide demultiplexer
  - Spectrum analyzsers
  - Others

Current Interest (2)

- **Optical waveguide in crystalline silicon**
  - Graded-index waveguides
    - – Performance of Epitaxial-silicon optical waveguides at λ =1.3nm (Soref and Lorenzo)
  - Epitaxial waveguides
  - Antiresonant reflecting optical waveguides
    - – Low loss, but expense of isolating the guided energy from crystalline-silicon substrate
  - Impurities introduced into the epitaxial silicon layer by ion implanatation (D.G. Hall)
    - – unacceptably high propagation losses
  - Use of silocon itself as a waveguide at wavelength >1.1um

Silicon On Insulator technology

- **Use single-crystal layer separated from a conventional silicon substrate by a thin layer of silicon dioxide**



- **Interest :**

Electrically resistant to radiation effect

Also an ideal waveguide for use in optics

(acceptably low radiation-leakage-loss limit 1dB/cm @ λ =1.3um)

SOI technology (2)

- **Use SIMOX (separation by Implanted Oxygen) process**

High dose of oxygen ions
(≈ 10^{18} ion/cm^2)
(150~200 keV, 450 ~ 500°C)

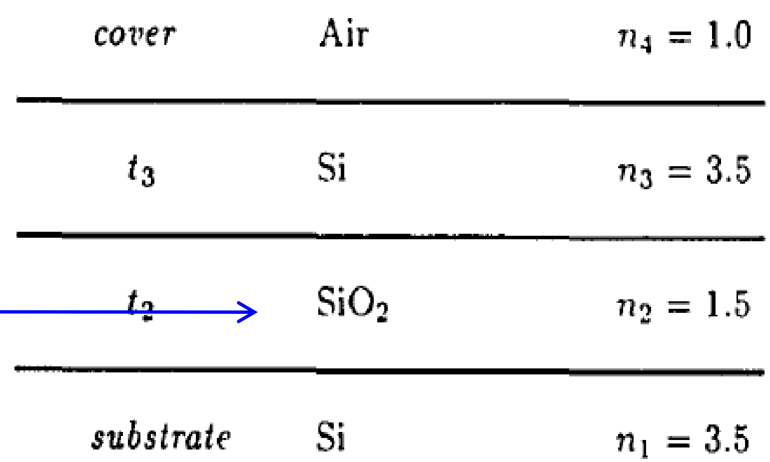


Fig. 1. Schematic of the structure of an oxygen-implanted buried-oxide SOI waveguide.

Analysis to determine SOI(1)

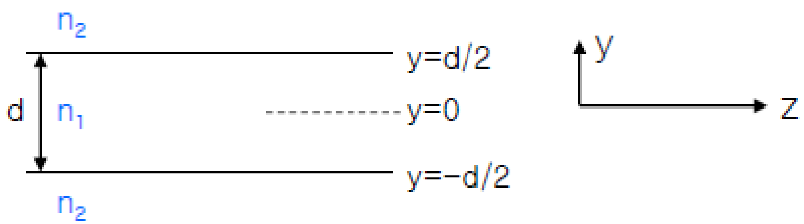
$$E = \hat{y} f(x) \exp[i(\beta z - \omega t)],$$

where, $\hat{y}$= unit vector,

$\beta = 2\pi N/\lambda$(propagation constant)

$N = \beta/k$ (effective index)

$k_0 = 2\pi/\lambda$



Consider TE Solution.

$$\overline{E}(y,z) = \overline{x}\, E(y)\, e^{-j\beta z}$$

$$\text{Then, } \frac{d^2E(y)}{dy^2} + (k^2(y) - \beta^2)E(y) = 0$$

$k^2(y) - \beta^2 > 0$ in core =>

$$E(y) \sim \sin(k_y y) \text{ or } \cos(k_y y)$$

$$k_y = \sqrt{(n_1 k_0)^2 - \beta^2}$$

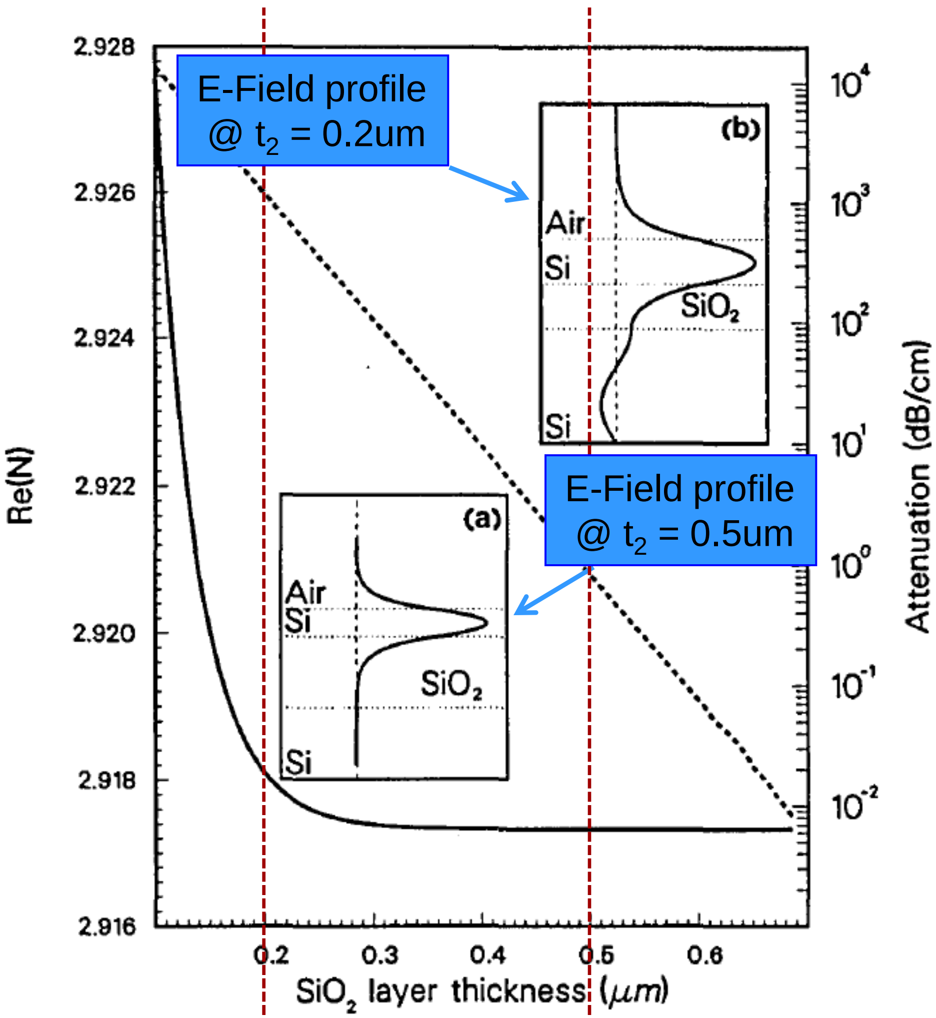
$k^2(y) - \beta^2 < 0$ in cladding =>

$$E(y) \sim \exp(\alpha y) \text{ or } \exp(-\alpha y) \text{ with}$$

$$\alpha = \sqrt{\beta^2 - (n_2 k_0)^2}$$

Analysis to determine SOI(2)

Re(N) and the attenuation of the TE_0 mode for the structure



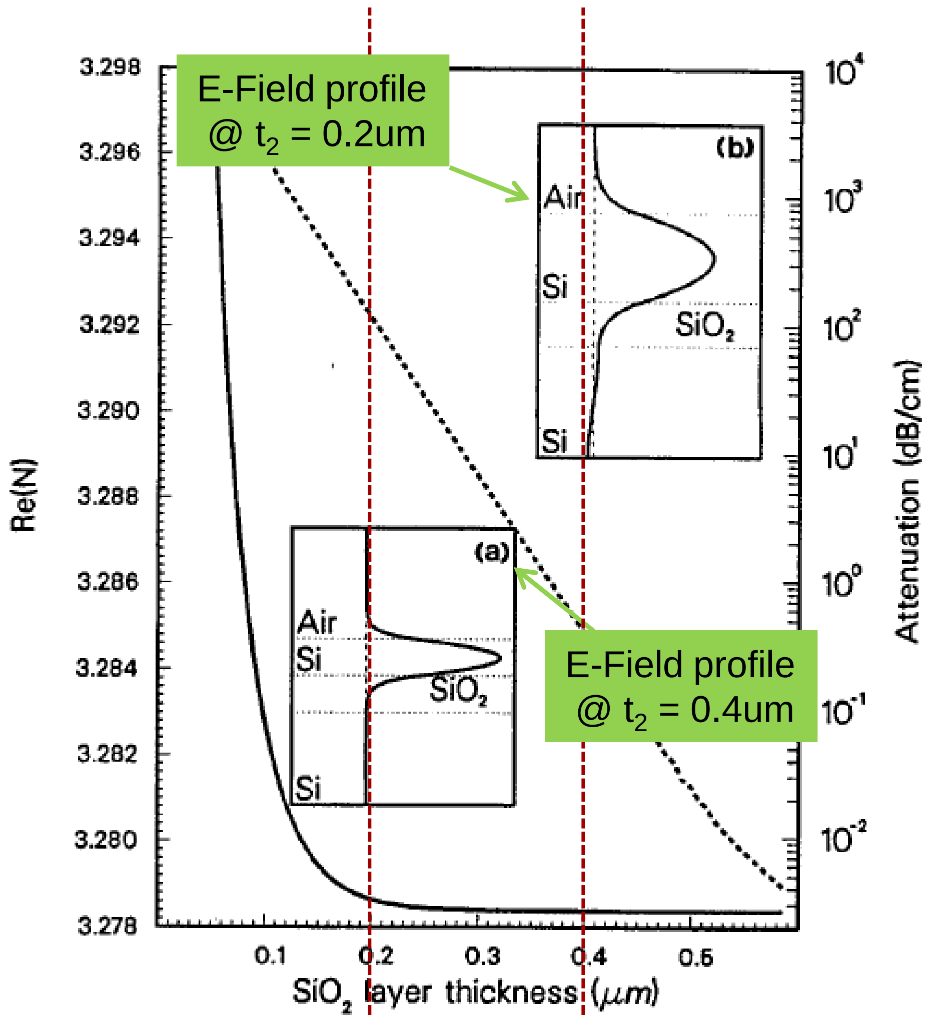
cover	Air	$n_4 = 1.0$
t_3	Si	$n_3 = 3.5$
t_2	SiO_2	$n_2 = 1.5$
substrate	Si	$n_1 = 3.5$

Fig. 1. Schematic of the structure of an oxygen-implanted buried-oxide SOI waveguide.

- **Full range of oxide thickness**
- **Attenuation varies 6 orders of magnitude**
- **At t_2 = 0.2um, leakage into silicon substrate is stronger**
- **Increased oxide thickness reduces the attenuation due to radiation leakage**

Analysis to determine SOI(3)

Re(N) and the attenuation of the TE_0 mode for the structure



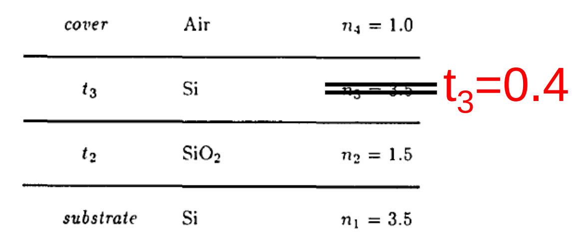


Fig. 1. Schematic of the structure of an oxygen-implanted buried-oxide SOI waveguide.

- **Re(N) ≈ 3.28 for t_2 > 0.2um, 1dB/cm attenuation**
- **Acceptable level of attenuation can be obtained for oxide thickness using SIMOX technology**

Analysis to determine SOI(4)

- Analyzed TM mode and higher-order TE mode ➔ rather high loss for these modes
- High-mode-power attenuation associated with TM mode (TM_0 is 2 orders of higher than TE_0)
- Other loss mehanisms can be minimized or eliminated by proper processing procedures
- Implantation damage can be reduced or removed by annealing

Conclusion

- **Leakage loss can be sufficiently low at SIMOX wavegudes**
- **useful for optical emission experiments & broad range of application in optics**