Dislocations in SiGe planar waveguides

Andrea Trita

Laboratory of Quantum Electronics and Nonlinear Optics
Electronics Department - University of Pavia

OUTLINE

- **Introduction**
  - **Silicon photonics**
  - **The SiGe/Si approach to Silicon Photonics**
  - **Dislocations formation at SiGe/Si interfaces**

- **Dislocations in SiGe planar waveguides:**
  - **Consequences on the guided optical field**

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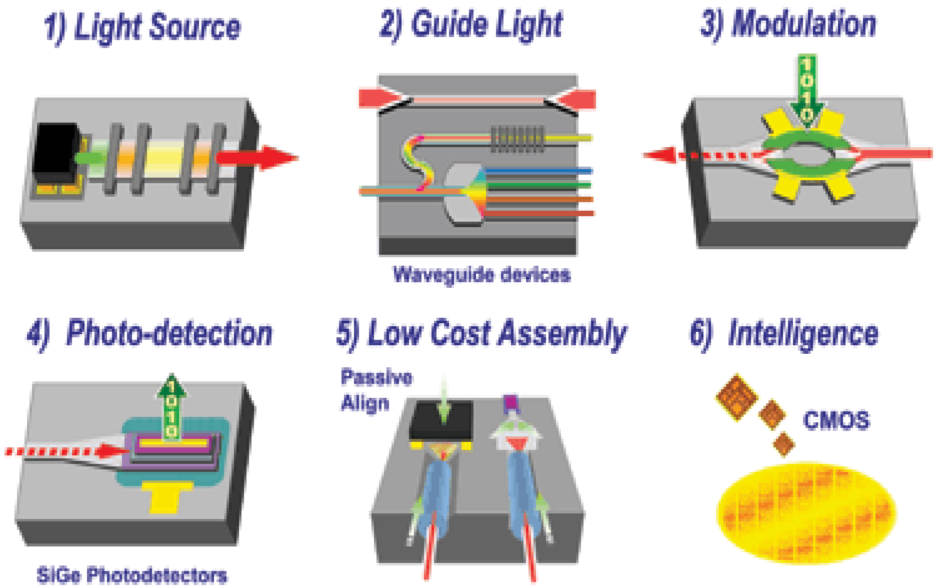
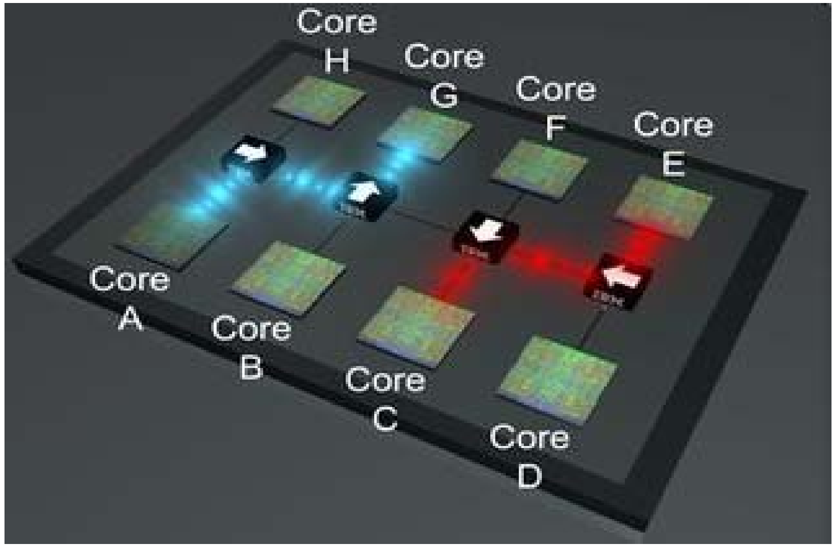
Silicon Photonics





- Cheap photonic chips for optical communications industry

- Optical interconnects

Silicon Photonics

➢Silicon as optical material

Advantages

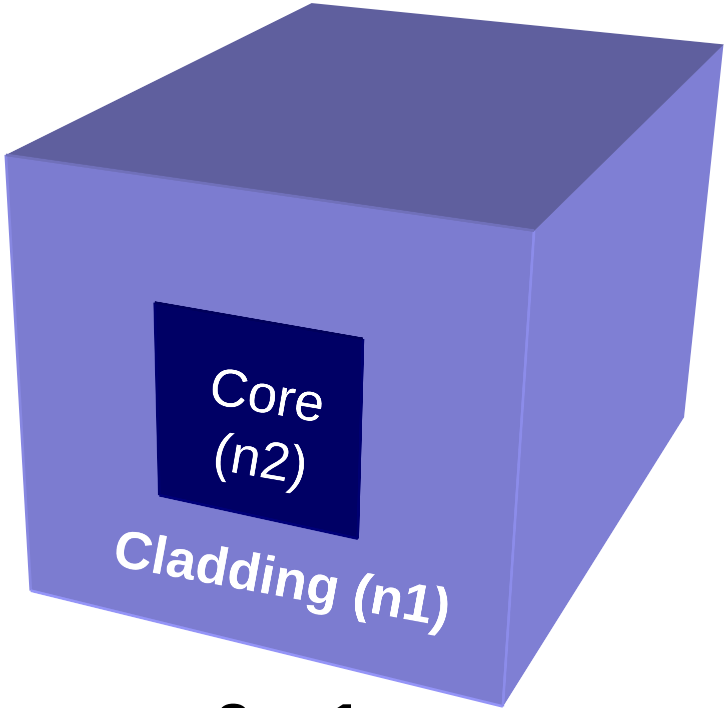
Bandgap energy = 1.12eV	→	High transparency at telecom wavelength(1.3-1.5μm)
At 1.3-1.5μm n_{si}~3.5	→	Tight optical confinement in combination with SiO_2
Crystalline structure	→	High nonlinear optical coefficients ($g_{R,Si}$~20cm/MW – $g_{R,Silica}$=0.93X10^{-5}cm/MW)

Disadvantages

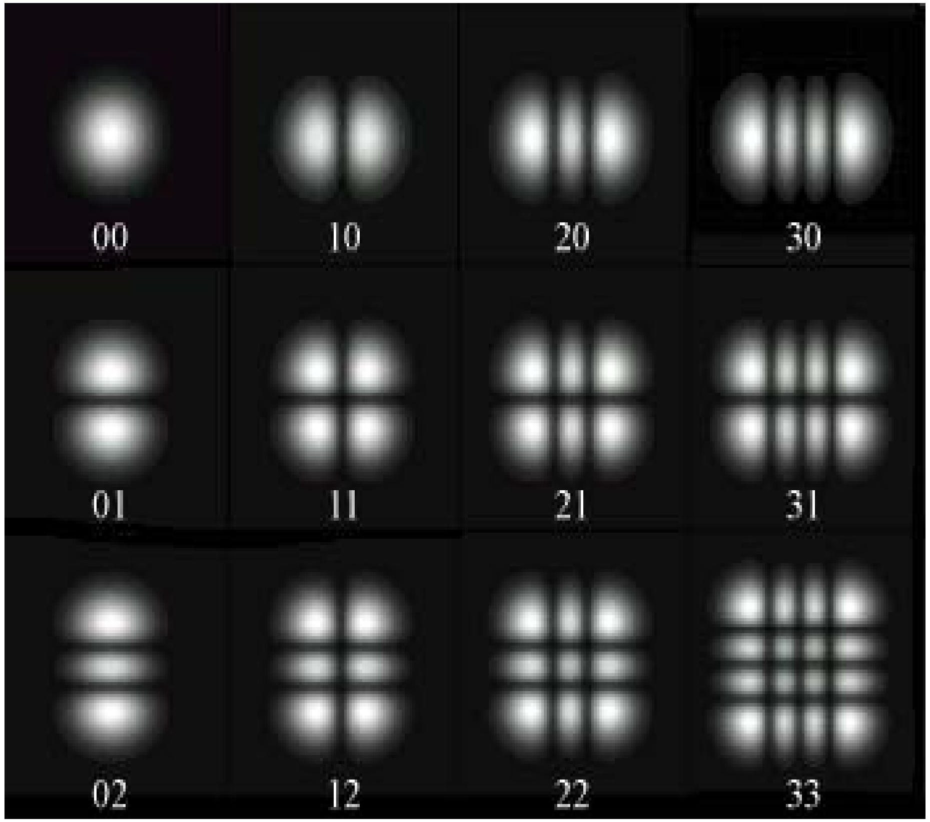
Indirect bandgap	→	Poor efficiency as light emitter
Centrosimmetric crystalline structure	→	Does not exhibit electro-optic effect

Silicon Photonics

- **The optical waveguide.**

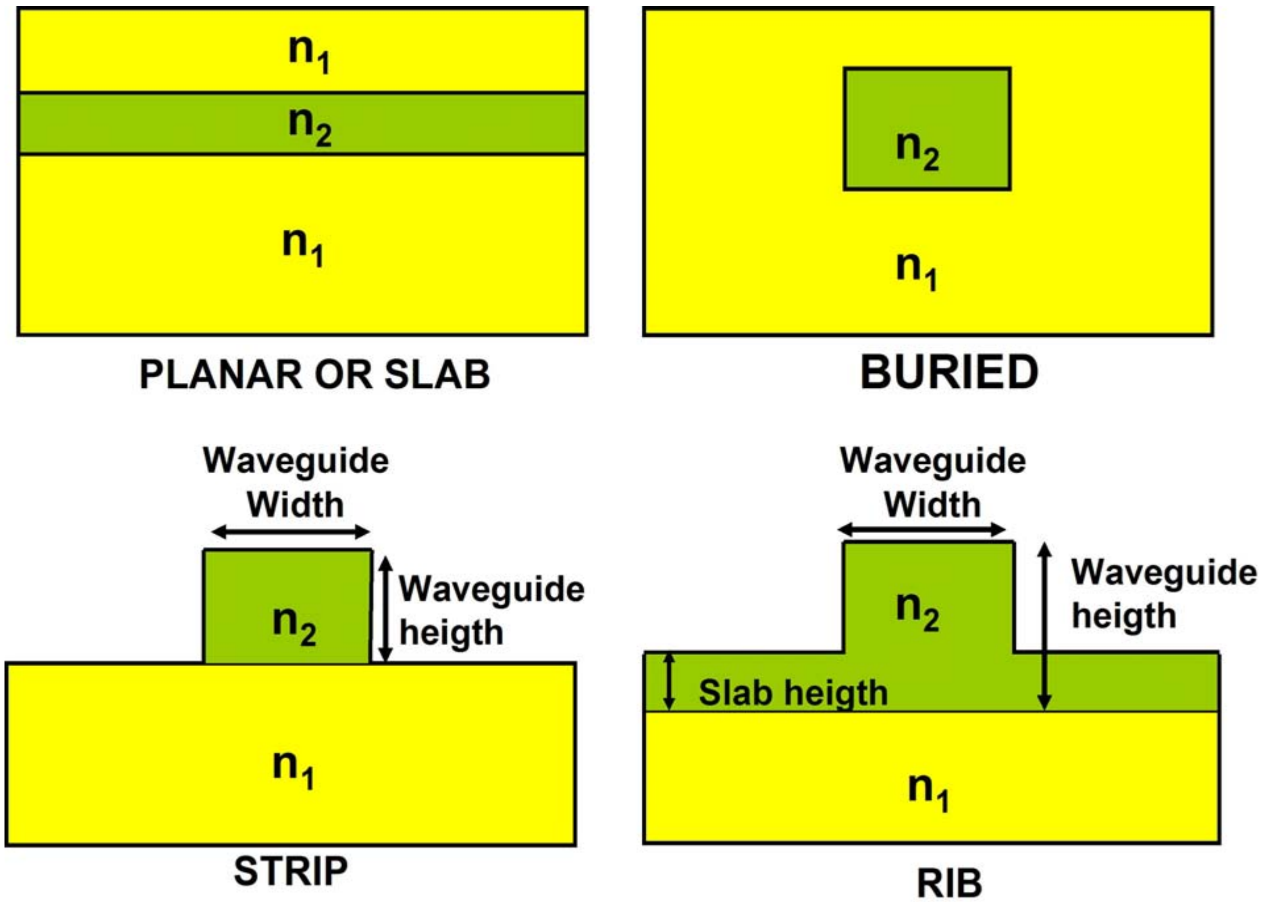


n2>n1



Silicon Photonics

- **The optical waveguide.**

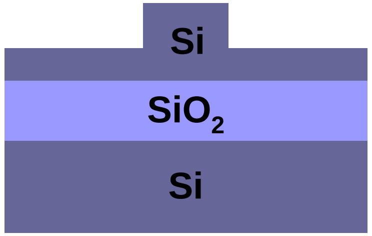


n2>n1

Silicon Photonics

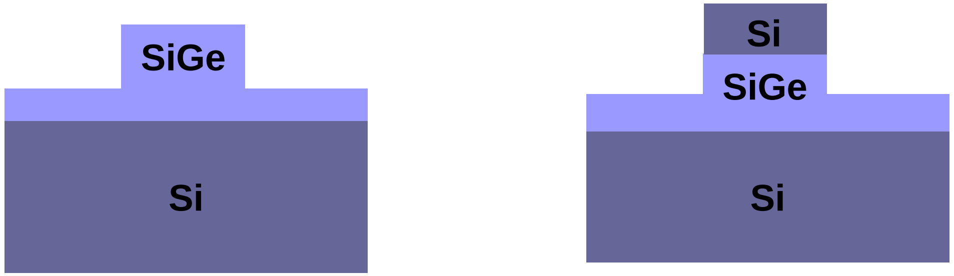
➢Technological approaches

SOI approach



O. Boyraz and B. *Jalali*, "Demonstration of a silicon Raman laser," Opt. Express 12, 5269-5273 (2004)

SiGe/Si approach

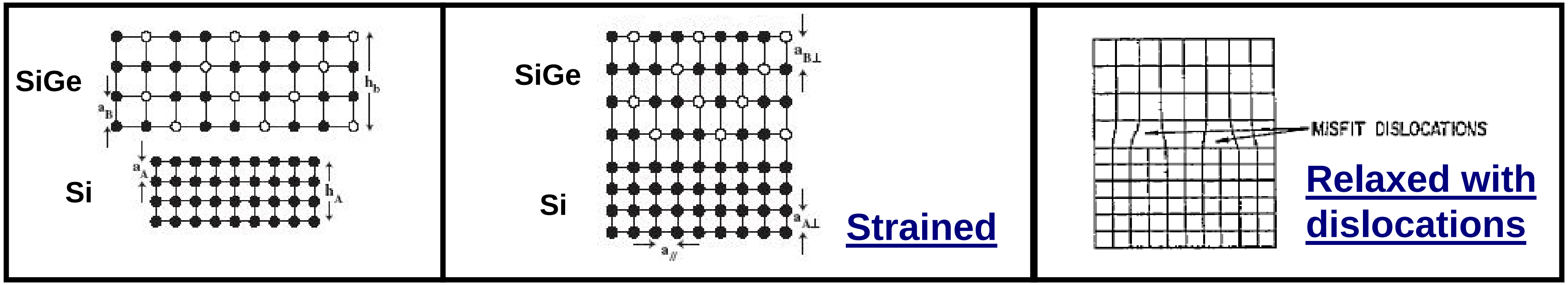


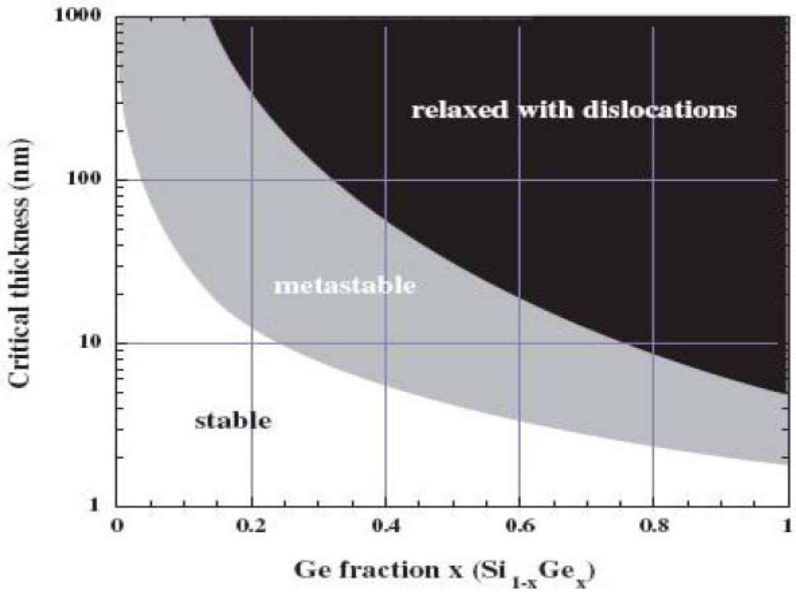
- ❑**Possibility to tune the optical properties of the material acting on the Ge fraction**
- ❑**At low Ge fraction the small index contrast between Si and SiGe allows for monomodal structures with micrometric dimensions**
- ❑**Elevated nonlinear optical coefficients**

Silicon Photonics

SiGe approach to optical waveguides

➢ **Ge has 4,2% larger lattice constant than Si**





J.W. *Matthews* and A.E. *Blakeslee*, *J. Crystal Growth 32* (1974), p. 265.

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- Dislocations in SiGe planar waveguides:
  - Consequences on the guided optical field

Dislocations in SiGe planar waveguides

➢***PRIN Project 2005:*** **"*SiGe optical waveguides: design, fabrication, characterisation and their application to Raman amplication*"**

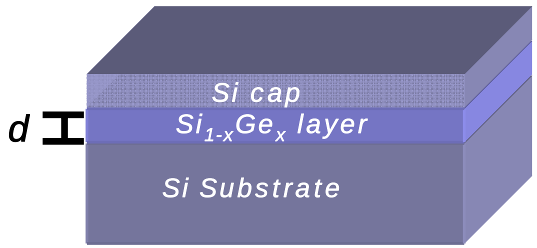
- **<u>Laboratory of Quantum Electronics and Nonlinear Optics-</u> University of Pavia**
- **<u>L-NESS (Laboratory for Epitaxial Nanostructures on Silicon and Spintronics)</u> – Politecnico di Milano**
- **<u>Material Science Department</u> - University of Milano Bicocca**
- **<u>Physics Department</u> -University of Insubria**

Dislocations in SiGe planar waveguides

Sample number	SiGe layer d [μm]	SiGe cap [μm]	Nominal x
#7645	0.2	10	2
#7646	0.4	10	2
#7693	0.8	10	2
#7689	1.5	10	2
#7382	2	10	2
#7546	2	10	4
#7544	2	10	5
#7542	2	10	6

Fixed x varying d (#7645 – #7382)

Fixed d varying x (#7382 – #7542)



Dislocations in SiGe planar waveguides

Consequences on the guided optical field

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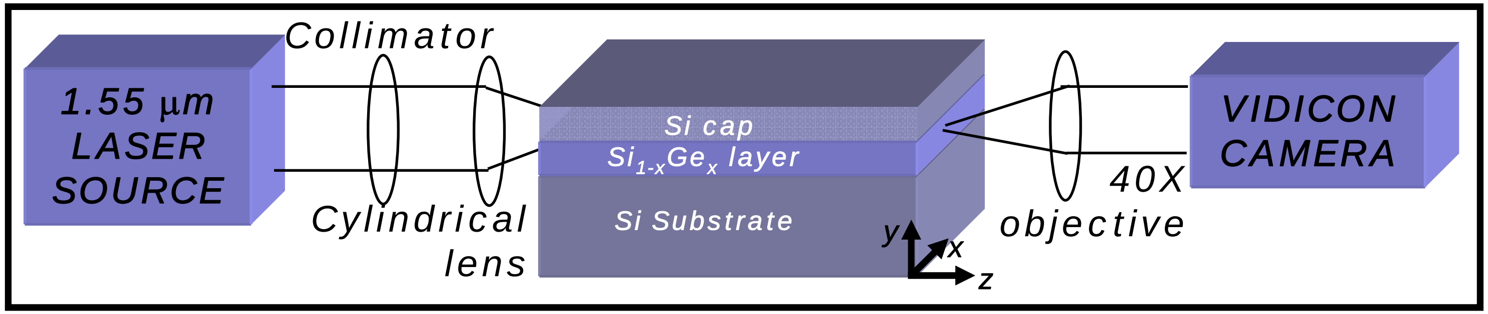
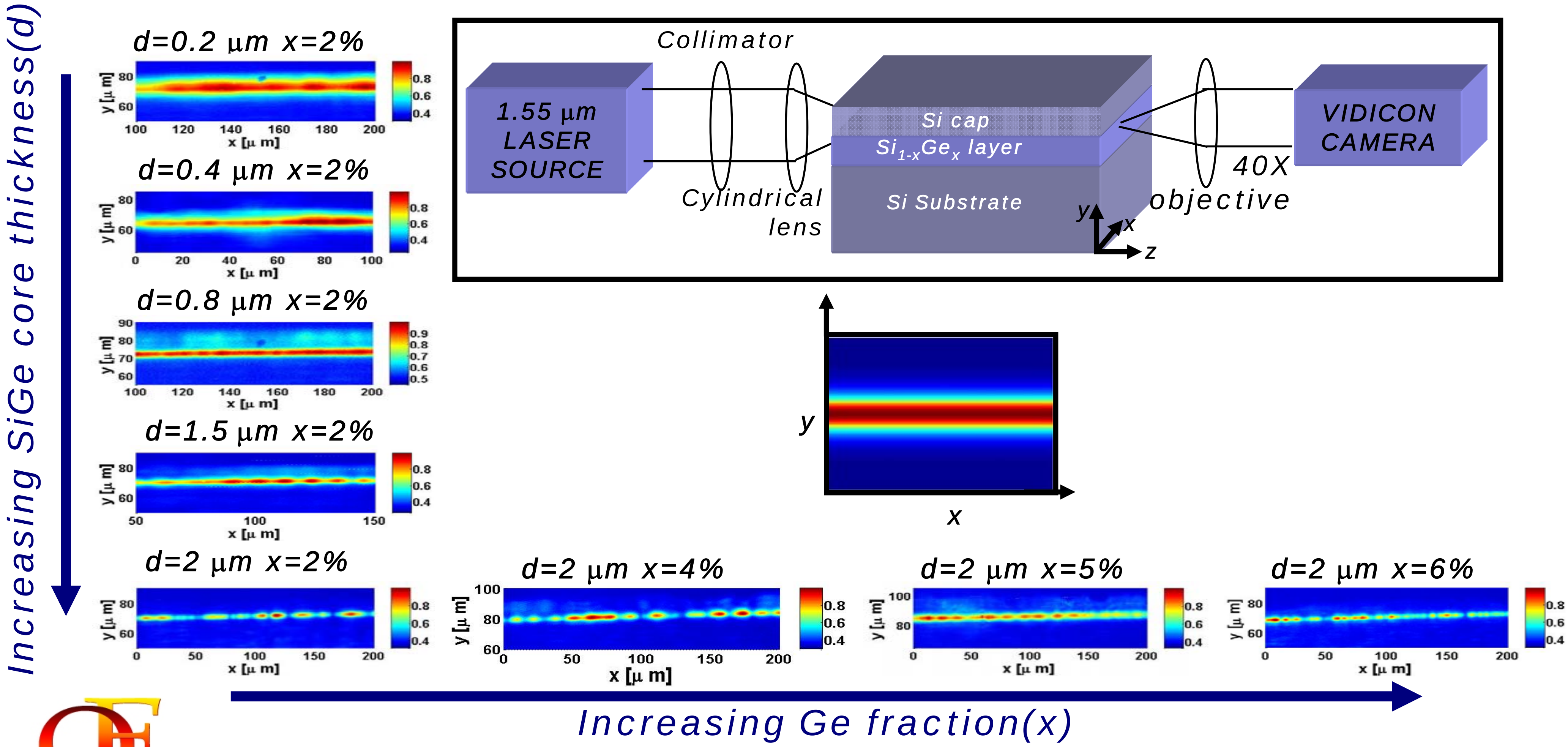


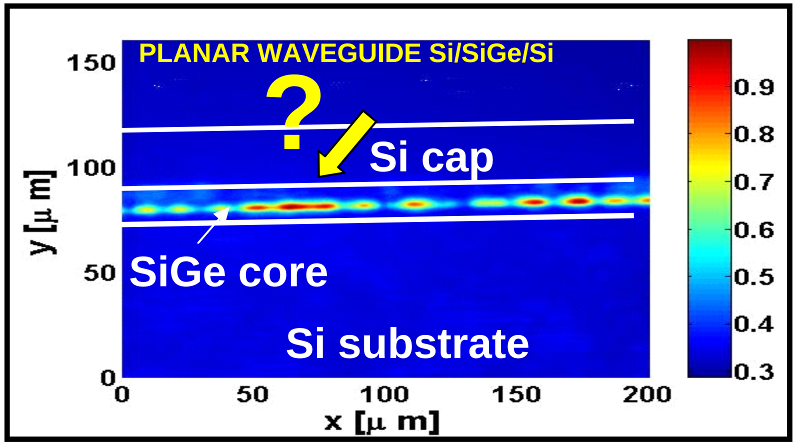
Dislocations in SiGe planar waveguides

Consequences on the guided optical field



Dislocations in SiGe planar waveguides

Consequences on the guided optical field

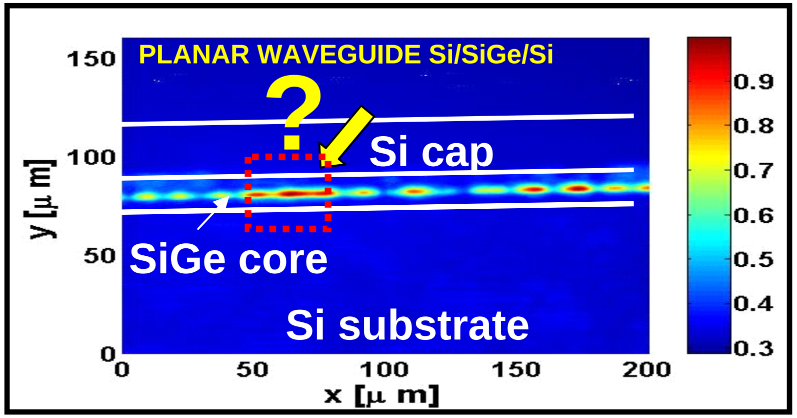


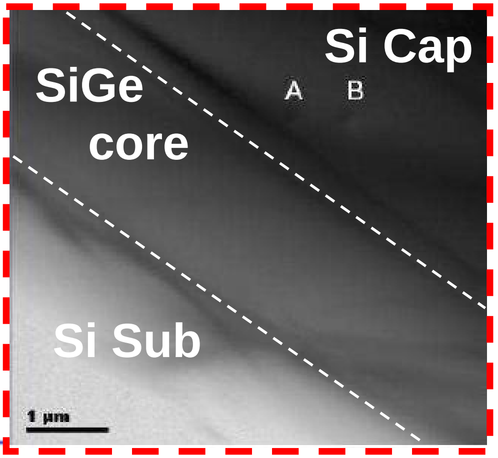
- Experimental results indicate that the refractive index inside the waveguides presents sharp localized variations
- The origin of these sharp refractive index variations can be ascribed to the presence of dislocations
- Dislocations are organized in bunches so that refractive index variations occur over a spatial scale comparable with λ

Dislocations in SiGe planar waveguides

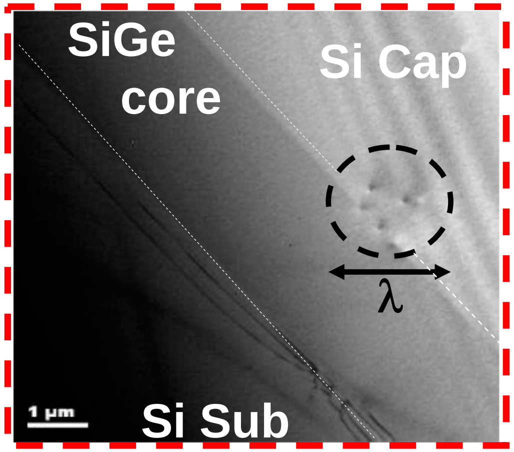
Consequences on the guided optical field

➢**Transmission Electron Microscope (TEM) at EMEZ (*Electron Microscopy centre of the ETH Zurich*)**

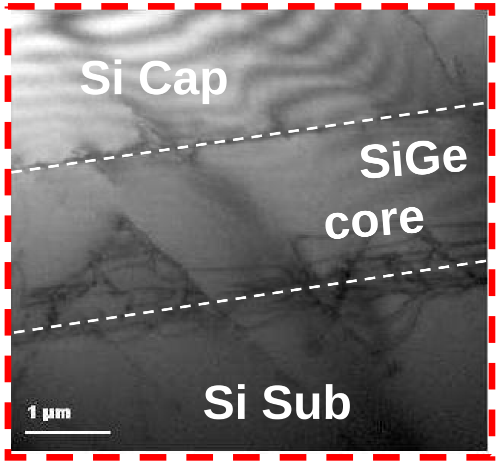




d=0.4 μm x=2%



d=2 μm x=2%

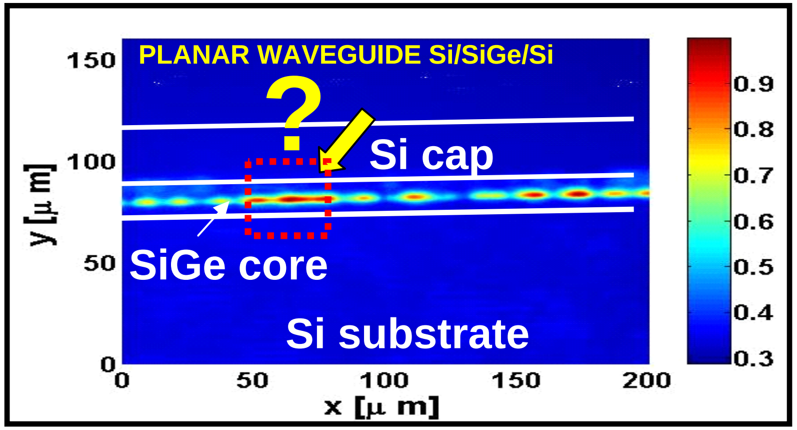


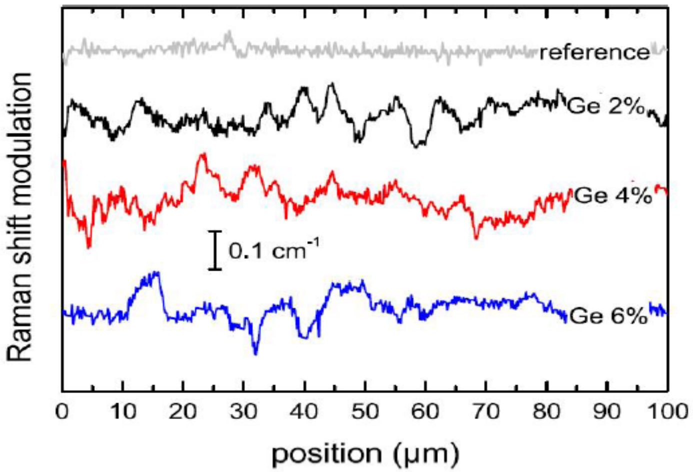
d=2 μm x=6%

Dislocations in SiGe planar waveguides

Consequences on the guided optical field

➢**Raman micro-spectroscopy at the University of Milano Bicocca**





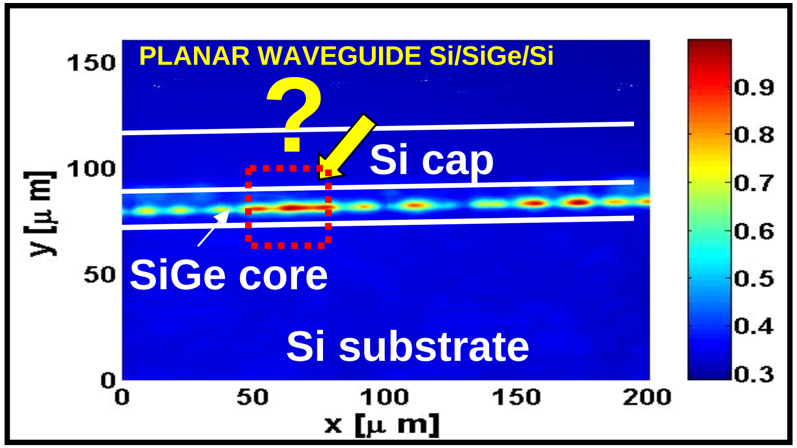
$|\varepsilon|=10^{-4}$

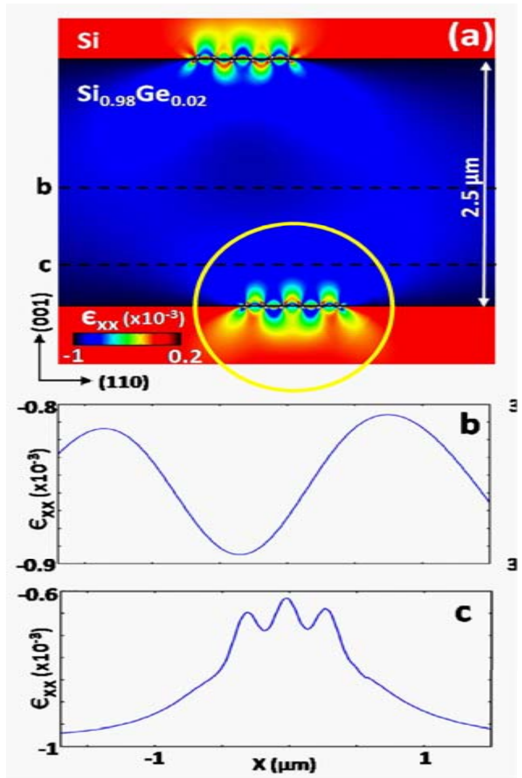
Dislocations in SiGe planar waveguides

Consequences on the guided optical field

➢**Finite Element Method (FEM) opto-structural model of the waveguide. (University of Pavia-University of Milano Bicocca)**

The strain field due to the bunches of dislocations is evaluated analitically and inserted in the FEM model





Strain field

Dislocations in SiGe planar waveguides

consequences on the guided optical field

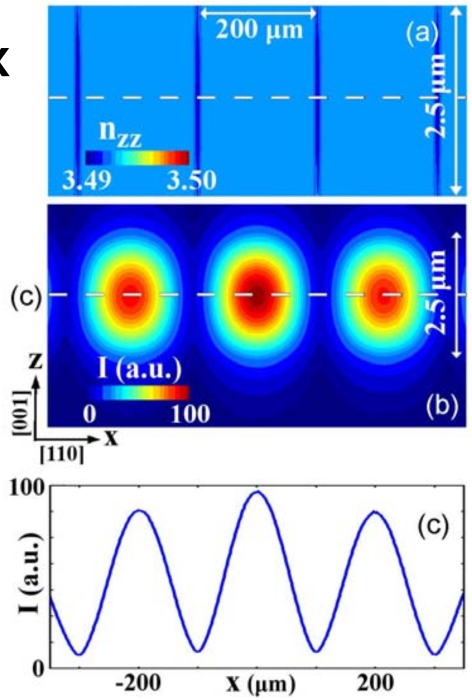
➢**Finite Element Method (FEM) opto-structural model of the waveguide.(University of Pavia-University of Milano Bicocca)**

The strain field is converted into a refractive index distribution through the elasto-optic tensor and optical modes supported by the structure are evaluated

Refractive index distribution(n_{zz})

Optical modes Intensity

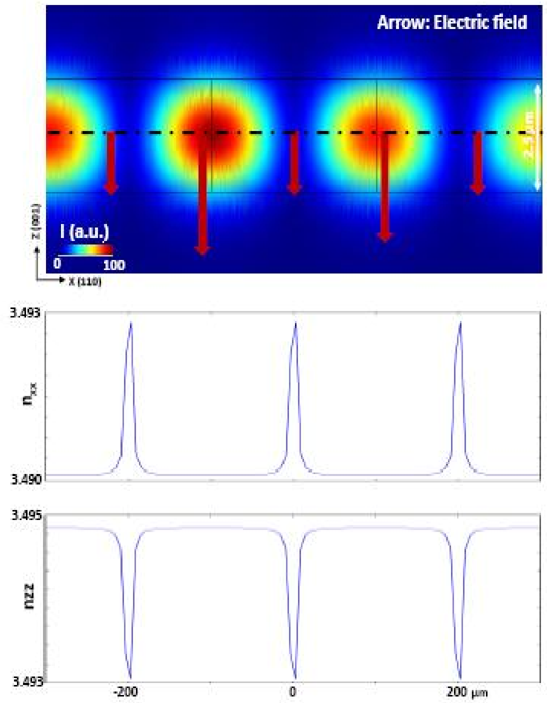
Optical modes Intensity (section)



Optical modes Electric Field

Refractive index distribution(n_{xx})

Refractive index distribution(n_{zz})



Dislocations in SiGe/Si planar waveguides

consequences on the guided optical field

Experimentally (optical characterization, TEM, Micro-raman) and theoretically (FEM model), it has been shown that:

- **Bunches of dislocations**

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consequences on the guided optical field

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- **Bunches of dislocations**
- **Sharp localized perturbations to the strain fields**

QE Lab

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consequences on the guided optical field

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- **Bunches of dislocations**
- **Sharp localized perturbations to the strain fields**
- **Sharp localized perturbation to the refractive index**

Dislocations in SiGe/Si planar waveguides

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Experimentally (optical characterization, TEM, Micro-raman) and theoretically (FEM model), it has been shown that:

- **Bunches of dislocations**
- **Sharp localized perturbations to the strain fields**
- **Sharp localized perturbation to the refractive index**
- **Detectable output intensity perturbation**

andrea.trita@unipv.it