Modeling of an Edge-Emitting strained-Ge laser

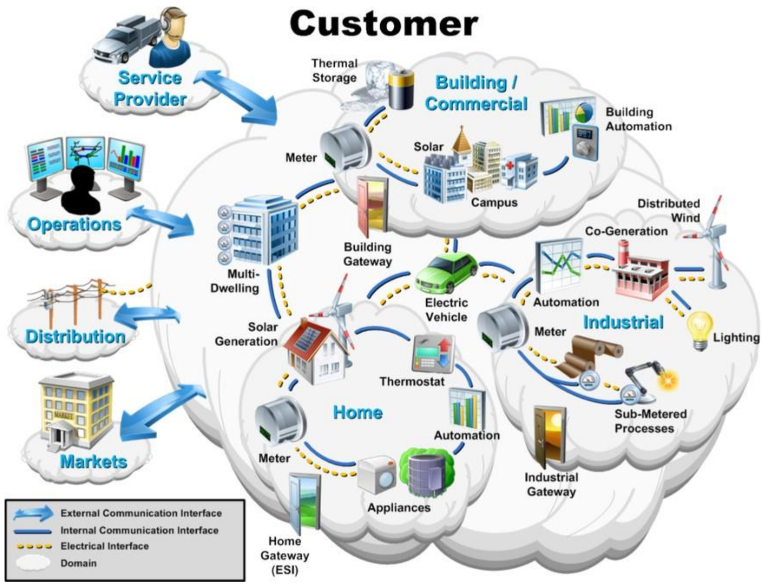
G. Capellini, M. Virgilio, Y. Yamamoto, L. Zimmermann, B. Tillack, D. Peschka, M. Thomas, A. Glitzky, R. Nürnberg, K. Gärtner, Th. Koprucki, and T. Schroeder

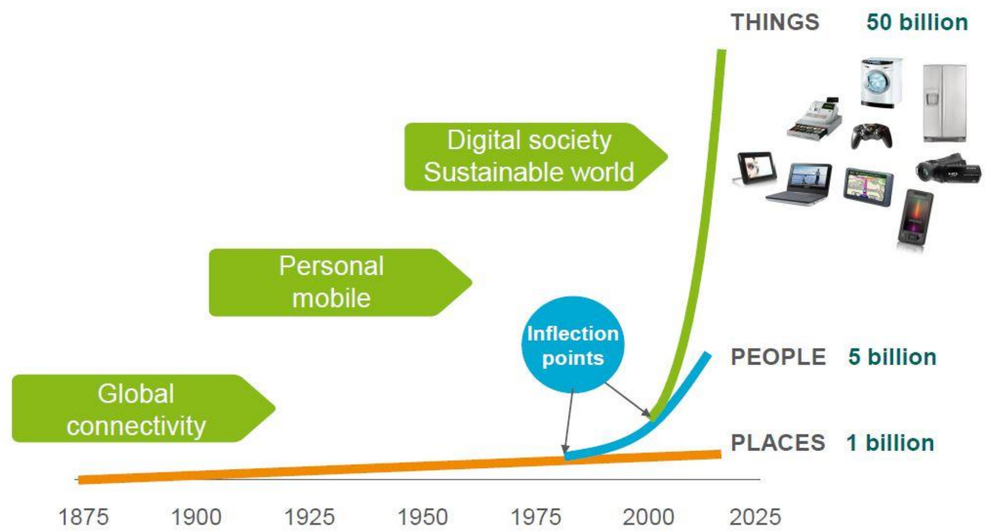
January 27th 2016
MMSDays 2016

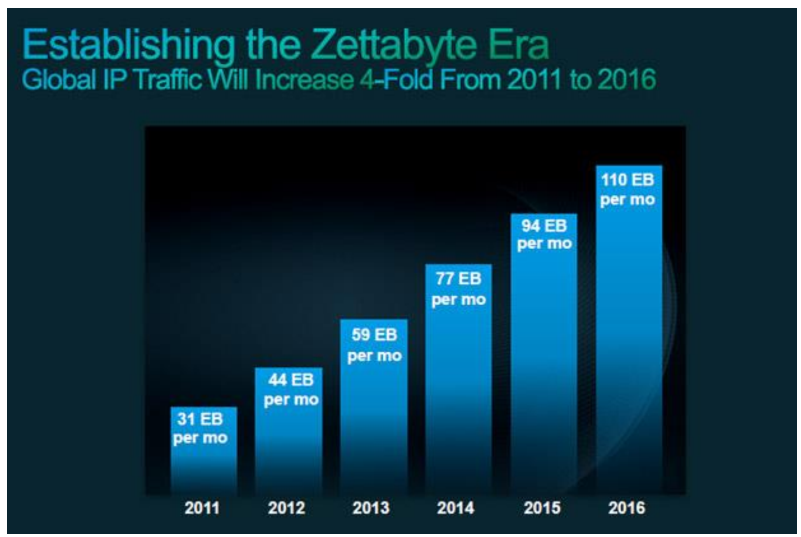
innovations for high performance microelectronics

Member of Leibniz Association

Motivation: the connected world





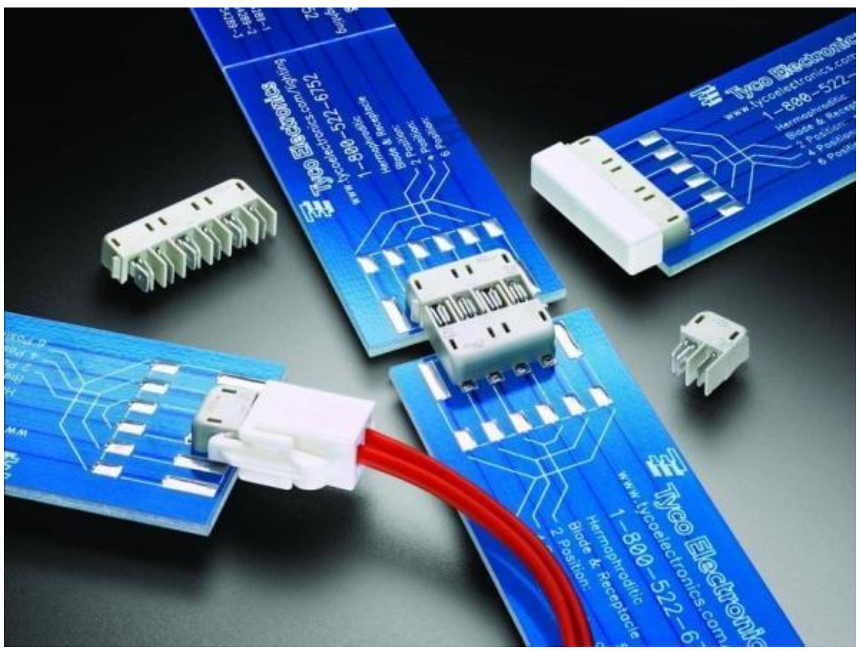


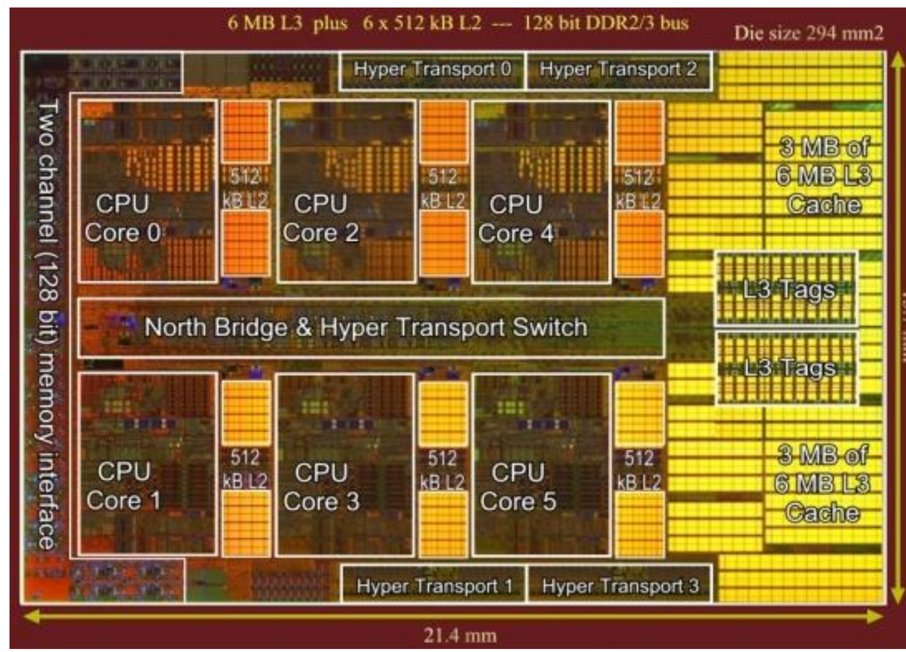
 | © 2014 - All rights reserved

Motivation: bandwidth, bandwidth, and banwidth

More bandwidth and lower power consumption needed at all scales:

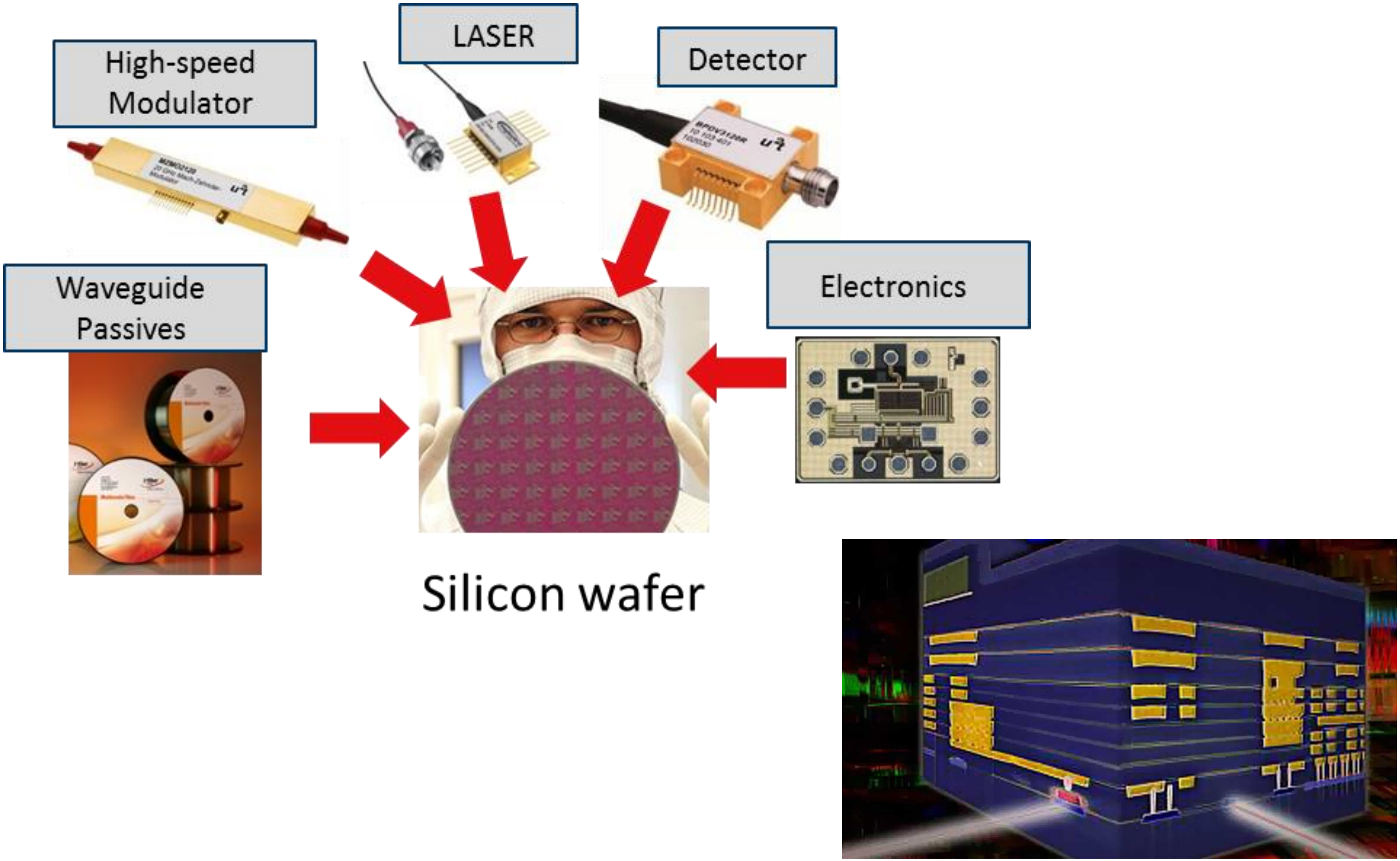
- **Rack-to-Rack**
- **Board-to-Board**
- **Chip-to-Chip**





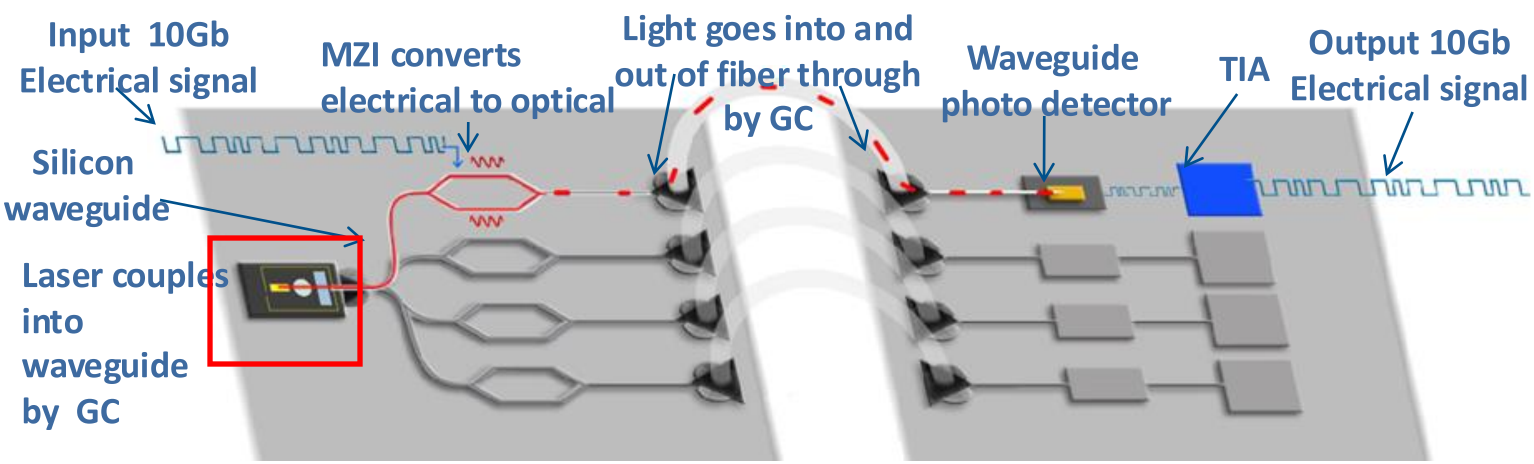
© 2014 - All rights reserved

Bringing light to the chip: a More-than-Moore solution



 © 2014 - All rights reserved

Light on chip: Laser is the Holy Grail

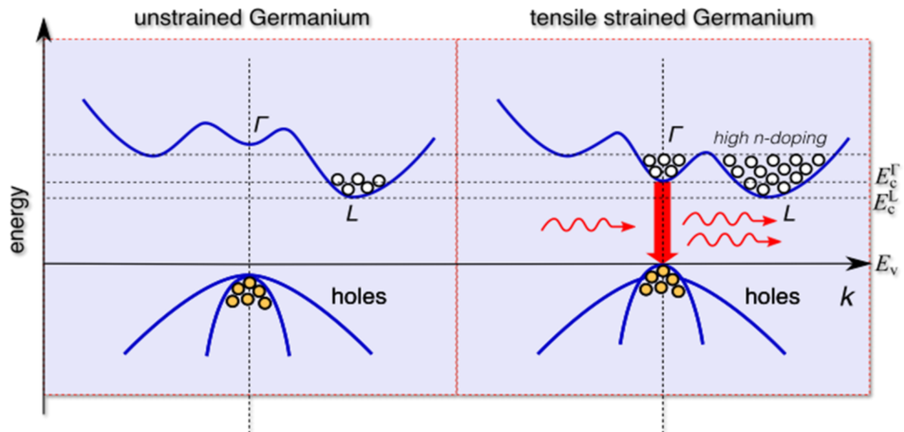


Integrated laser is the only missing piece: a Ge Laser?

 © 2014 - All rights reserved

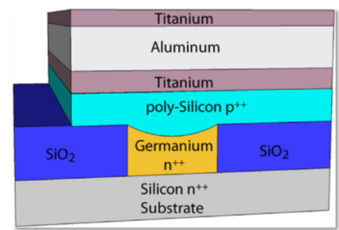
Ge-Laser

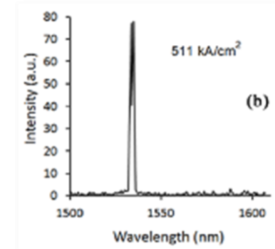
TOWARDS A LASER MONOLITHICALLY INTEGRATED IN THE SILICON PHOTONICS: how to turn a group IV semiconductor in a direct band gap material



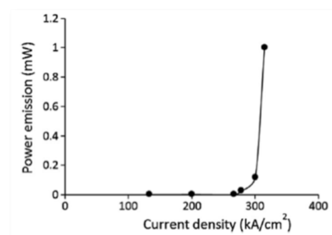
- **TENSILE STRAIN**
- **ULTRA-HIGH n DOPING (difficult in Ge)**
- **ALLOYING WITH Sn**

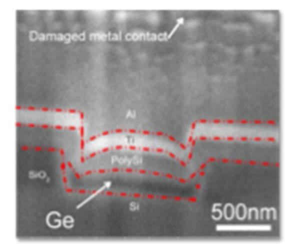
OK: INTEGRABLE, EMISSION DEMONSTRATED





KO: LARGE I_{th}, LIMITED DEVICE LIFETIME





RT Electrically pumped Ge laser

Camacho-Aguilera (MIT), 2012 : ϵ_{bi}=0.2% I_{th}~ 300kA/cm^2 W_{out}<1mW λ~1.6-1.7 µm n_{dop}~4x10^{19}cm^{-3}

Koerner (IHT), 2015: ϵ_{bi}<0.2% I_{th}~ 500kA/cm^2 W_{out}<1mW λ~1.66-1.7 µm n_{dop}~3x10^{19}cm^{-3}

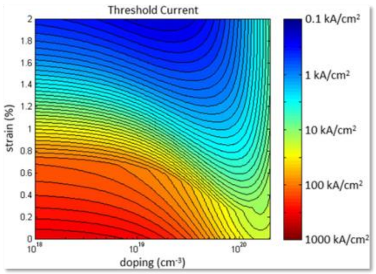
T=80K Optically pumped GeSn laser

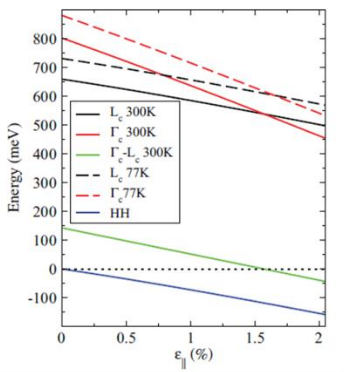
Wirths (FZ-Juelich), 2015 : xSn= 0.13 ϵ_{bi}=-0.7% P_{th}~ 325kW/cm^2 W_{out}= NA (gain ~100cm^{-1}) λ~2.25 µm

© 2014 - All rights reserved

Ge-Laser

B. Dutt et al., IEEE Photon. J. 4, (2012)





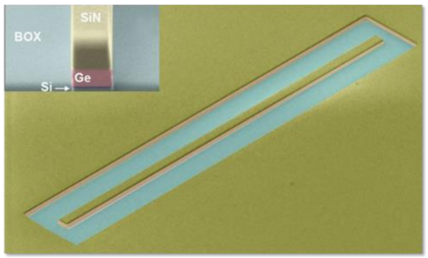
M. Virgilio et al., Phys.Rev. B 87, 235313 (2013)

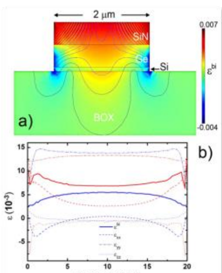
 | © 2014 - All rights reserved

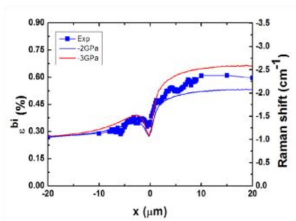
Modeling strategy

FROM MATERIAL PROPERTIES TO FULL 2D OPTOELECTRONIC SIMULATIONS: UPSCALING

MATERIAL FABRICATION AND FEM OF THE ELASTIC PROPERTIES. EXPERIMENTAL VERIFICATION





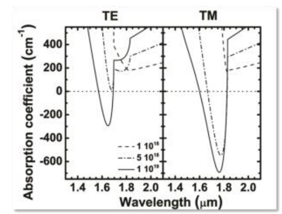


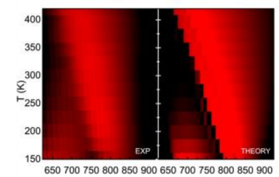
G. Capellini et al., Optics Express 22, 399 (2014)
G. Capellini et al., J. Appl. Phys. 113, 013513 (2013)

STRAIN FIELD

QUANTUM MODELING OF THE ELECTRONIC PROPERTIES (TB). EXPERIMENTAL VERIFICATION

- Multi-valley effective mass and deformation potential theory
- Direct and indirect recombination from Fermi golden rule
- Spatially resolved excess carrier distribution (Surface, Auger, and SRH recombination, doping and carrier diffusion)
- Strain effect on the dipole matrix elements
- Spatially resolved self-absorption effects to relate $R_{int}(\omega)$ to external PL





OPTICAL PROPERTIES

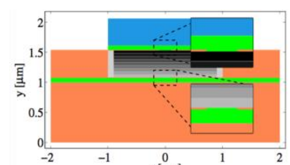
FULL 2D OPTOELECTRONIC SIMULATIONS

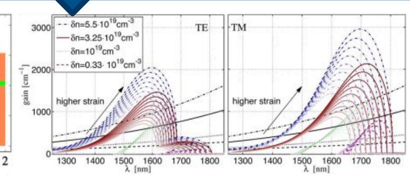
INPUT IN WIAS TeSCA:

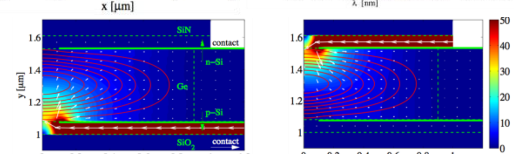
- Device 2D geometry including doping. FB cavity with or w/o aperture
- Spatially-resolved spectral gain as a function of carrier density, strain, and polarization

Calculation includes

- the van Roosbroeck system
- the Helmholtz equations for the transverse optical field
- the balance equations for the corresponding photon numbers

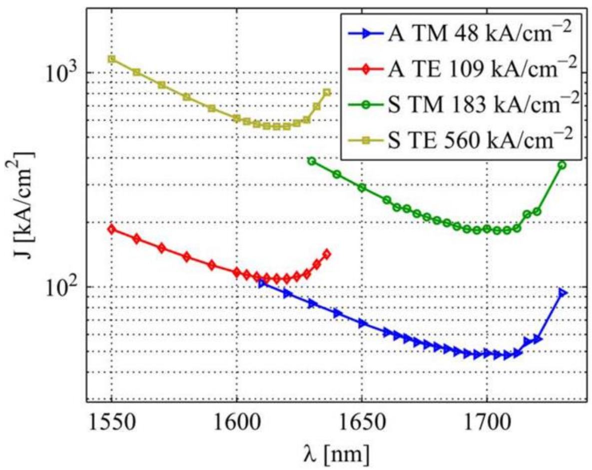


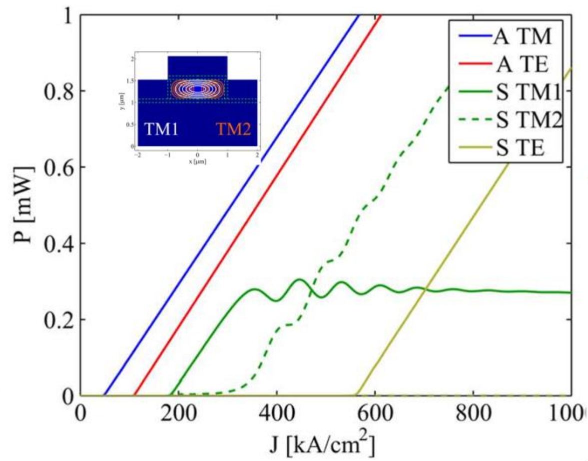


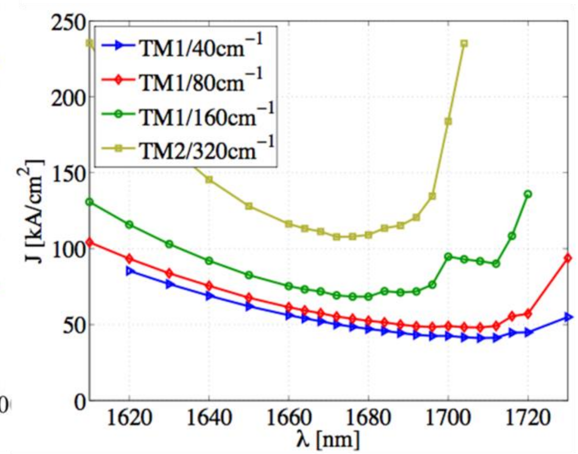


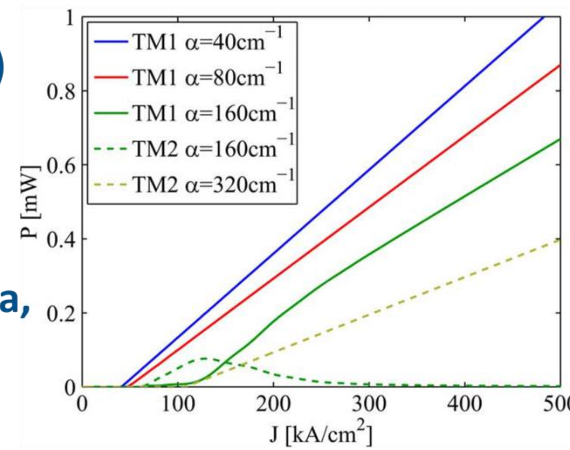
© 2014 - All rights reserved

Results and Outlook



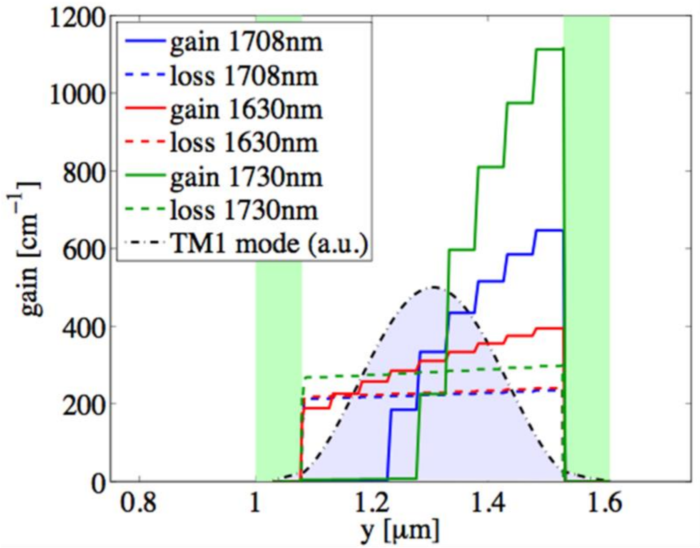


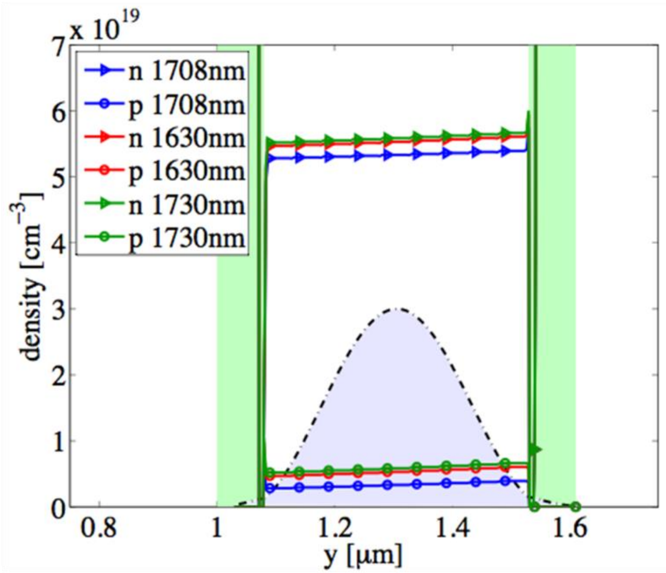




- TM PREFERRED OVER TE (higher gain due to LH-HH splitting)
- APERTURE INJECTION REDUCES THRESHOLD BY 4×
- EMISSION POWER IN THE mW RANGE AT 30 mA
- BLUE SHIFTED EMISSION FOR HIGHER LOSSES (wg, mirror, fca, etc. Agrees with MIT)
- SWITCHING TO TM2 AT HIGHER LOSSES

Results and Outlook





INHOMOGENEOUS STRAIN DISTRIBUTION

SPATIALLY-DEPENDENT GAIN

MATERIAL GAIN

≠

MODAL GAIN

OVERLAP ENGINEERING

Thank you for your attention!

Giovanni Capellini

IHP – Innovations for High Performance Microelectronics
Im Technologiepark 25
15236 Frankfurt (Oder)
Germany
Phone: +49 (0) 335 5625 317
Fax: +49 (0) 335 5625 681
Email: capellini@ihp-microelectronics.com

www.ihp-microelectronics.com

innovations
for high
performance
microelectronics

Member of
Leibniz Association