

Theory of Gain in a Ge-on-Si Laser

SAND2012-8821P

Weng Chow, *Sandia National Laboratories, Albuquerque, NM, USA*

Experiment

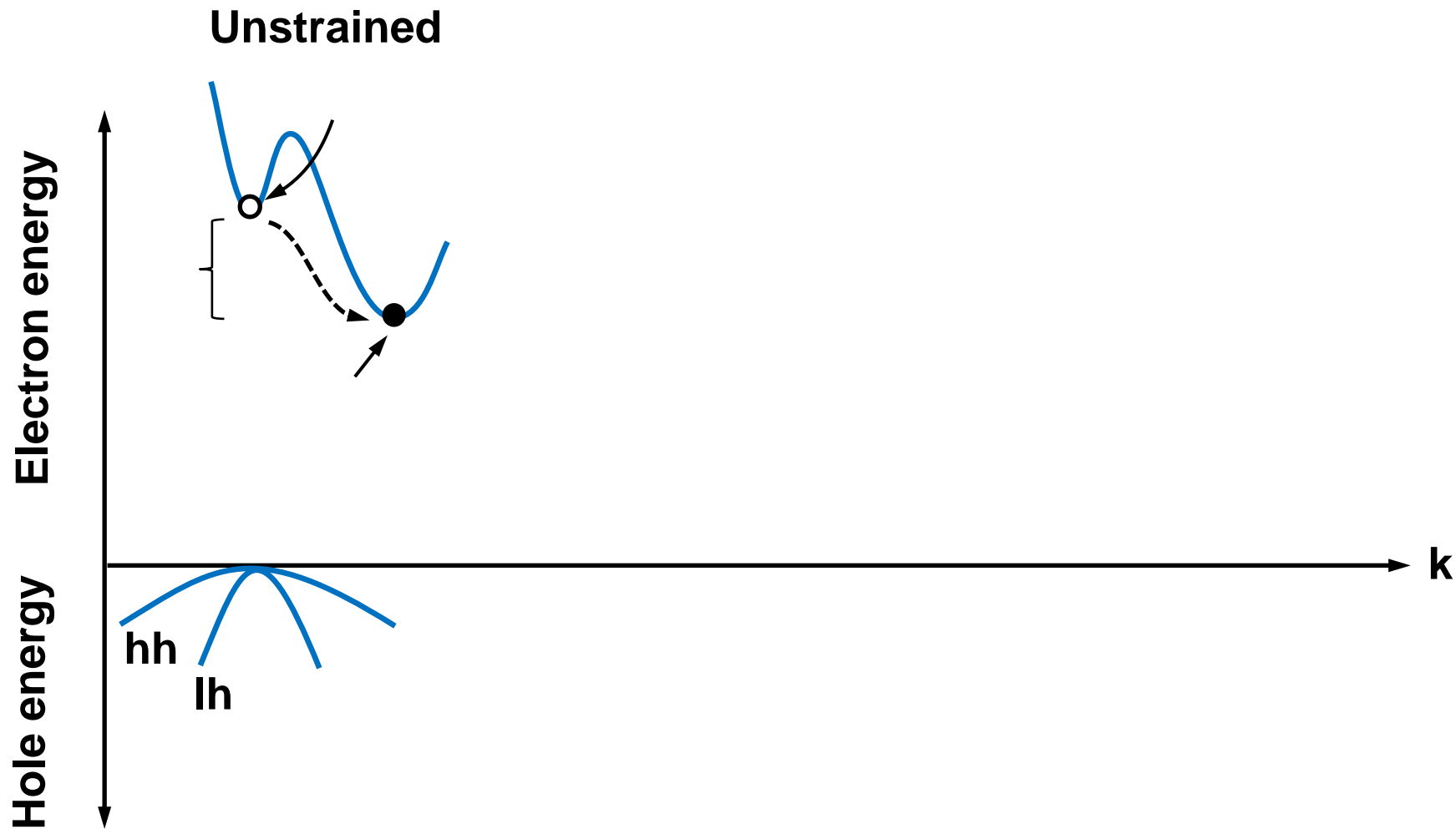
Laser model

Results -- Required current vs. desired gain
for different strain and doping densities

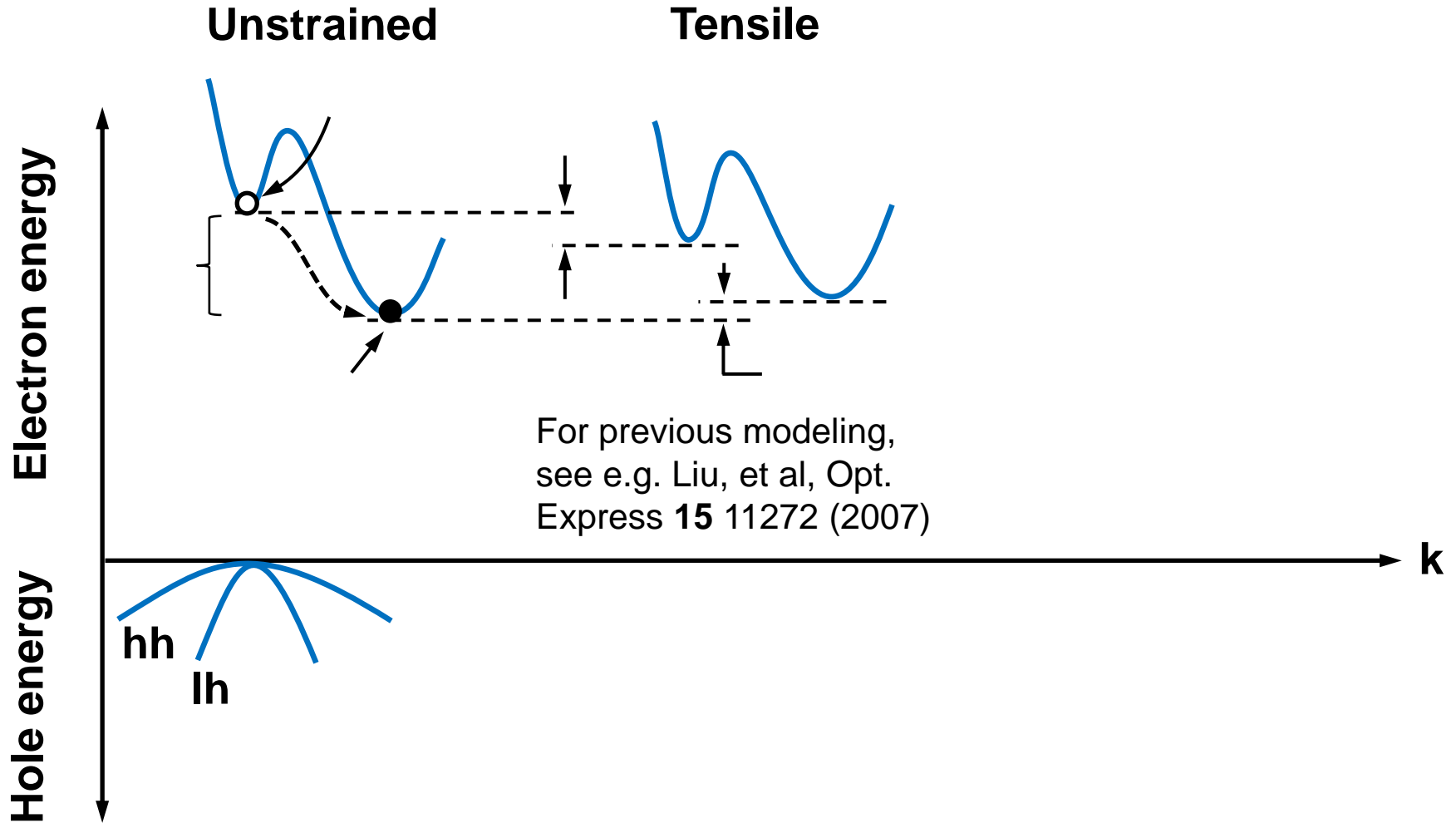
Summary

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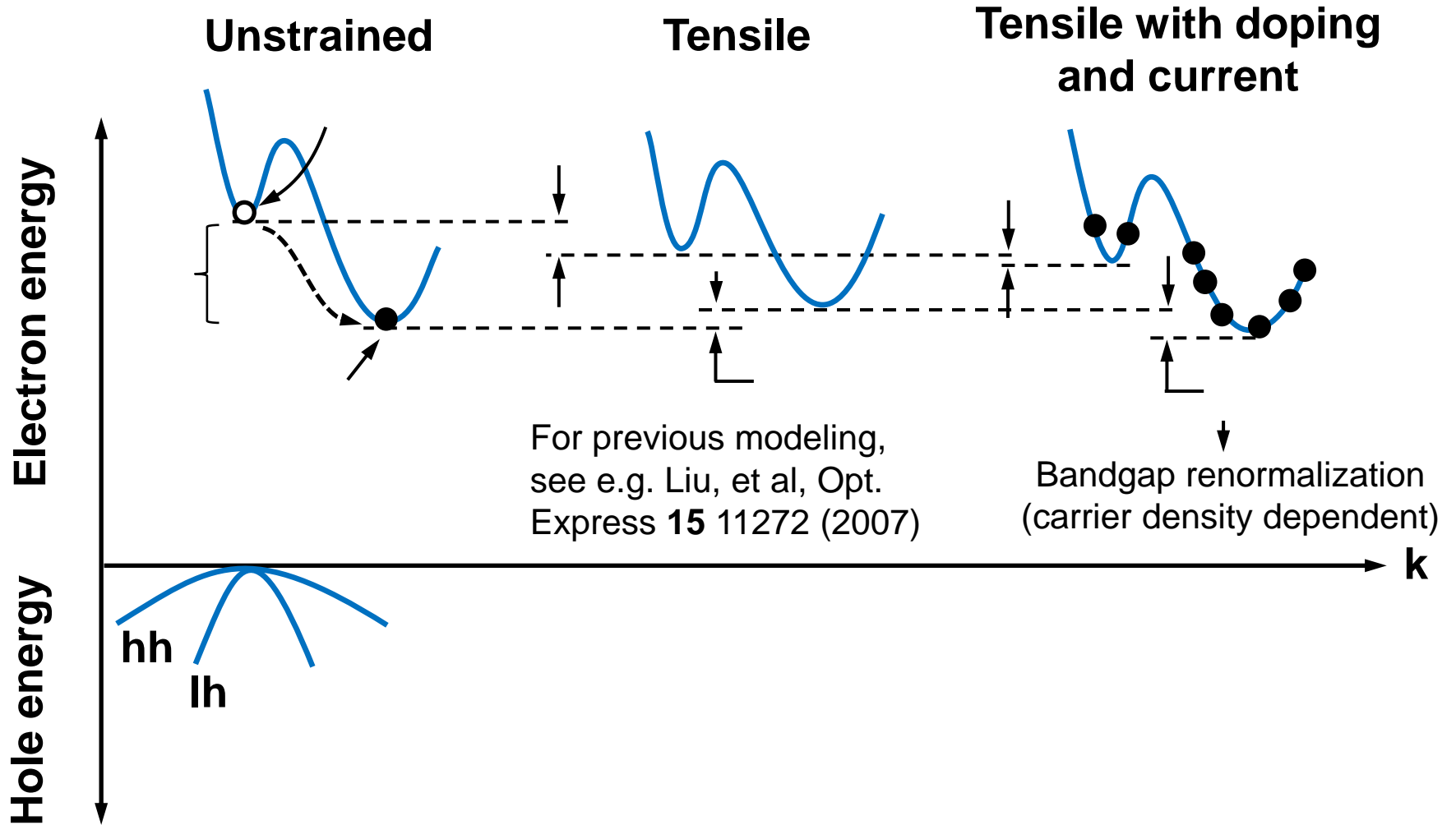
Effects of strain and doping on Ge



Effects of strain and doping on Ge



Effects of strain and doping on Ge



Hamiltonian: H = Single-particle energy + Light-matter interaction + Coulomb interaction

Laser field

Bandstructure

Hamiltonian

— []

Hartee-Fock

Collisions

+



Non-radiative factors

Free-carrier absorption

Defect losses

Auger scattering, ...

+

Gain and spontaneous emission spectra

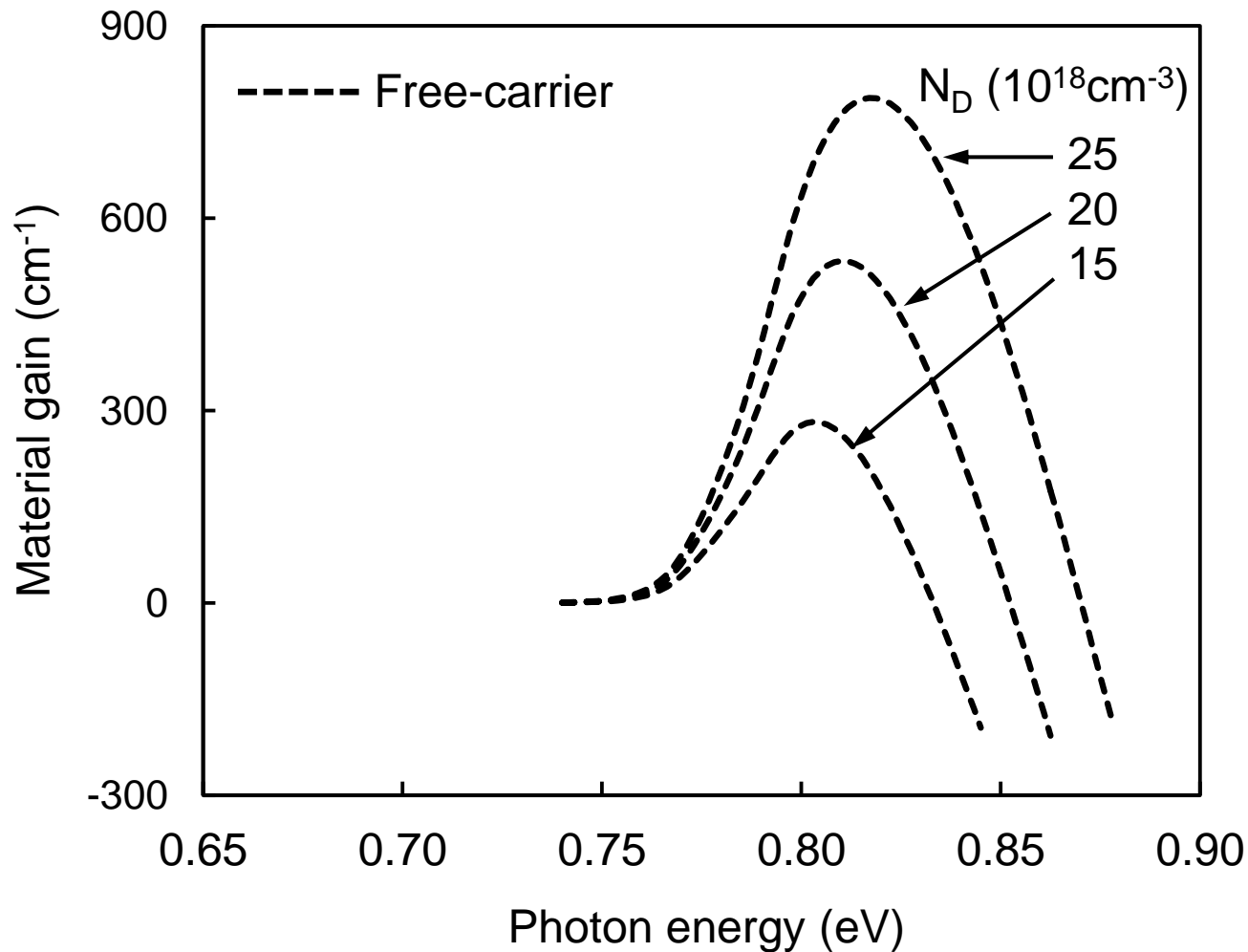
Desired gain

Required current density

Different strains and n-doping densities

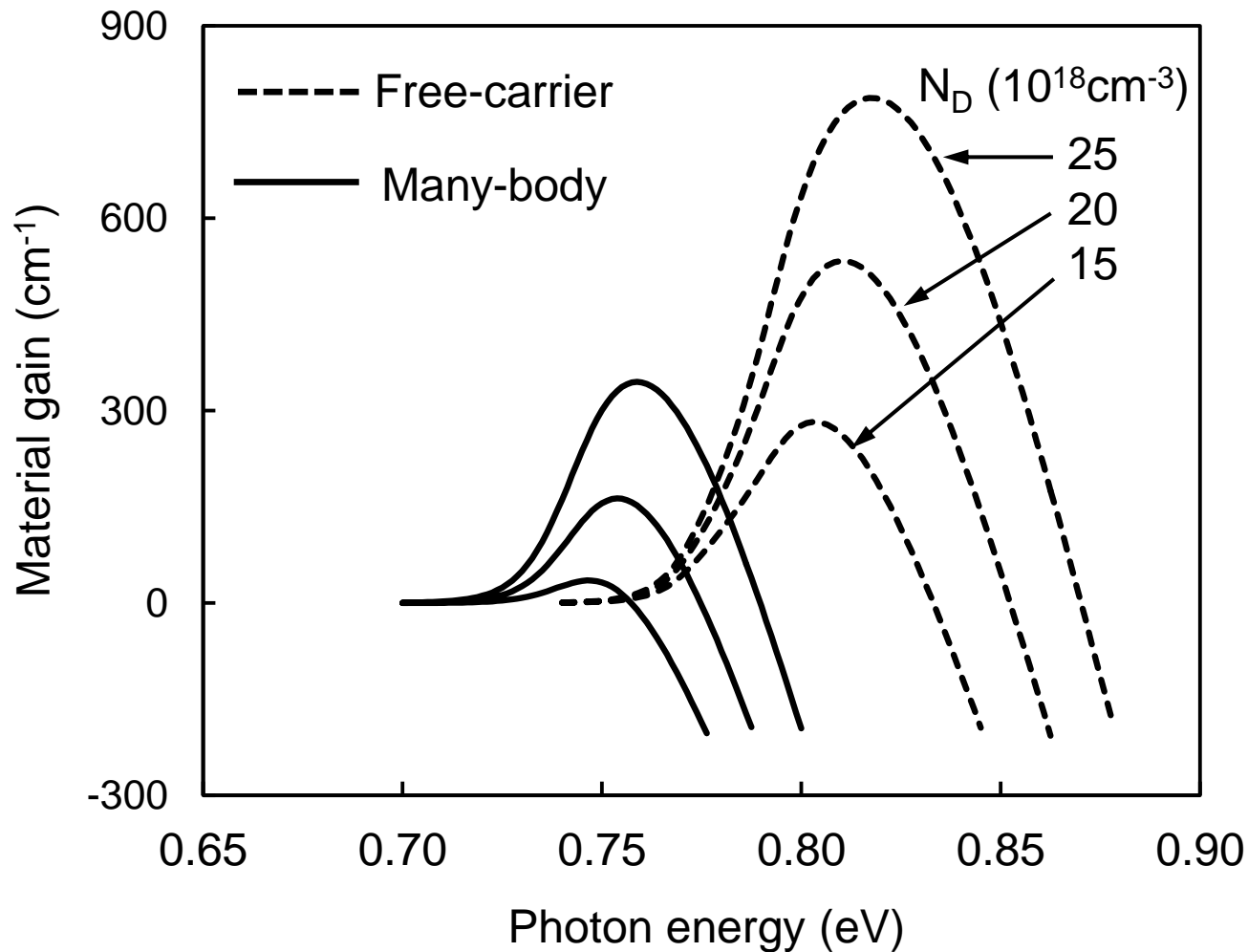
Coulomb-interaction correlations

Gain spectrum



$T = 300\text{K}$, 0.2% tensile strain, $\gamma = 10^{13}\text{s}^{-1}$, $N_I = 8 \times 10^{18}\text{cm}^{-3}$

Gain spectrum



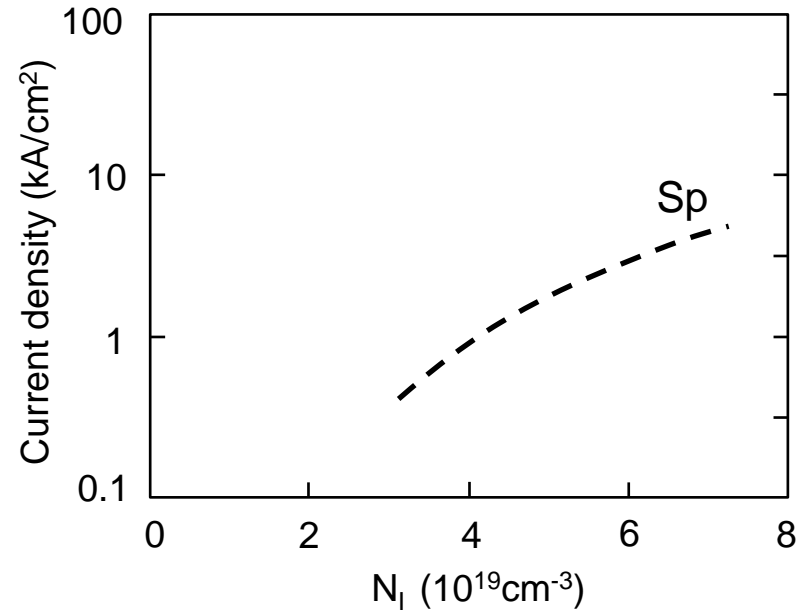
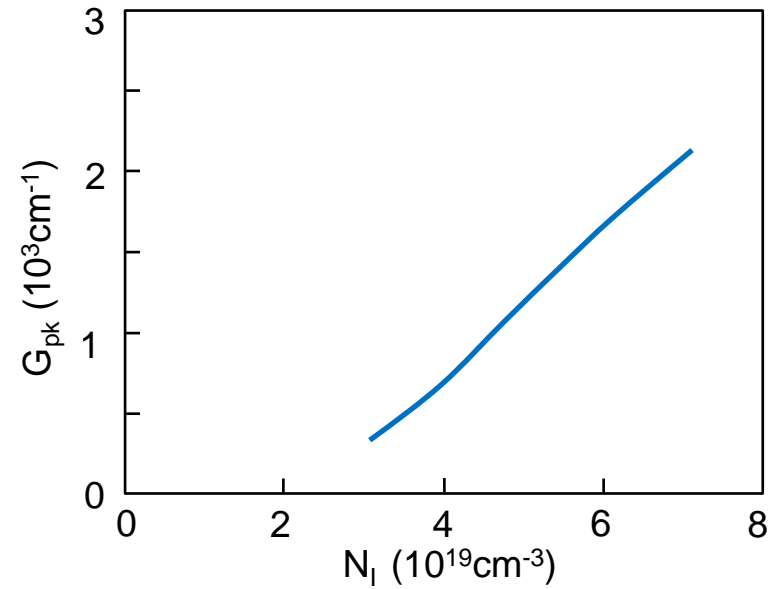
$T = 300\text{K}$, 0.2% tensile strain, $\gamma = 10^{13}\text{s}^{-1}$, $N_I = 8 \times 10^{18}\text{cm}^{-3}$

From gain spectrum:

- 1) Peak gain versus injected carrier density
- 2) Spontaneous emission contribution to current density:

$$- \left(- \right) \quad \frac{ \left(\right) }{ \quad }$$

Unstrained, undoped



From gain spectrum:

- 1) Peak gain versus injected carrier density
- 2) Spontaneous emission contribution to current density:

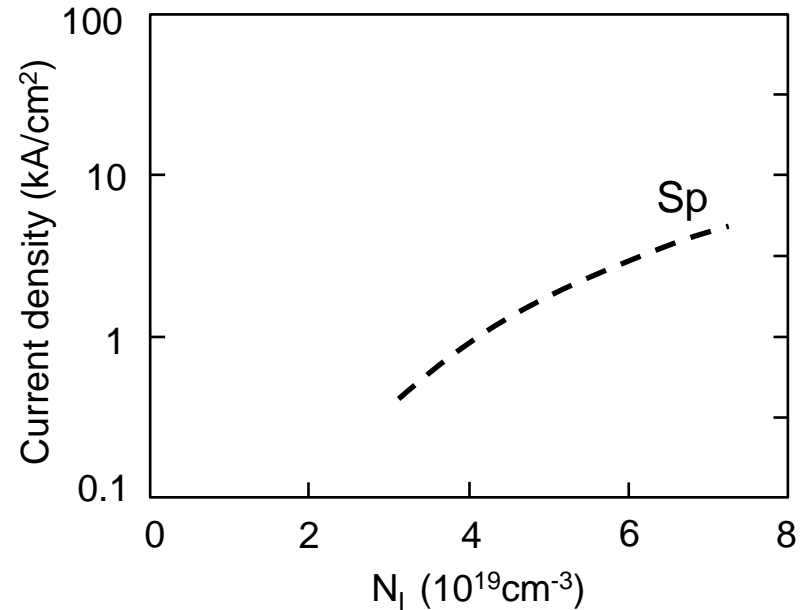
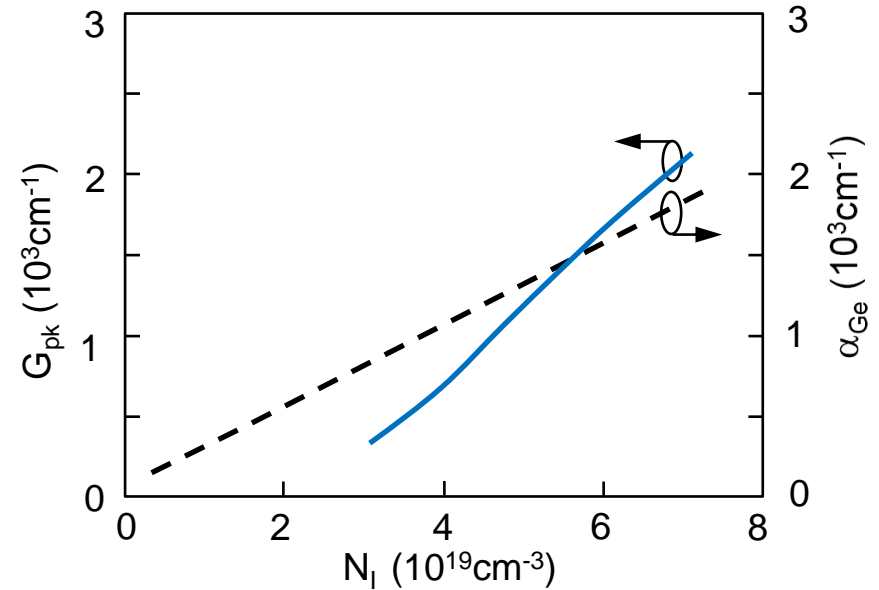
$$- \left(- \right) \qquad \frac{ \left(\right) }{ \quad }$$

Free-carrier absorption:

$$\left(\quad \right)$$

Net (available) gain:

Unstrained, undoped



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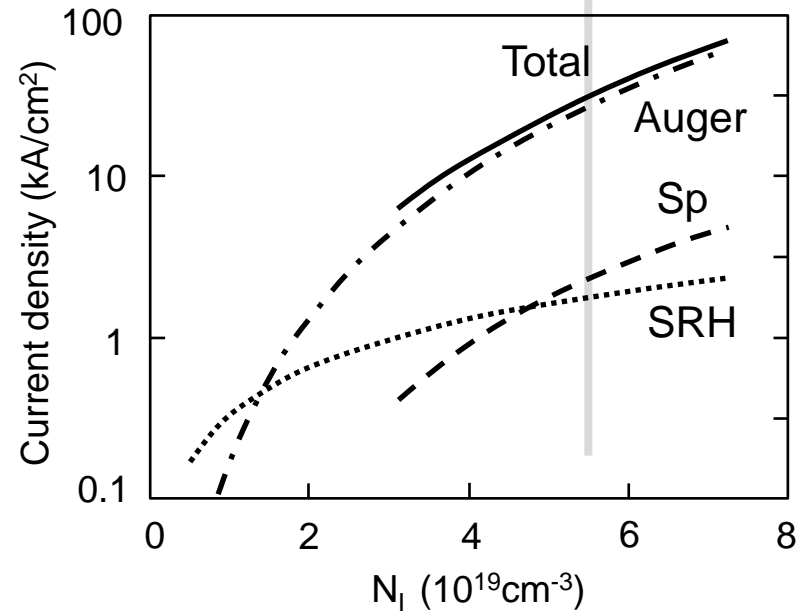
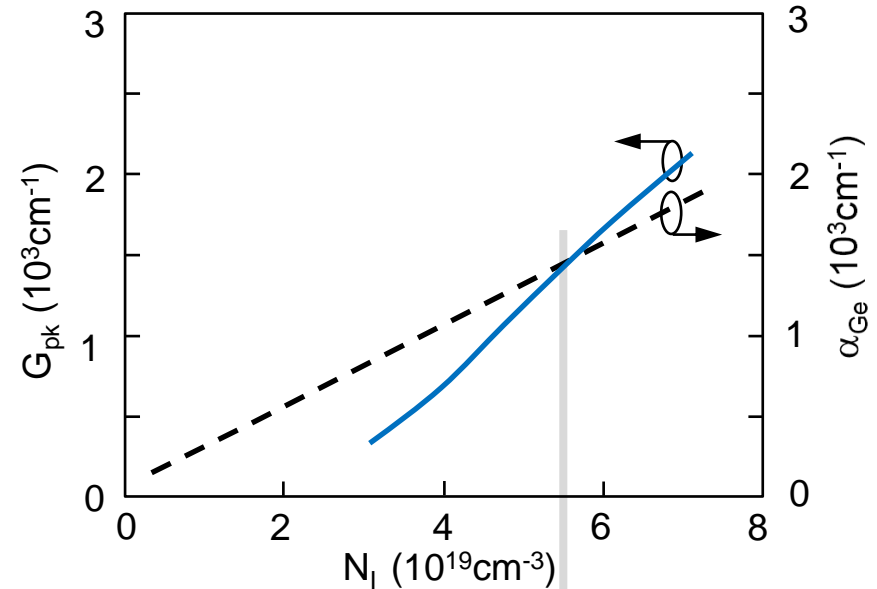
Non-radiative contributions to current density:

Defect (Shockley-Read-Hall) loss
Auger scattering

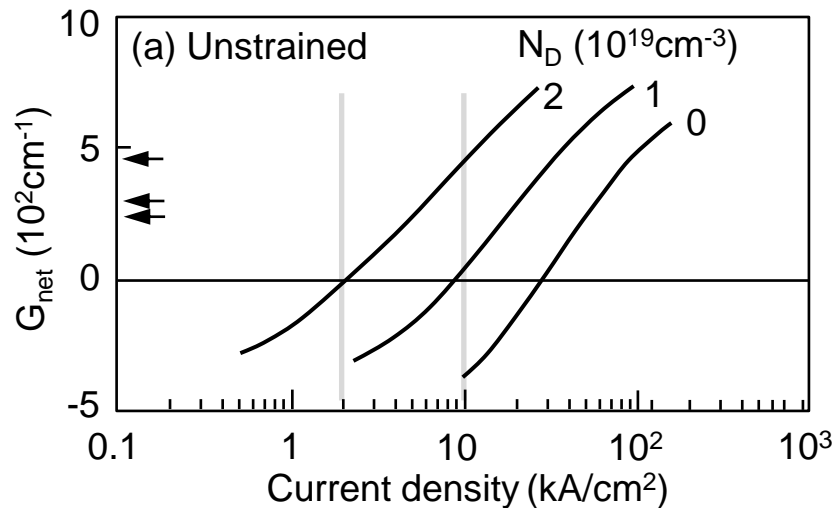
Total current density:

$$(\quad)$$

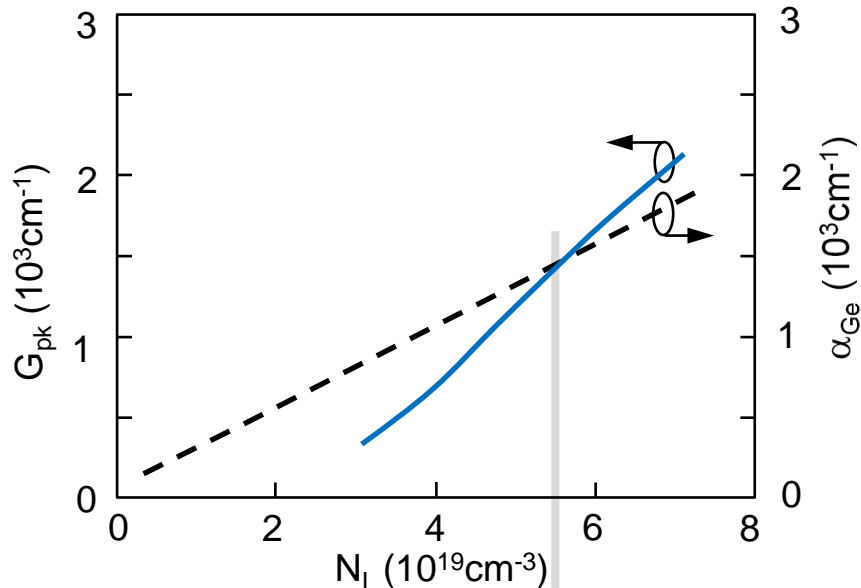
Unstrained, undoped



$$\gamma_{SRH} = 10^7 \text{s}^{-1} \quad C = 5 \times 10^{-32} \text{cm}^6 \text{s}^{-1}$$



Unstrained, undoped

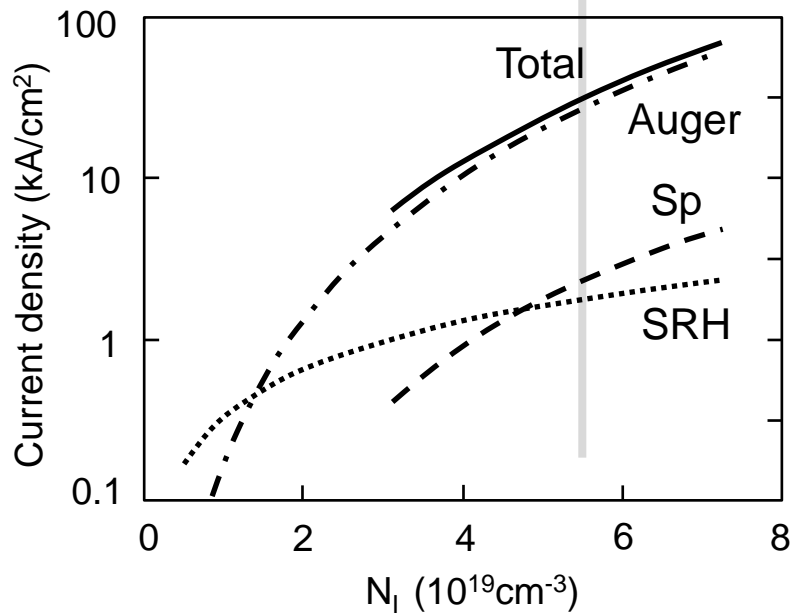


Required threshold gain

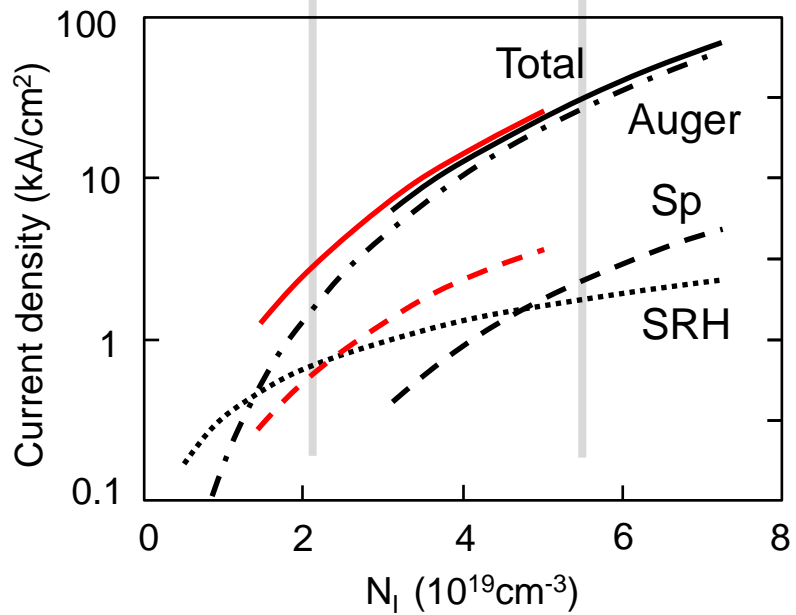
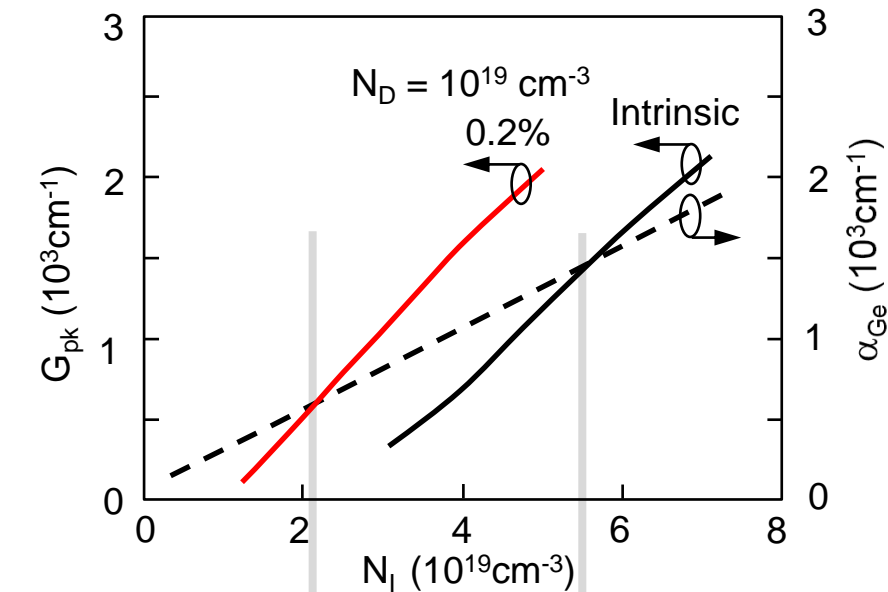
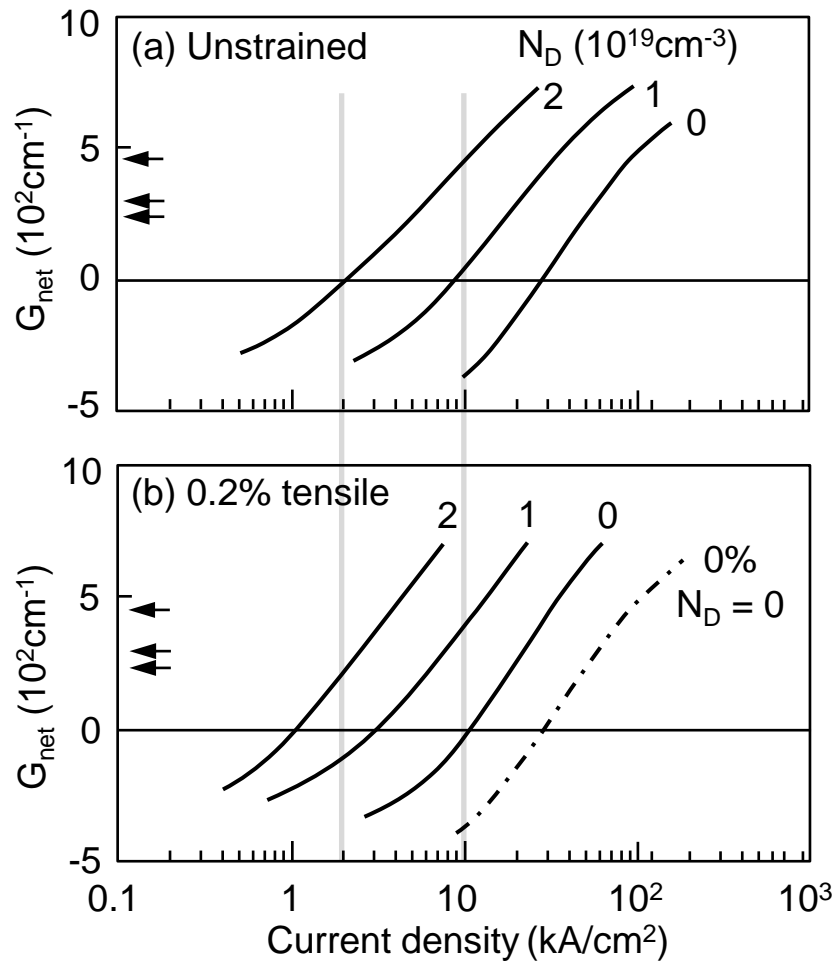
[()]

Uncoated facets, $\Gamma = 0.4$

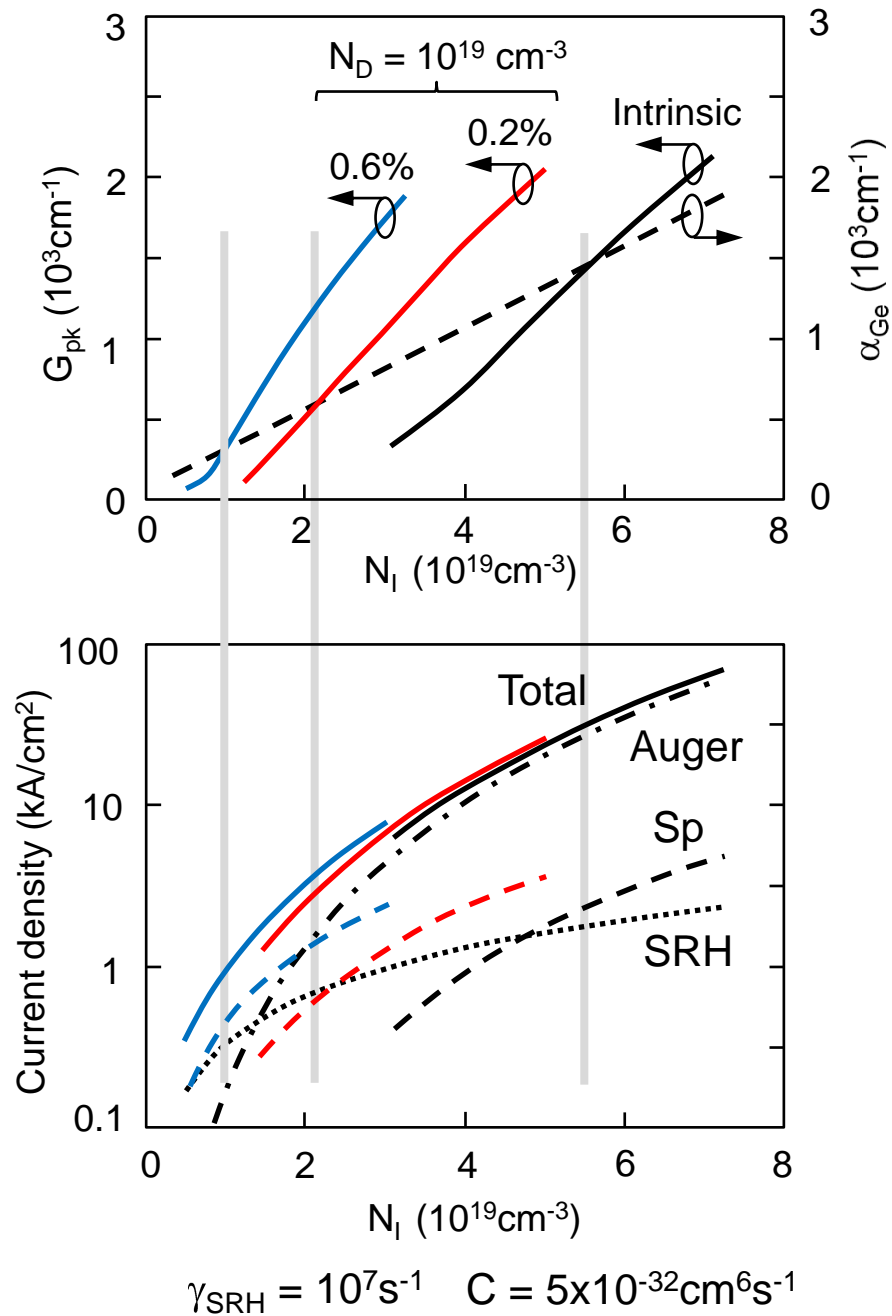
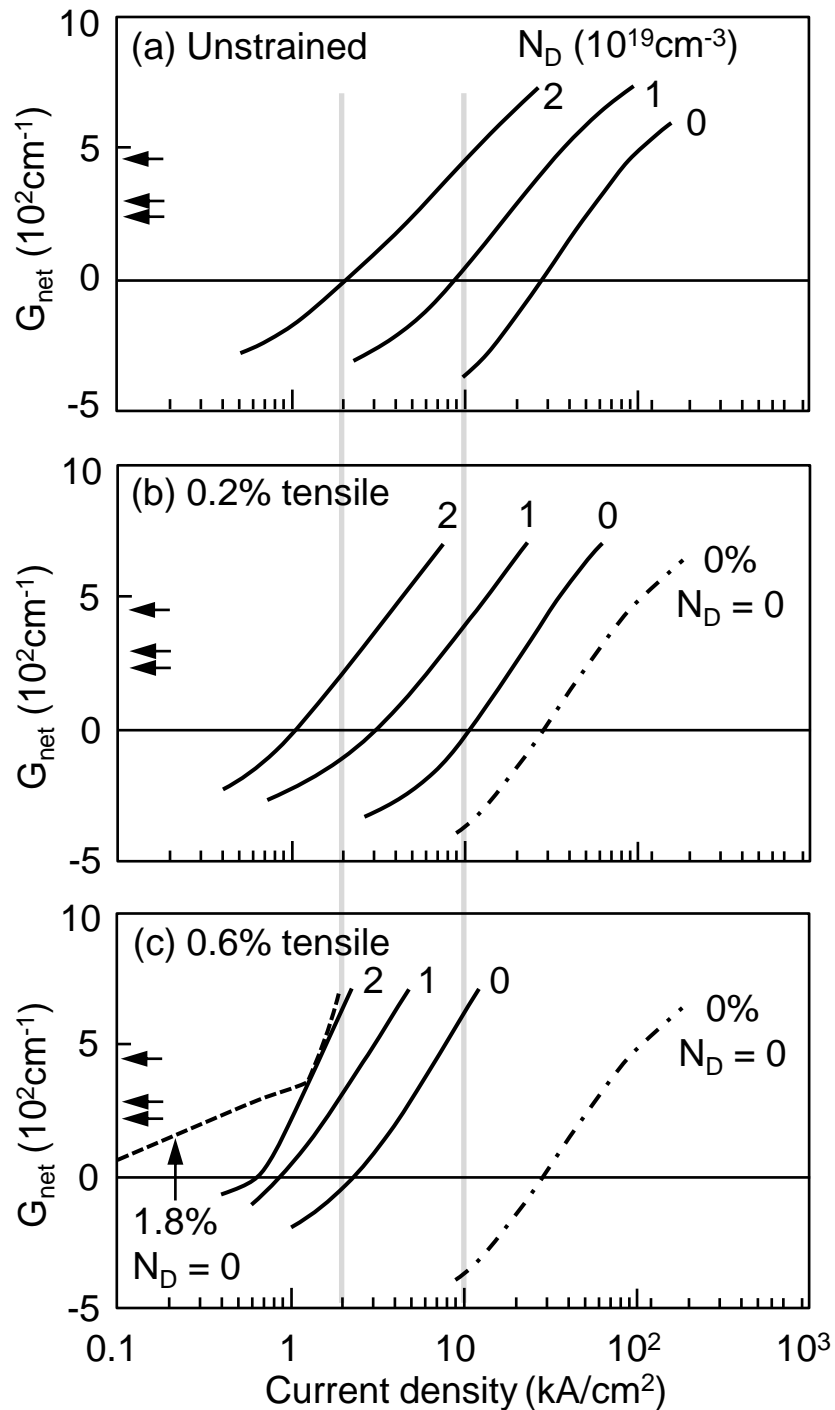
L	G_{net}
1mm	135cm^{-1}
$500\mu\text{m}$	291cm^{-1}
$200\mu\text{m}$	457cm^{-1}



$$\gamma_{\text{SRH}} = 10^7\text{s}^{-1} \quad C = 5 \times 10^{-32}\text{cm}^6\text{s}^{-1}$$



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Loose ends

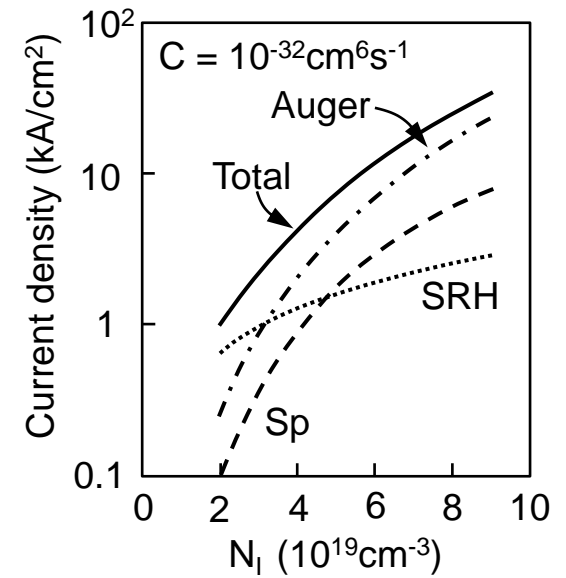
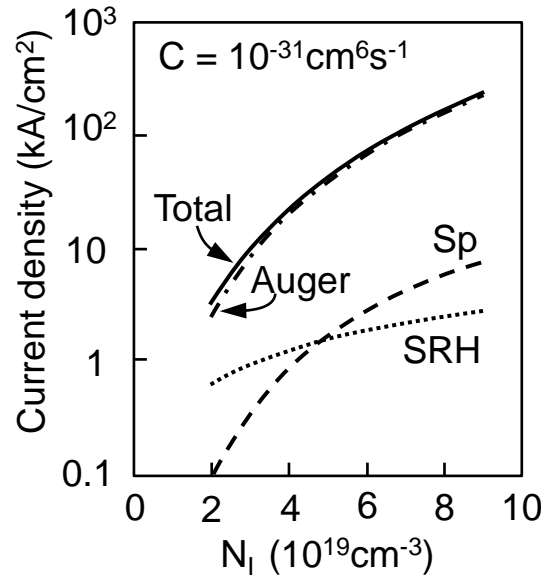
$$10^{-32} \text{ cm}^6 \text{ s}^{-1} < C < 10^{-31} \text{ cm}^6 \text{ s}^{-1}$$

Marachetti, et al, Phys. Scr. **64** 509 (2001)

Sun, et al, IEEE J. Select. Topics in Quantum Electron. **16** 124 (2010)

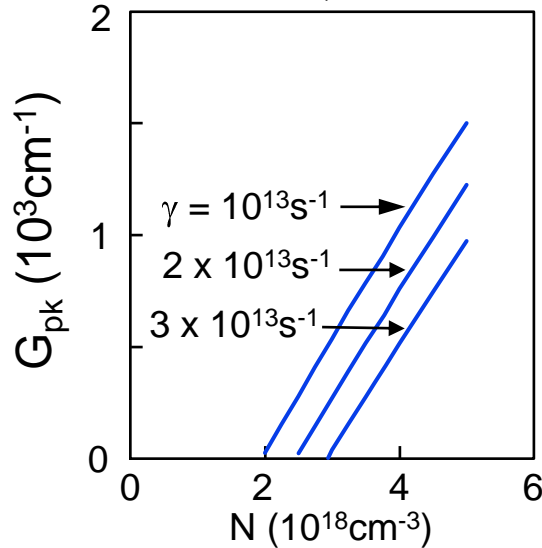
Liu, et al, Opt. Exp. **15** 11272 (2007)

Unstrained, $N_D = 0$



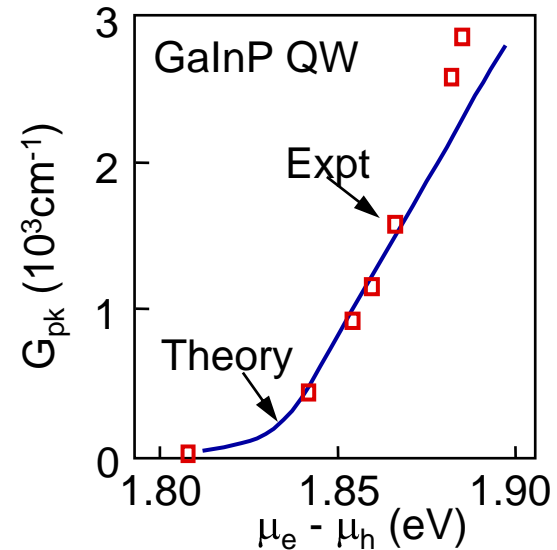
Present theory

Dephasing rate γ is a free parameter



Available

Precisely determined gain peak



WWC, P. M. Smowton, P. Blood, A. Girdnt, F. Jahnke and S. W. Koch, APL **71**, 157 (1997)

Summary: Theory of Laser Gain in a Ge-on-Si Laser

Motivation

Have computation tool for parametric studies of gain in Ge-on-Si lasers

Design parameters: strain and n-doping density

Nonradiative factors: defect and Auger losses, free-carrier absorption

Environmental factors: temperature

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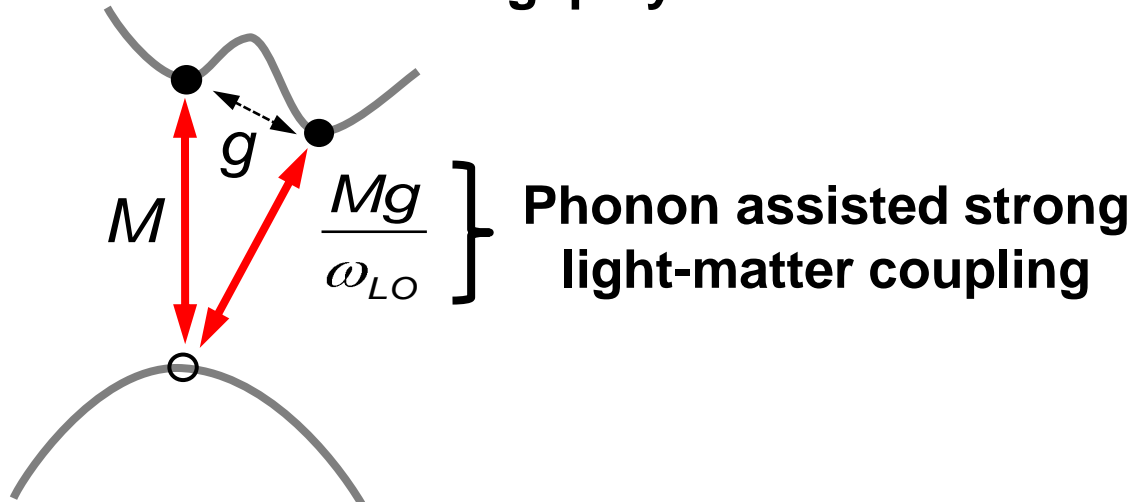
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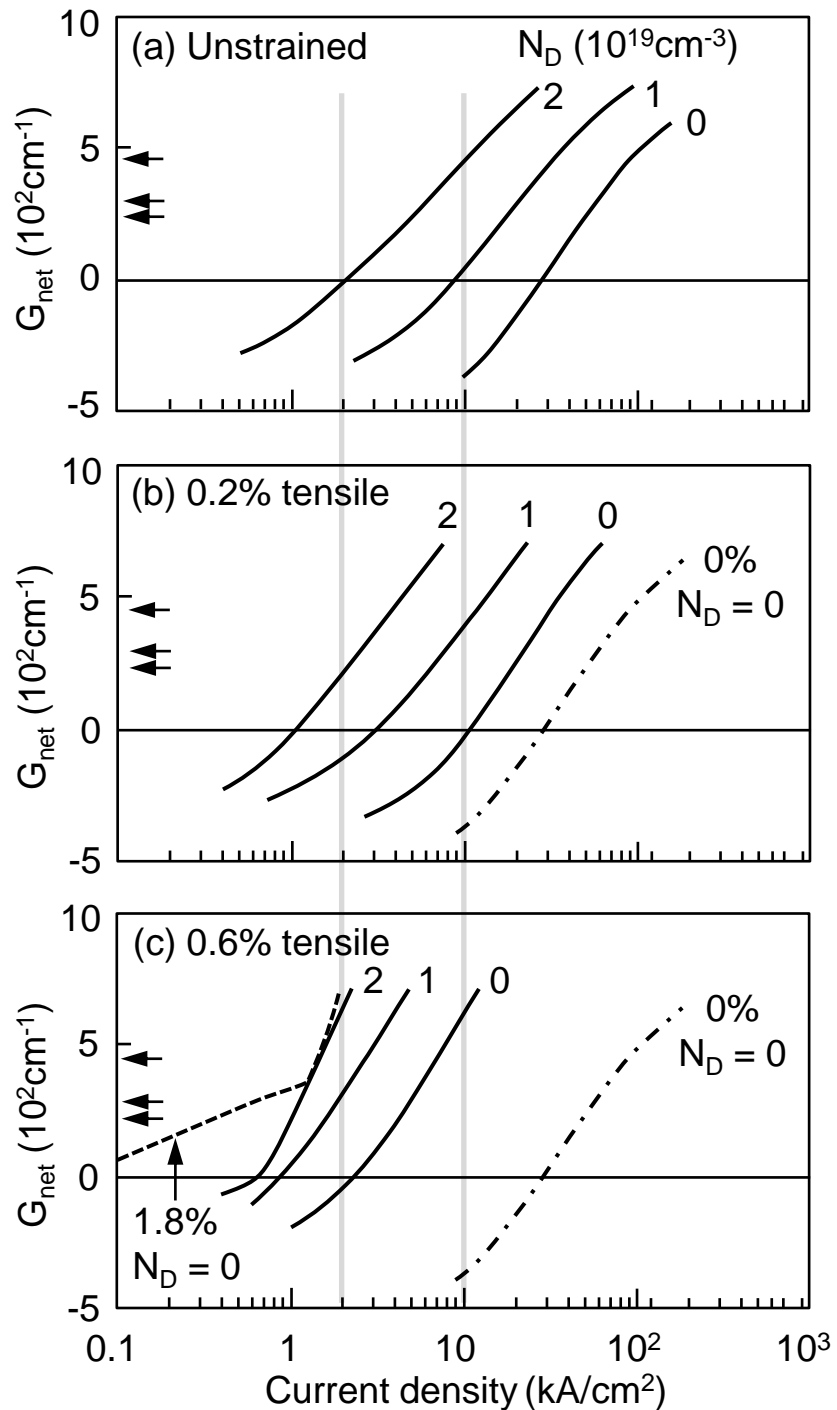
?Interesting dynamics or quantum optics?

Indirect bandgap systems

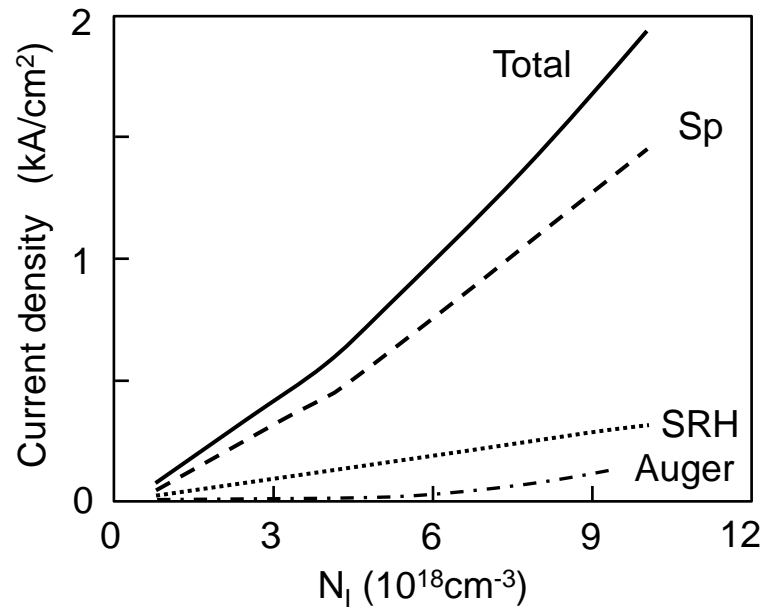
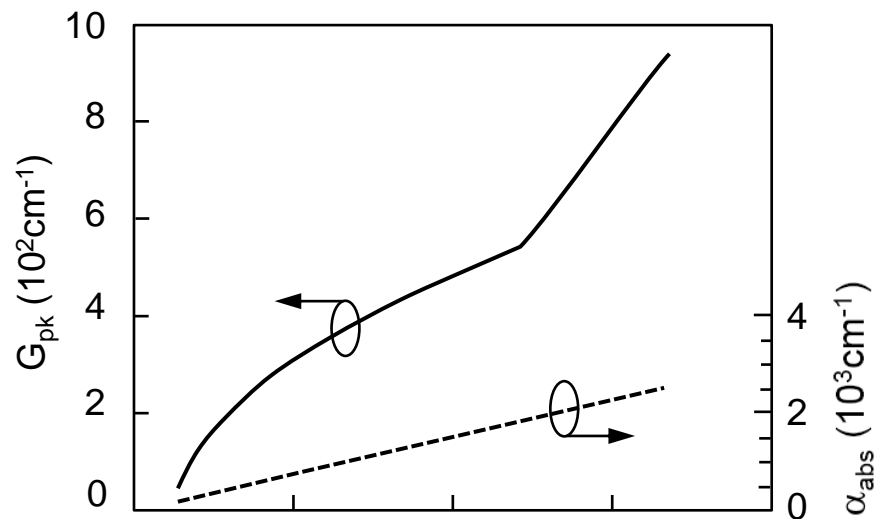


- Optical buffer in Si?
- LWI in Si?
- Peltier cooling in the strong coupling limit?

Carmelet, Kabuss and Chow, "Highly-detuned Rabi oscillations in a quantum-dot-microcavity system", PRB rapid comm. (TBR)



Direct gap Ge
(Undoped, 1.8% tensile strain)



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