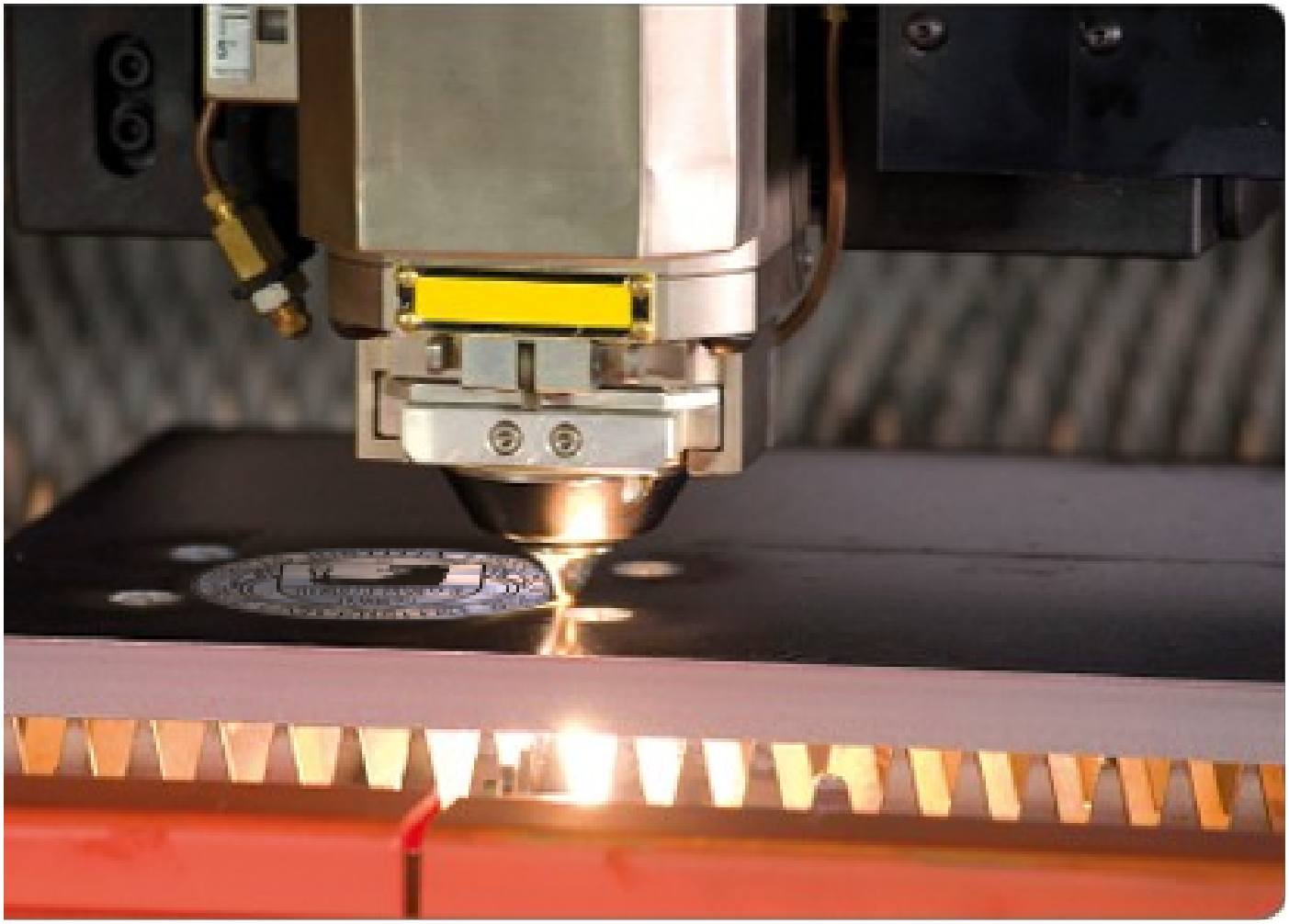
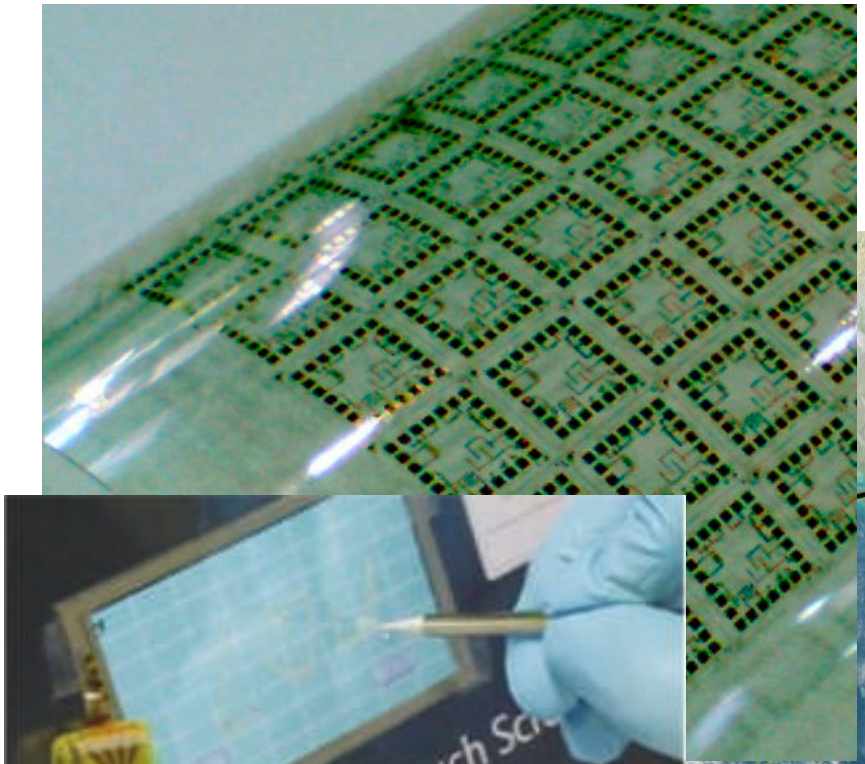
Nonlinear Optics and Photonics

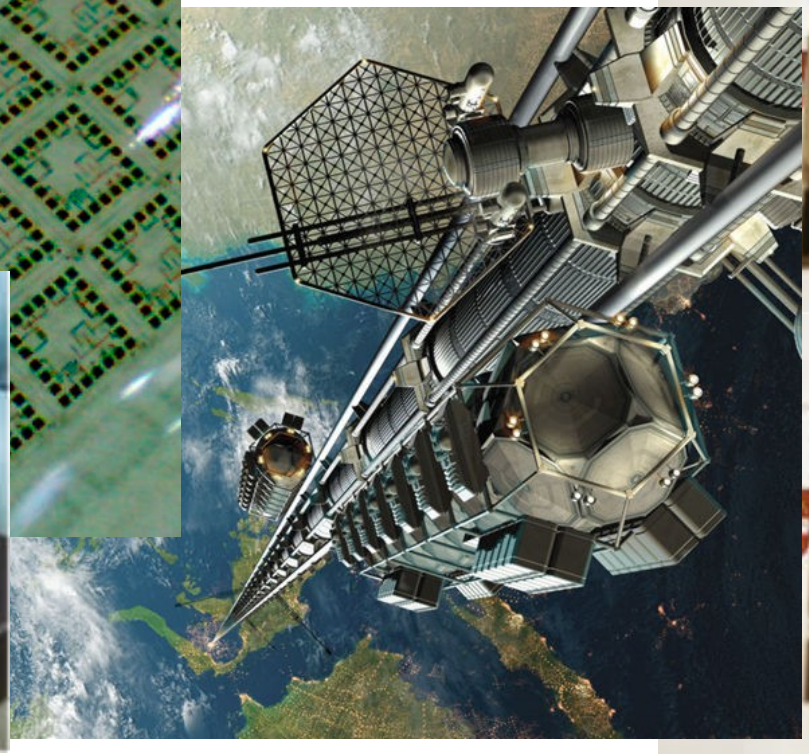


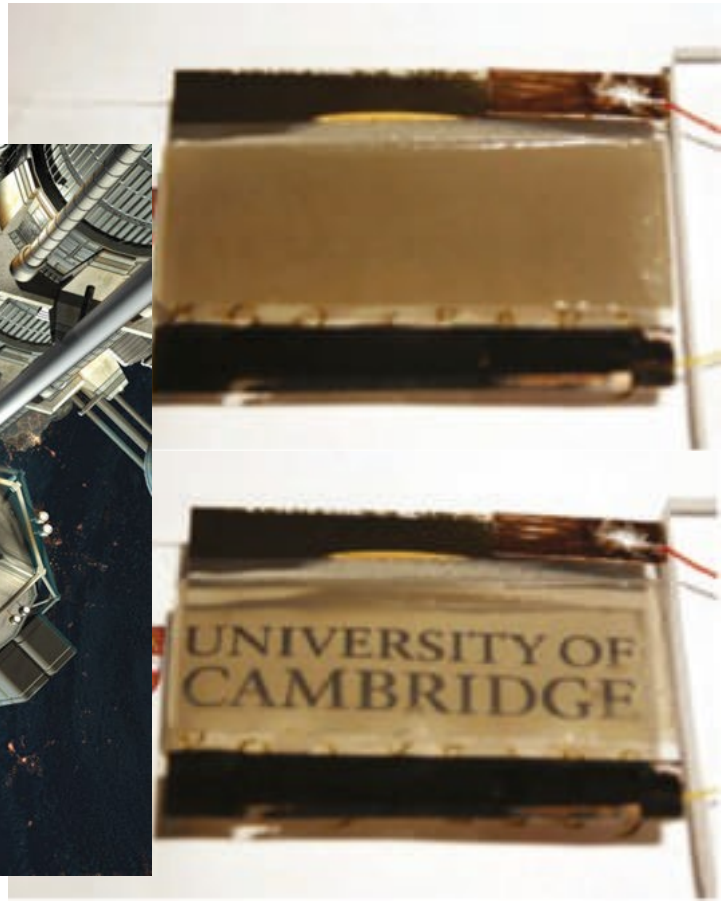
Markus Krecik

16.6.2011

Carbon: Applications





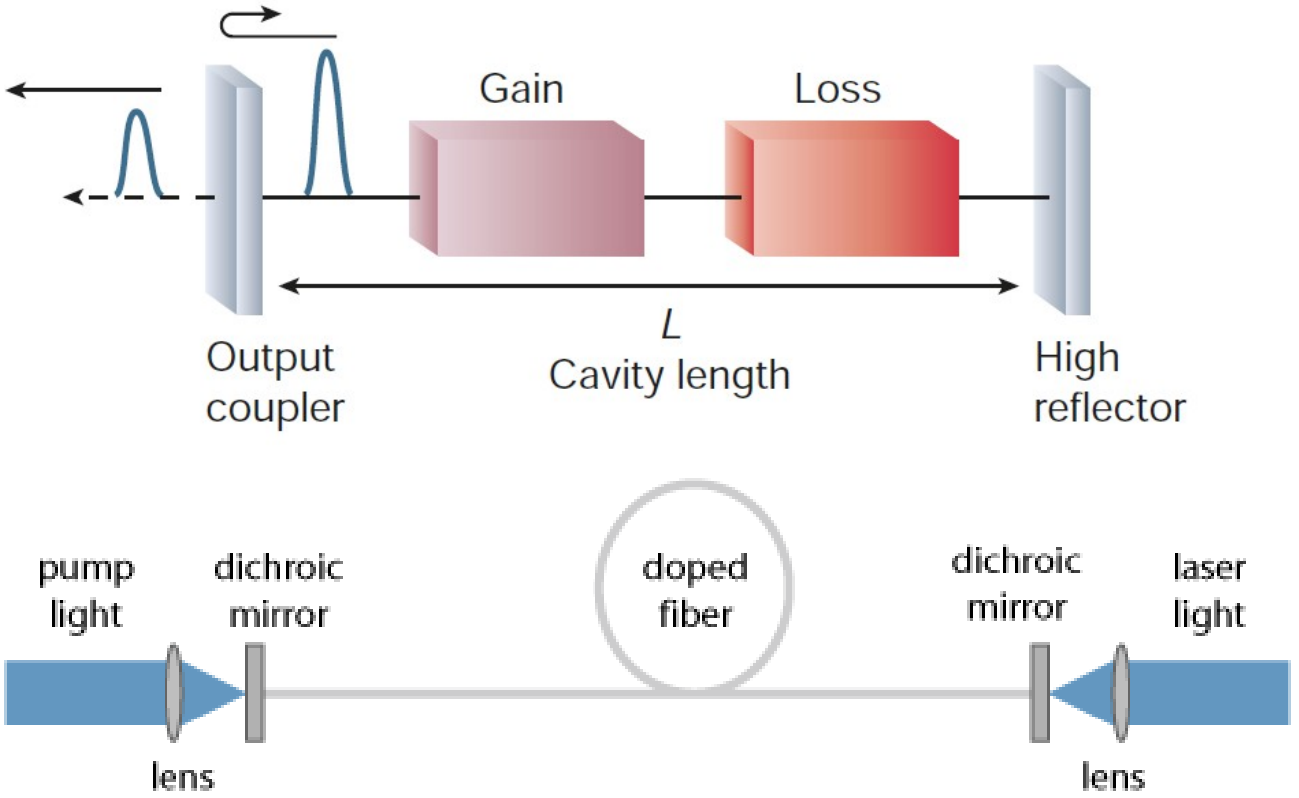


F. Bonaccorso, Z. Sun, T. Hasan, A. C. Ferrari, Nature Photonics 4, 611 - 622 (2010)
http://www.elektroniknet.de/fileadmin/user_upload/wor_pics/186eb793c950fac9e3b8e8303b1b49f9_885x823.jpg
http://lenanoblog.files.wordpress.com/2010/07/06_spaceelevator.jpg

Outline

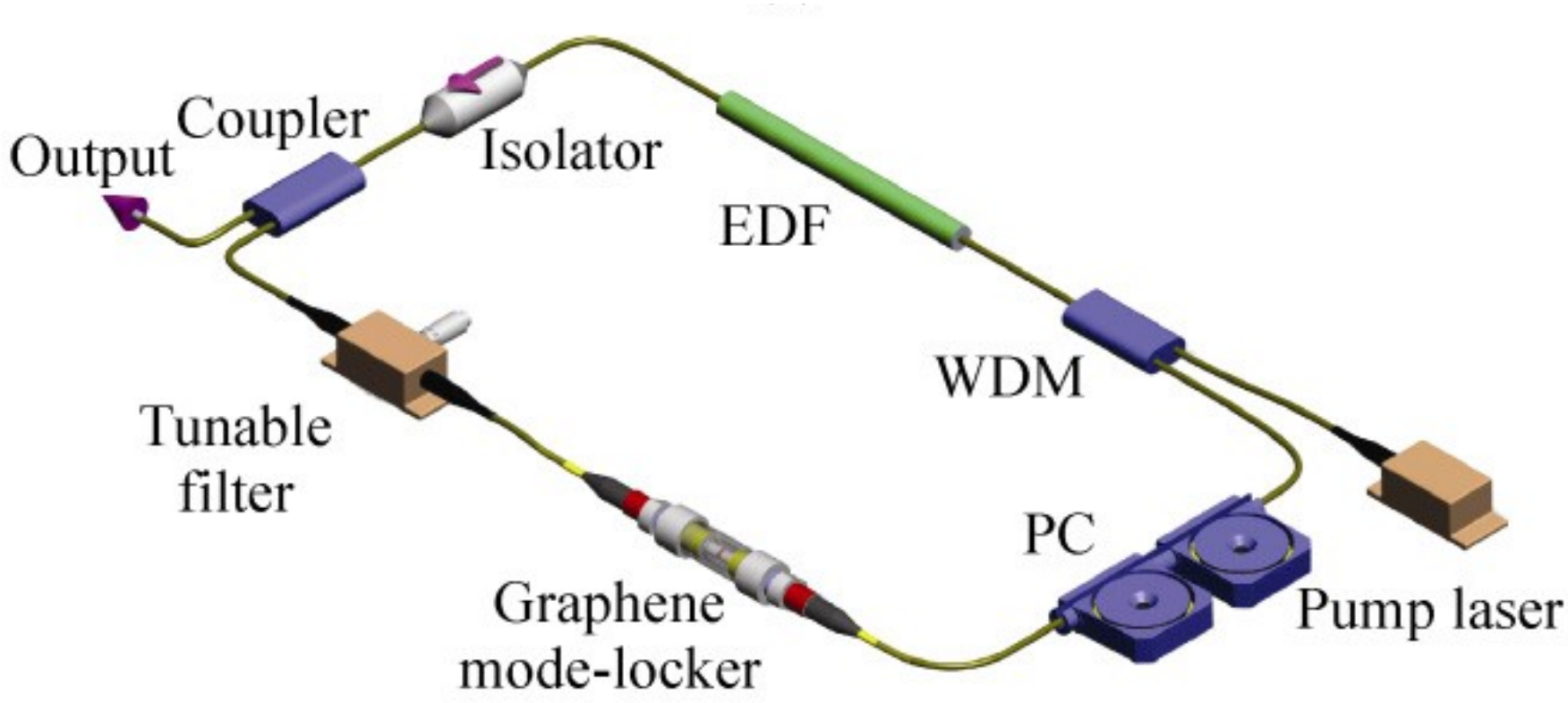
- Fiber Laser: Femtosecond Pulse Generation
  - Mode-Locking with Saturable Absorber
  - CNT/Graphene as Modelocker
- Plasmonics: Enhanced Raman Spectroscopy
  - Introduction
  - Surface Enhanced Raman Scattering (SERS)
  - Tip-Enhanced Raman Scattering (TERS)
  - TERS on CNTs
- Summary

Fiber Laser



U. Keller, Nature 424, 831-838 (2003)
http://www.rp-photonics.com/fiber_lasers.html

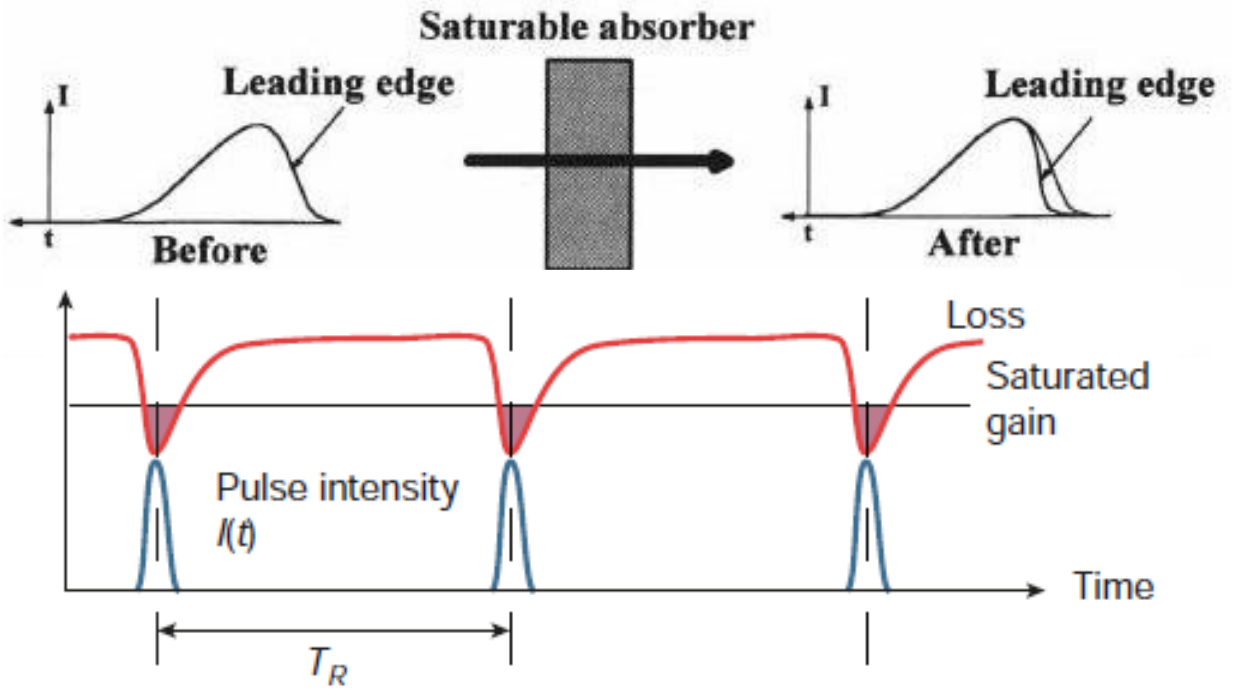
Fiber Laser



Sun et al., Nano Res. 2010, 3(9): 653–660

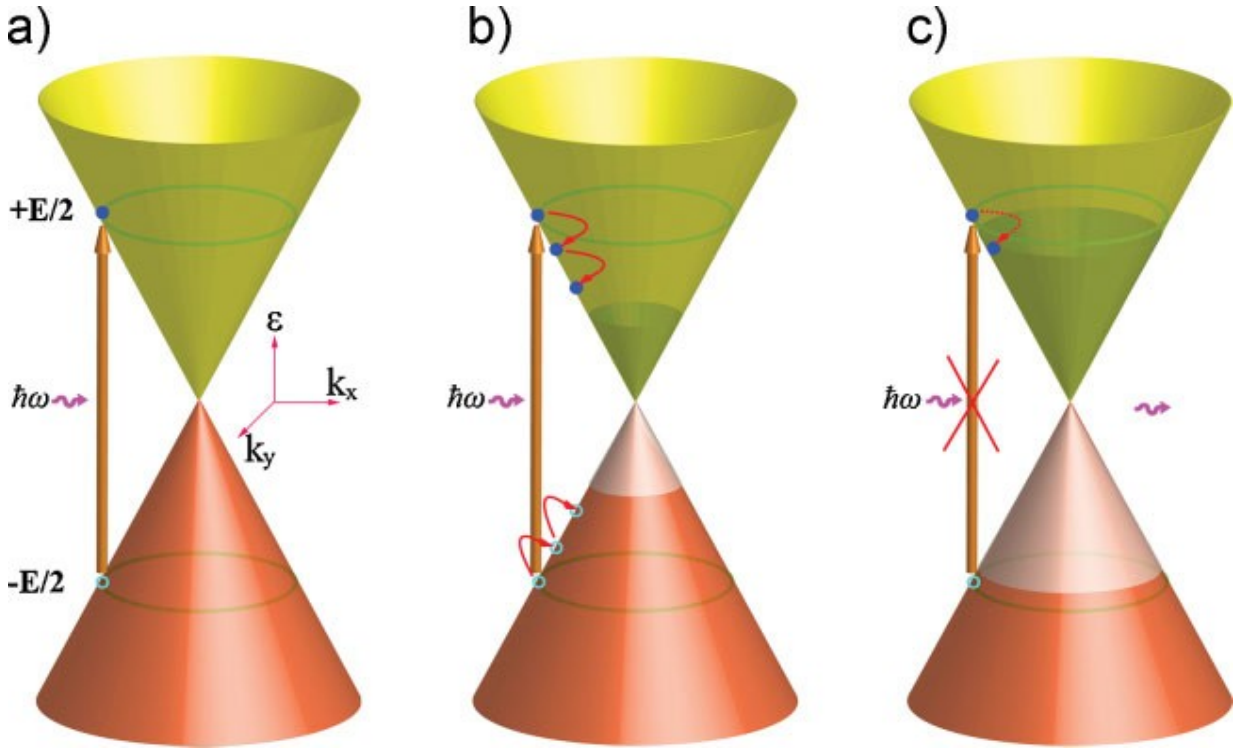
Fiber Laser Mode-Locking: Saturable Absorber

- Types: Semiconductor (SESAM), CNT, Graphene...
- Nonlinear Absorption: $\alpha = \alpha(I)$



C. Rulliere, Femtosecond Laser Pulses, Springer, 2nd ed. (1947)
U. Keller, Nature 424, 831-838 (2003)

Fiber Laser: Graphene, CNT



Graphene:

a) Light absorption

b) Carrier-carrier collisions (~100fs)

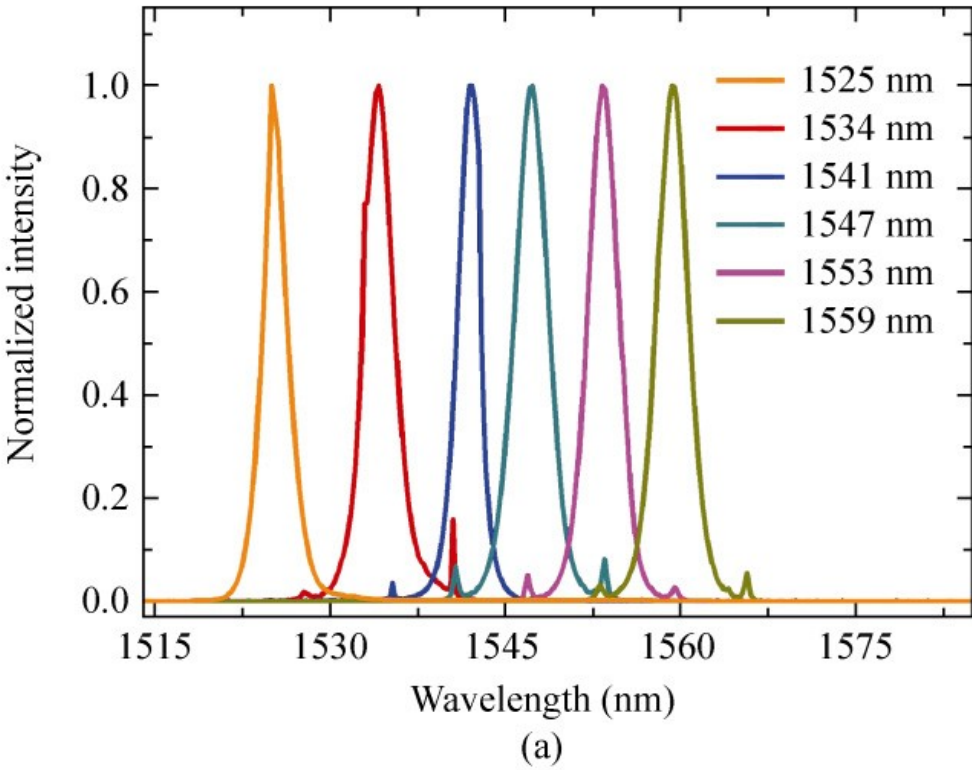
c) Filled states, no further absorption (Pauli blocking)

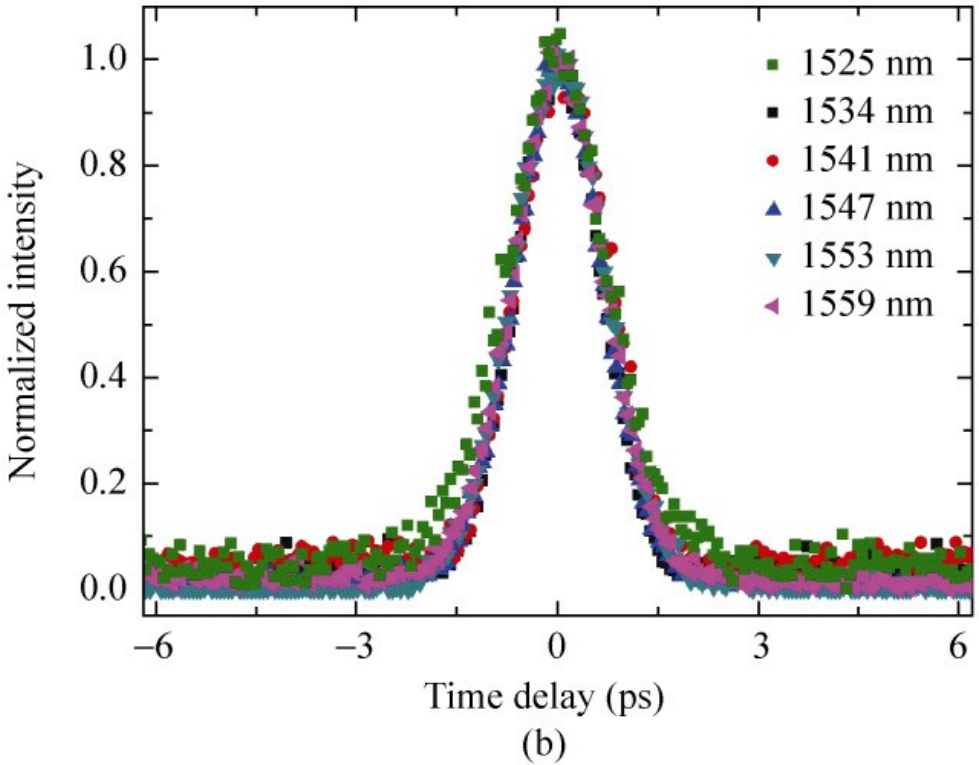
CNT: Distribution of bandgaps

Q. Bao et al. Adv. Funct. Mater. 19, 3077–3083 (2010)

Fiber Laser: Pulse Profile

- e.g. Graphene:





Z. Sun et al., Nano Res. 2010, 3(9): 653–660

Fiber Laser: Graphene, CNT

Comparison

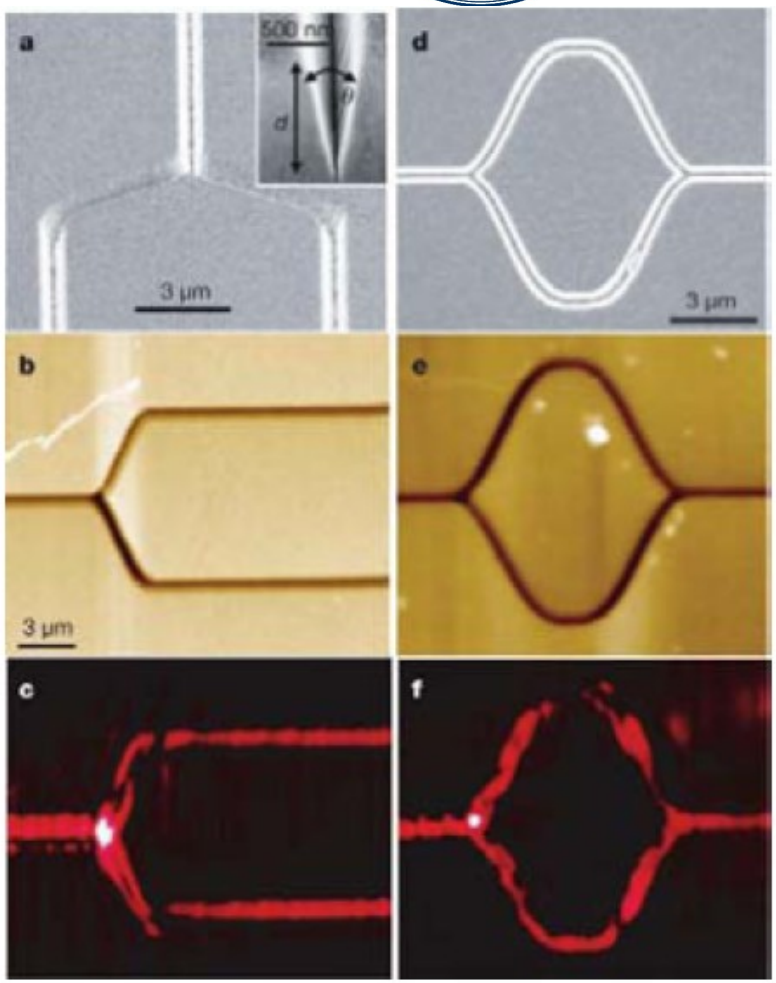
Graphene	CNT
Broadband tuneablility	
Fast relaxation times	
Low saturation intensity	
Low cost	
	Off-resonance produces additional loss

Plasmonics

http://www.nature.com/nphoton/journal/v1/n4/images/nphoton.2007.38-f1.jpg

Plasmonics: Applications

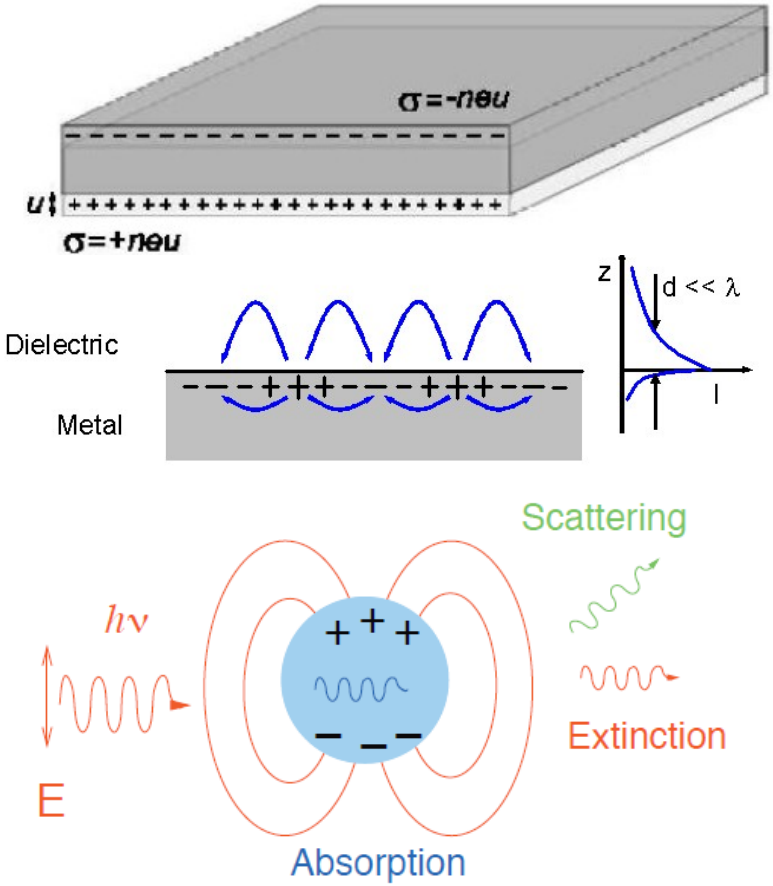
- Waveguides
- Nonlinear Light Generation
- Metamaterials:
  - Negative Refraction Index
  - Superlenses
- Surface/Tip Enhanced Raman Scattering (SERS/TERS)
- ...



S. A. Maier, Plasmonics: Fundamentals and Applications, Springer, 1st ed. (2007)

Plasmonics: Types

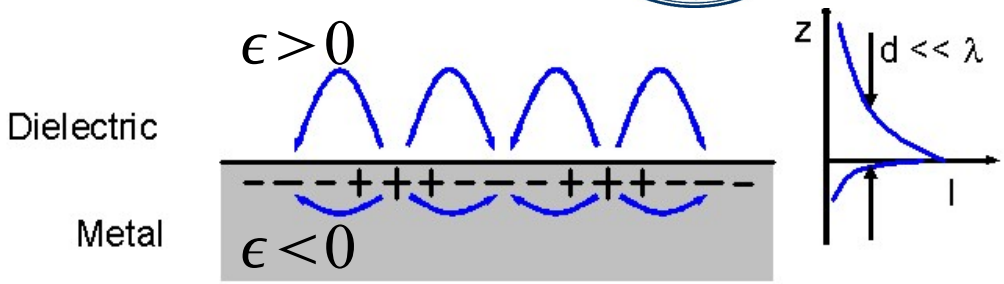
- Volume Plasmon:
- Surface Plasmon Polariton (SPP):
- Localized Surface Plasmon Polariton:

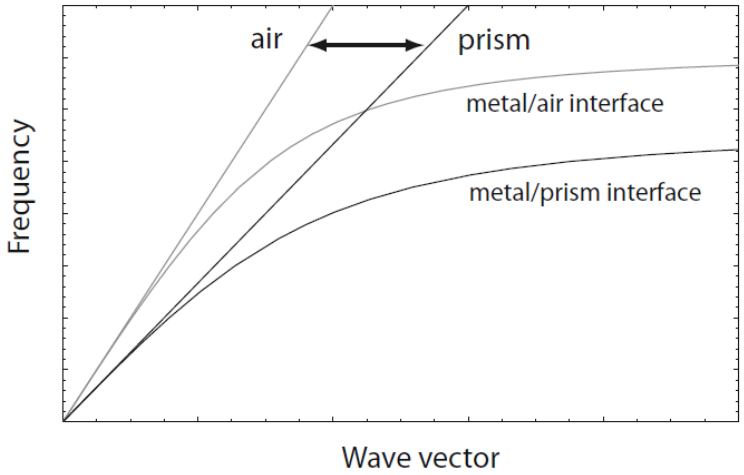


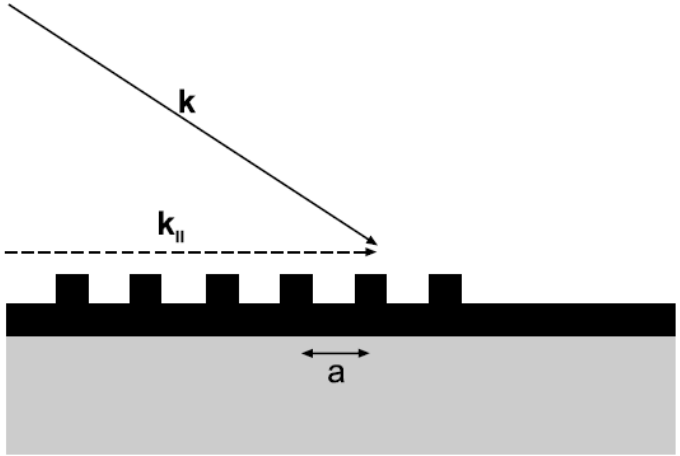
S. A. Maier, Plasmonics: Fundamentals and Applications, Springer, 1st ed. (2007)
http://upload.wikimedia.org/wikipedia/commons/6/65/Electron_density_wave_-_plasmon_excitations.jpg
M. Pelton et al., Laser & Photon. Rev. 2, No. 3, 136–159 (2008)

Plasmonics: Surface Plasmon Polariton

- 2d plasma oscillations at metal surface
- Coupling by prism or grating







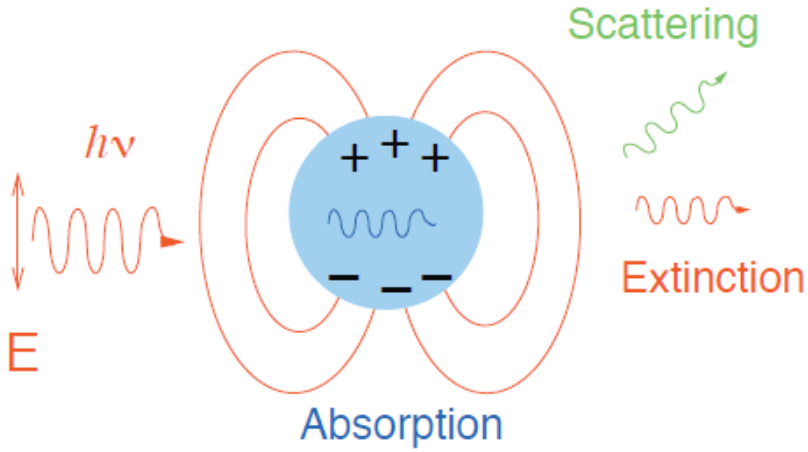
S. A. Maier, Plasmonics: Fundamentals and Applications, Springer, 1st ed. (2007)
http://upload.wikimedia.org/wikipedia/commons/6/65/Electron_density_wave_-_plasmon_excitations.jpg

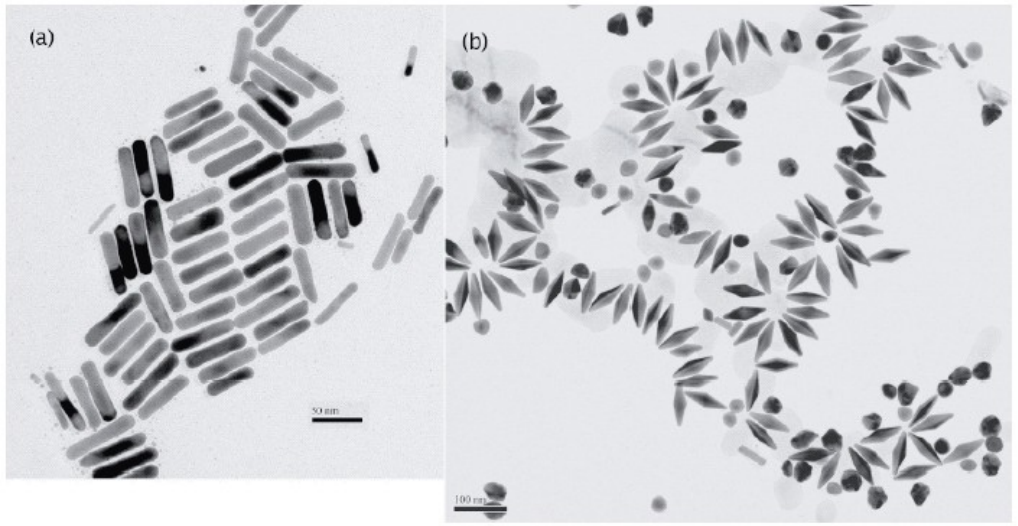
Plasmonics: Localized SPP

- SPP confined to small volume

  $d \ll \lambda$

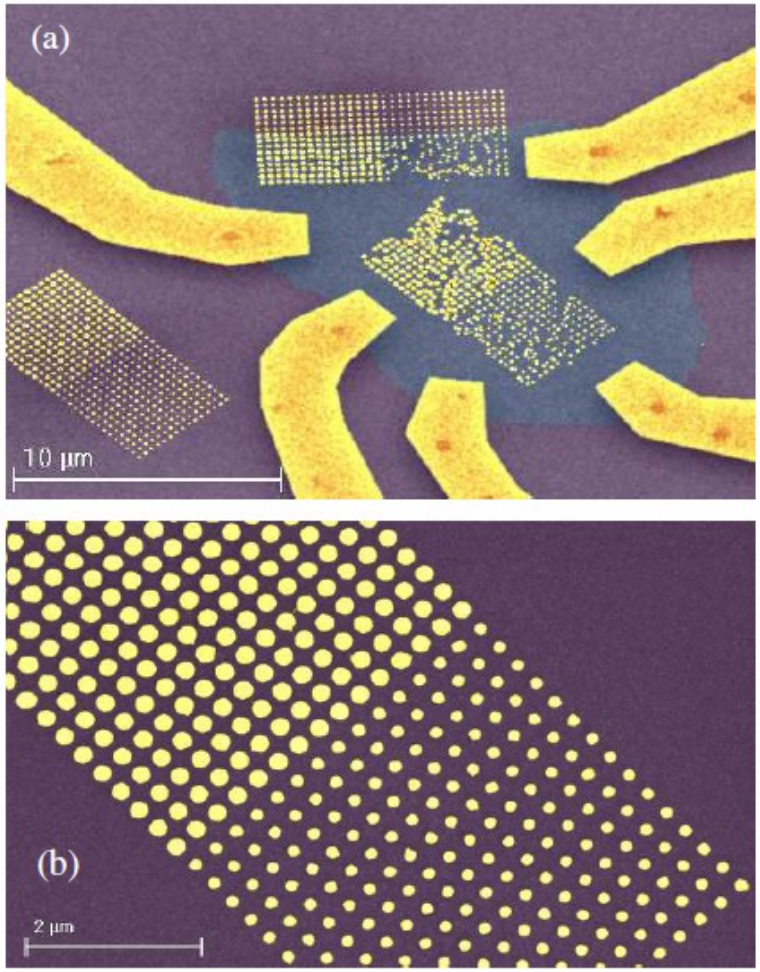
- Electric field enhancement due to localized SPP and lightning rod effect

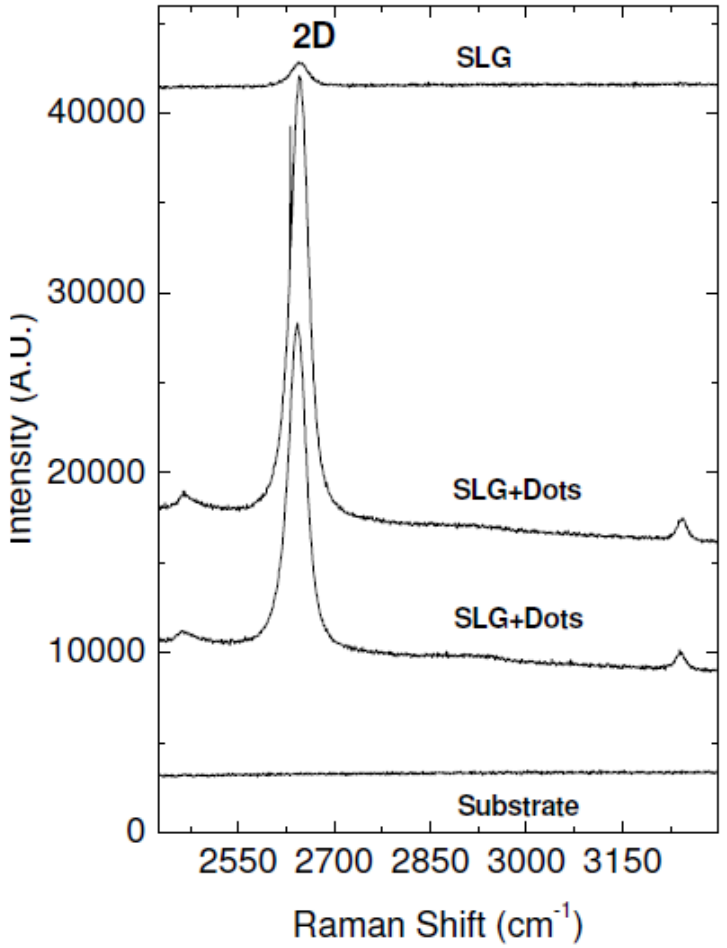




M. Pelton et al., Laser & Photon. Rev. 2, No. 3, 136–159 (2008)

Plasmonics: SERS on Graphene

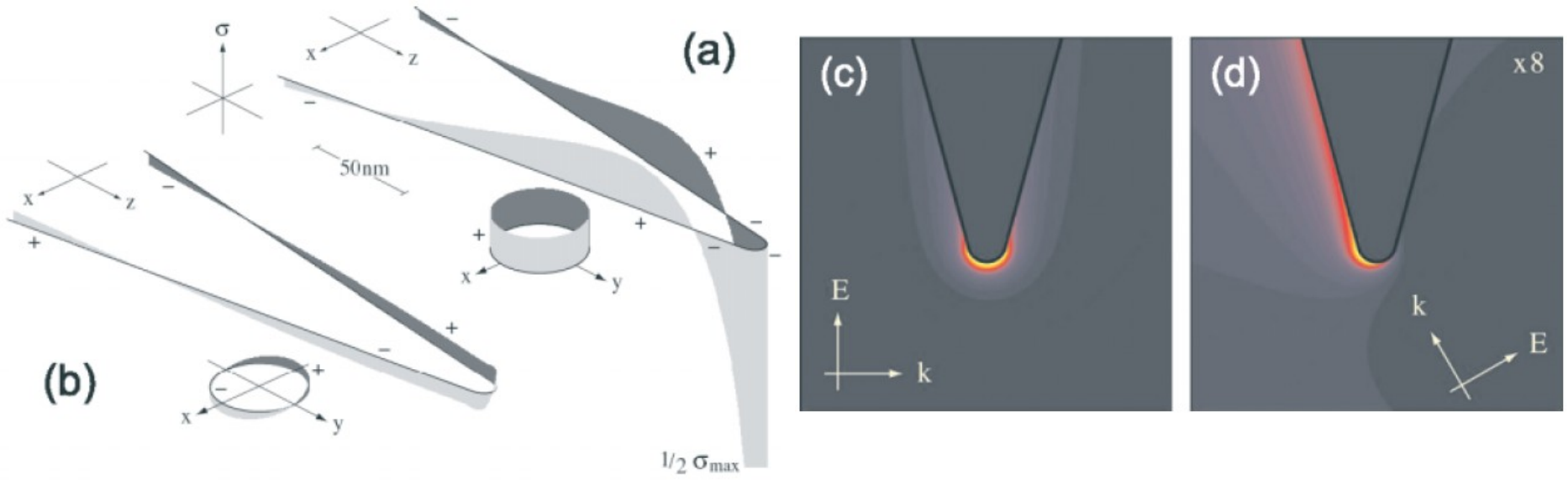




F. Schedin et al, ACS Nano 4, 5617 (2010)

Plasmonics: TERS

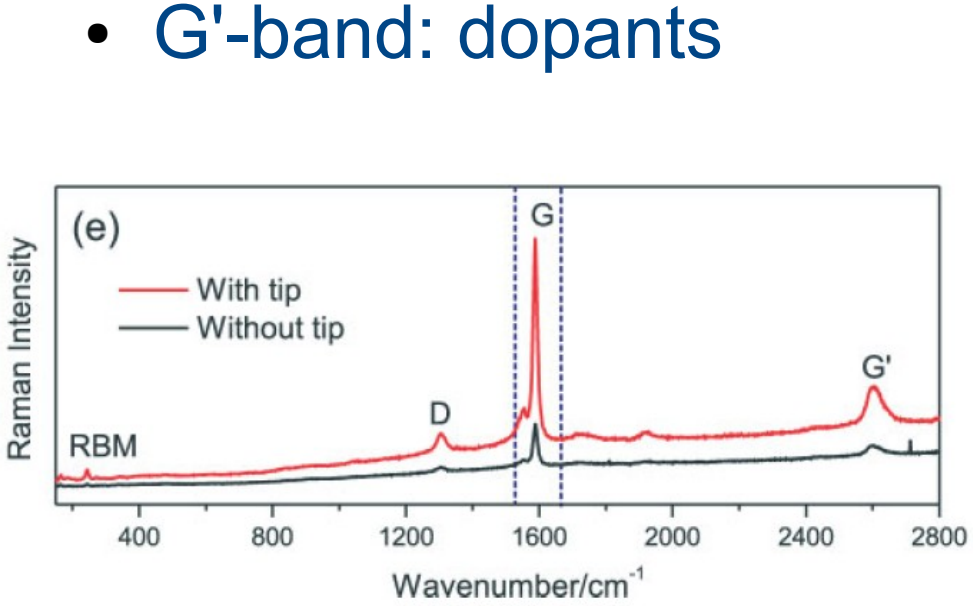
- Localized SPP at AFM-tip
- No averaging, high spatial resolution, high sensitivity

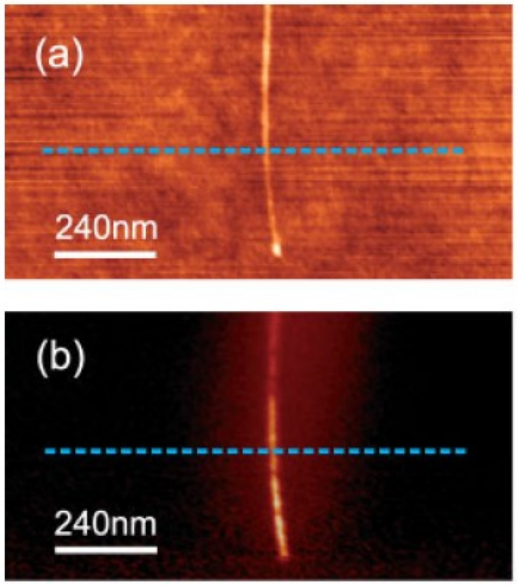


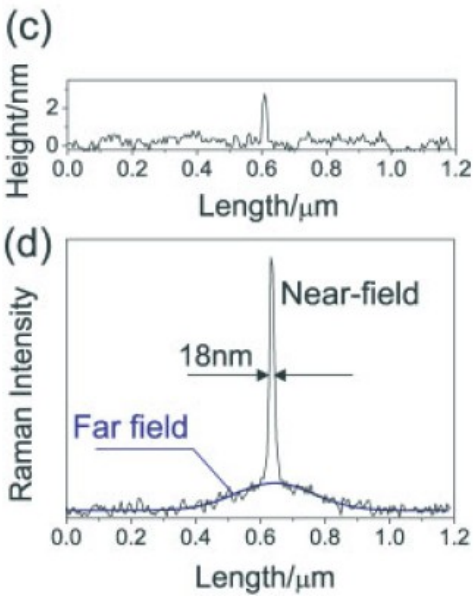
L. G. Cançado et al., J. of Raman Spec. 40, Issue: 10, Pages: 1420-1426 (2009)

Plasmonics: TERS with CNT

- RBM: diameter, chirality
- D-band: defects
- G-band: metallic/semiconductor
- G'-band: dopants







L. G. Cançado et al., J. of Raman Spec. 40, Issue: 10, Pages: 1420-1426 (2009)

Summary

- Fiber Laser powerful and flexible type of pulse laser
- Great advantages of CNT/Graphene in femtosecond pulse generation (especially Graphene)

- Greatly enhanced electric field in vicinity of nanoparticles
- Application in TERS for high spatially resolved, intensity enhanced Raman spectroscopy
- Obtain properties of single CNTs

Thank you for your Attention!

References

- Title image taken from: http://www.halderschneidtechnik.de/_bilder/laserschneiden/laserschneiden.jpg
- S. A. Maier, Plasmonics: Fundamentals and Applications, Springer, 1st ed. (2007)
- F. Bonaccorso, Z. Sun, T. Hasan, A. C. Ferrari, Nature Photonics 4, 611 - 622 (2010)
- T. Hasan et al., Adv. Mat., 21 (38-39). pp. 3874-3899
- U. Keller, Nature 424, 831-838 (2003)
- Z. Sun et al., Nano Res. 2010, 3(9): 653–660
- Z. Sun et al., ACS Nano 4, 803 (2010)
- F. Wang et al., Nature Nanotechnology 3, 738 - 742 (2008)
- M. Pelton et al., Laser & Photon. Rev. 2, No. 3, 136–159 (2008)
- L. G. Cançado et al., J. of Raman Spec. 40, Issue: 10, Pages: 1420-1426 (2009)
- N. Hayazawa et al., Chem. Phys. Lett. 376 (2003) 174–180
- F. Schedin et al., ACS Nano 4, 5617 (2010)
- S. Lefrant, Curr. Appl. Phys. 2 (2002) 479–482