Photocurrent measurement techniques

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Outline

- Photocurrent/-voltage
  - p-n junction
  - Schottky – contact
- Photoconductance
- Extract of possible effects:
  - Photodoping
  - Photogating
  - Photodesorption
- Experimental setup
- Dynamic photoconductive gain effect
- Optically induced transport measurements
- Spatially resolved measurements

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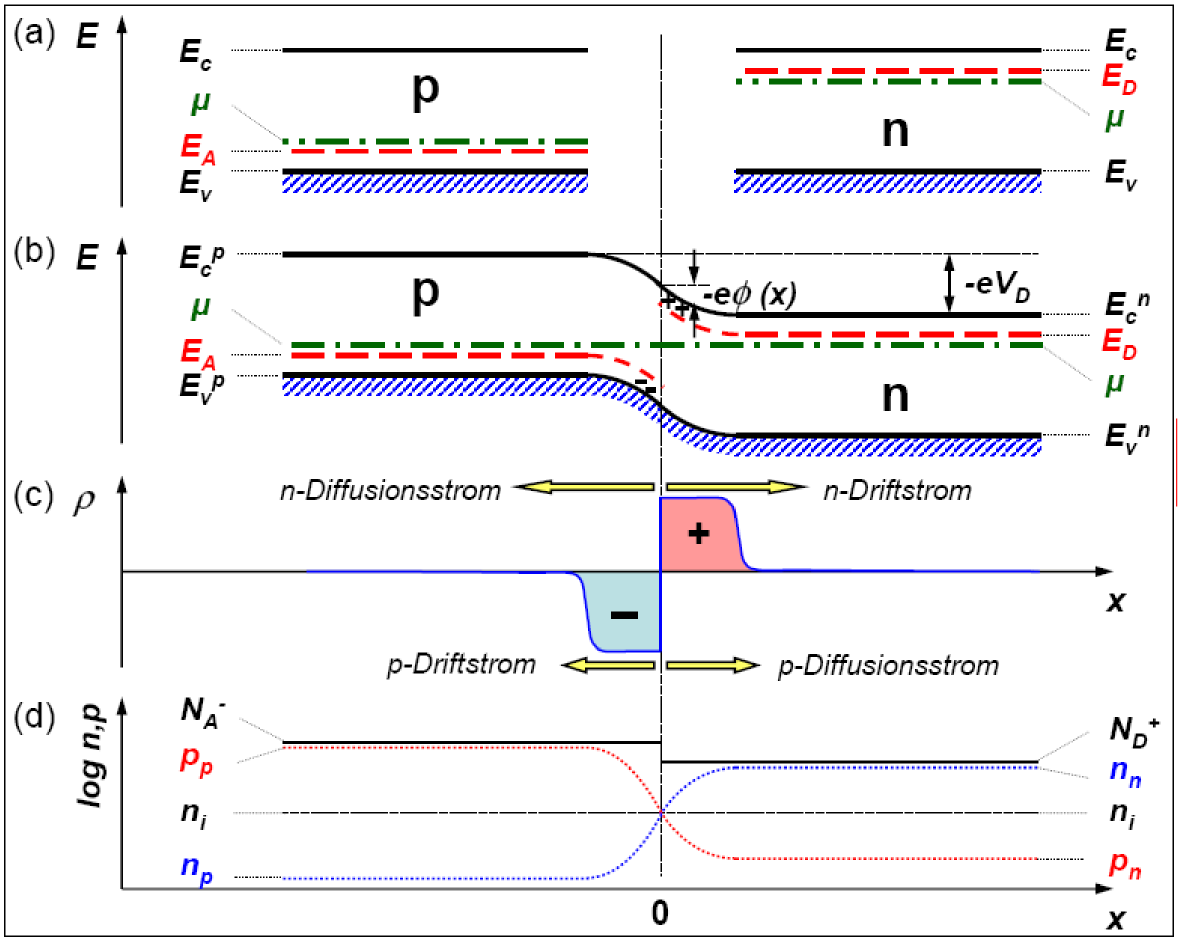
Photocurrent/-voltage (p-n junction)

[5]



Schematic view of a p-n junction in thermal equilibrium

Band structure at complete separation of p- and n-doped semiconductor

Band alignment after contacting

$$eV_D = E_g + k_B T \, \ln\left(\frac{n_i^2}{n_c^{\mathrm{eff}} \, p_v^{\mathrm{eff}}}\right) = E_g + k_B T \, \ln\left(\frac{n_n \, p_p}{n_c^{\mathrm{eff}} \, p_v^{\mathrm{eff}}}\right)$$

[5]

Distribution of the space charge

Qualitative distribution of donors, acceptors, electrons and holes

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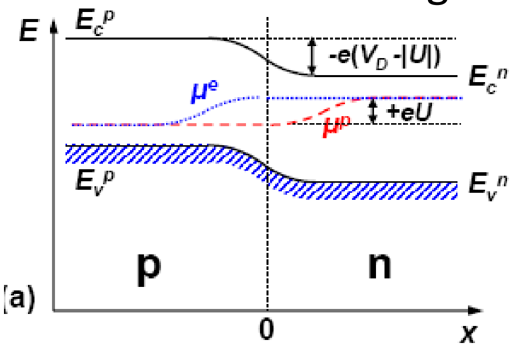
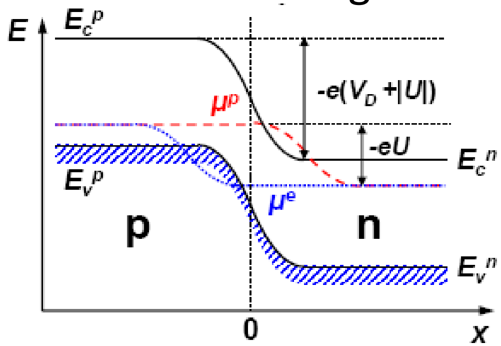
Photocurrent/-voltage (p-n junction)

forward-biasing

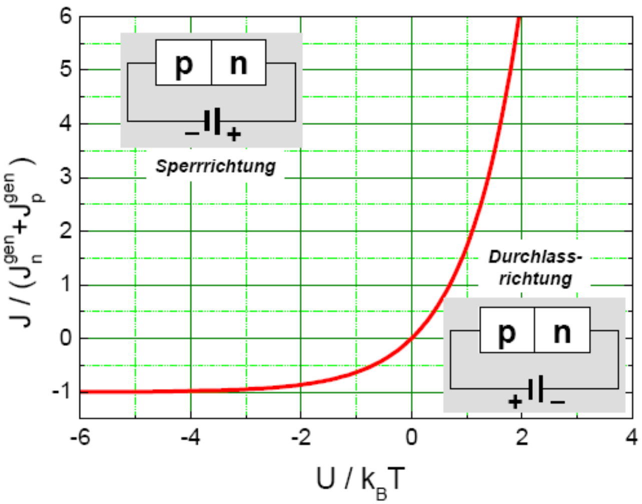


reverse-biasing



[5]

$$J(U) = \left(\frac{eD_p}{L_p}p_n + \frac{eD_n}{L_n}n_p\right)\left(e^{eU/k_BT} - 1\right)$$



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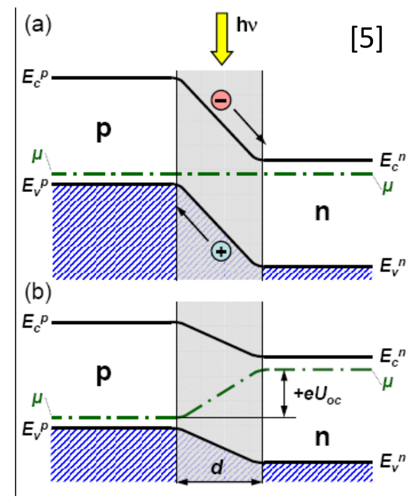

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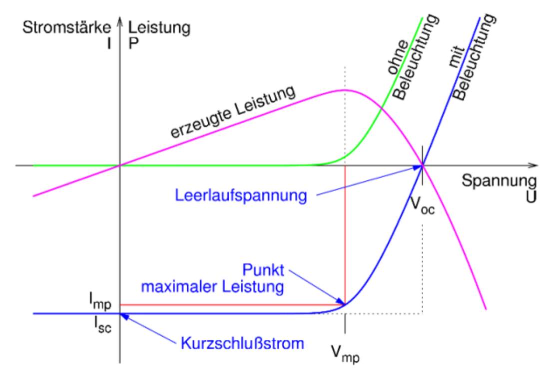

[7]

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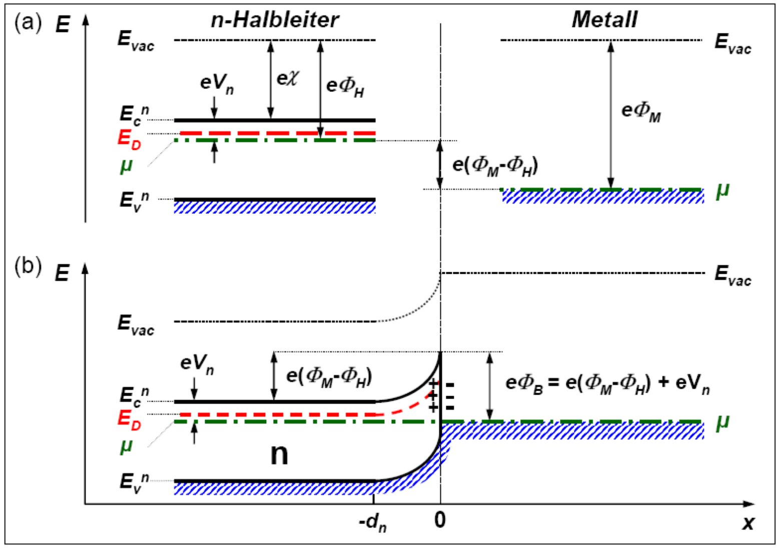
Photocurrent/-voltage (Schottky – contact)



Schematic view of a Schottky-contact in thermal equilibrium

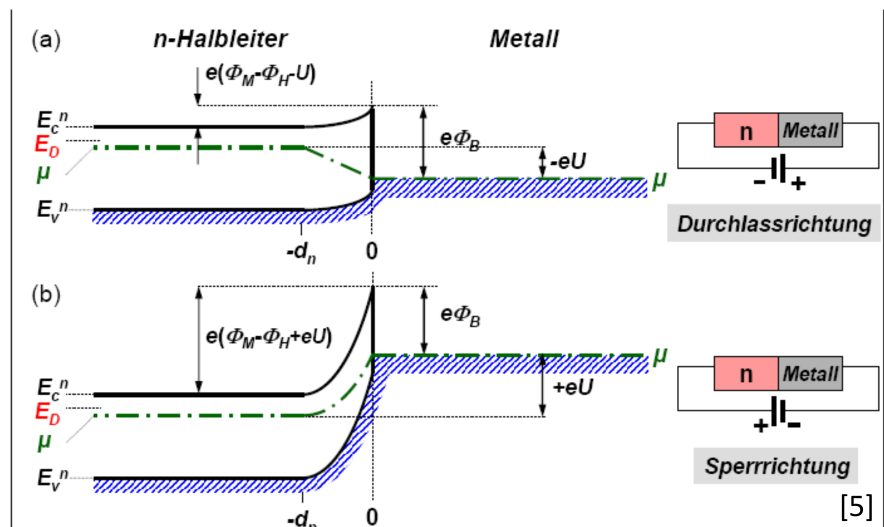
Band structure at complete separation of a n-doped semiconductor and metal

Band alignment after contacting

[5]

$$J(U) \;=\; J_s\left(e^{eU/k_BT}-1\right)$$

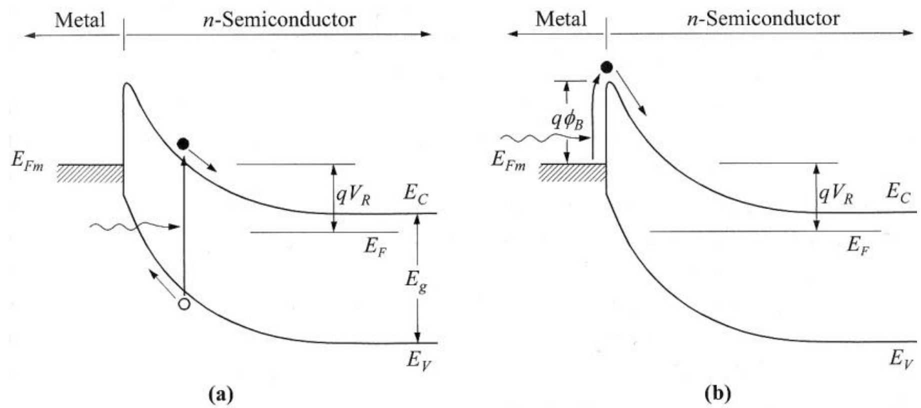
→ same I-U characteristic as for a p-n junction

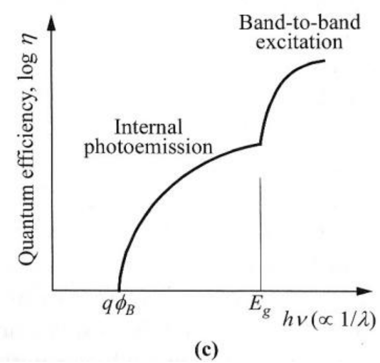


Schematic view of a Schottky-contact for forward / backward biasing

Photocurrent/-voltage (Schottky – contact)

a) Radiation produces electron-hole pairs
b) Smaller energy than Eg: photoexcited electrons in the metal can surmount the barrier and be collected by the semiconductor
   “internal photoemission”





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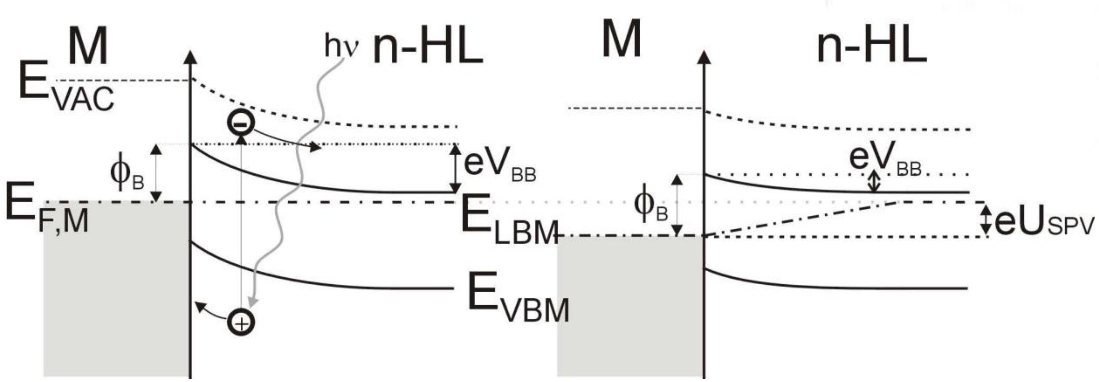

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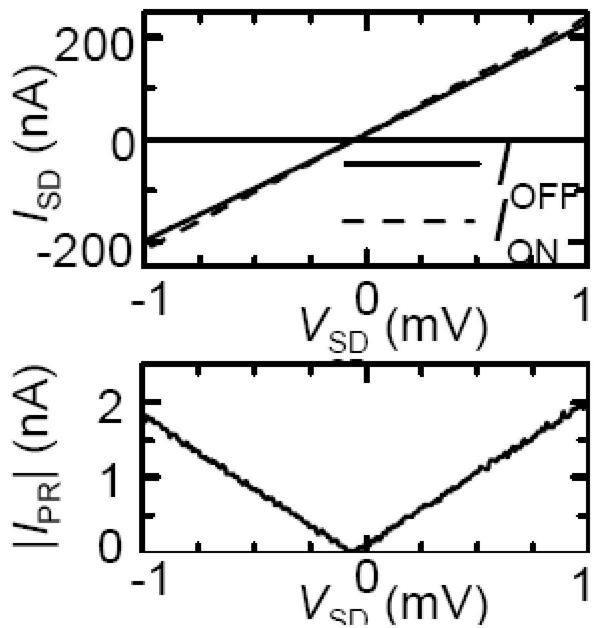
Photoconductance

What is photoconductance?

→ It is the first derivative of the current I with respect to the Voltage V : $\frac{dI_{pc}}{dV_{SD}}$



[1]

Here we have a very clear PR ~ 10^{-2} , often it is ~ 10^{-6}

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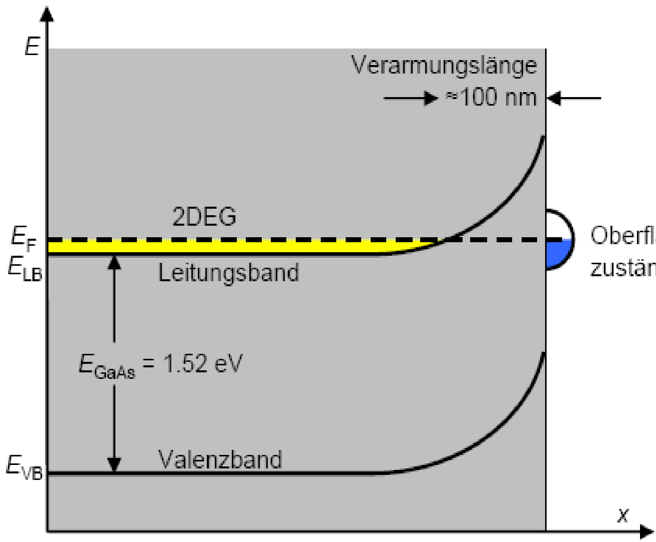
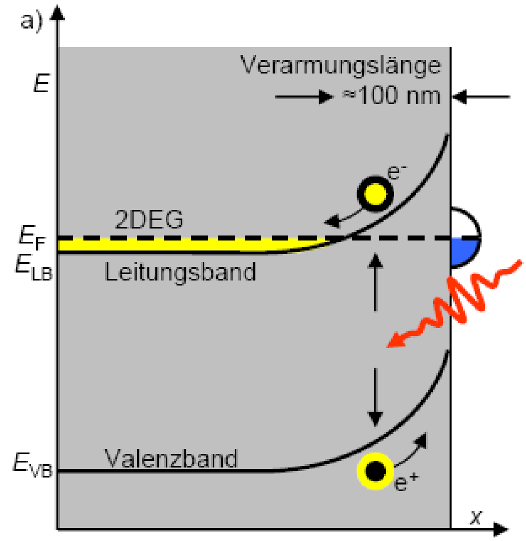
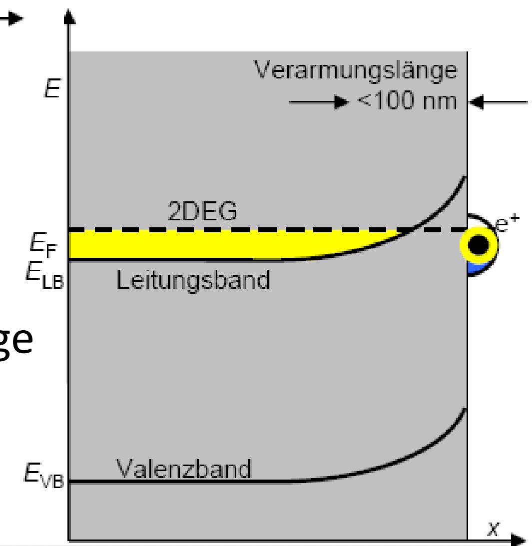
Photodoping/-gating





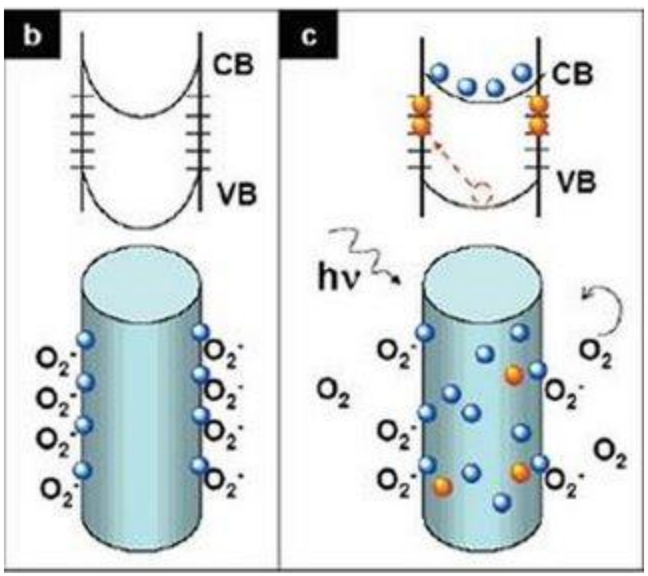


Photodoping: free excess electrons raise the Fermi-energy of the 2DEG throughout the device

Photogating: trapped excess holes act as positive gating voltage

Photodesorption
ZnO - nanowires

Upon UV-illumination the conductance of the nanowire increases !



[7]

Oxygen molecules Schematic of the trapping and photoconduction mechanism in ZnO nanowires.

At the top of each box are "energy band diagrams" ("b" represents the situation in darkness and "c" under UV illumination). In ZnO nanowires (as compared to some other semiconducting nanowires), the lifetime of the unpaired electrons is further inreased by oxygen molecules desorption from the surface when holes neutralize the oxygen ions.

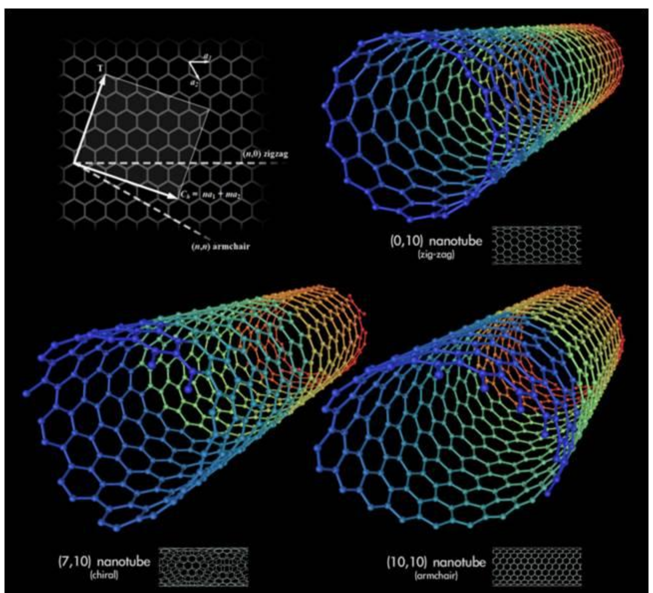
Conductance G is direct proportional to the diameter of the ZnO – wire without oxygen molecules !

Photodesorption

SWNTs

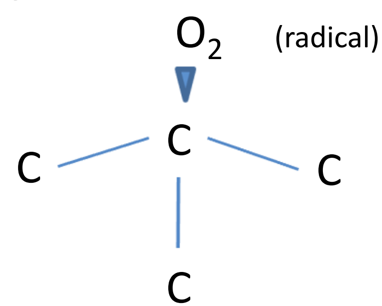
Upon UV-illumination the conductance of the nanotube decreases dramatically !

- Oxygen molecules adsorb under ambient conditions
- Wavelength-dependant studies: photons induce molecular detachment via electron plasmon excitations



[8]

Oxidation of the SWNT by withdrawing one tenth of a molecule:



→ SWNT is p-doped, leading to hole conduction!

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Photodesorption

SWNTs

Appl. Phys. Lett., Vol. 79, No. 14, 1 October 2001 Chen *et al.* 2259

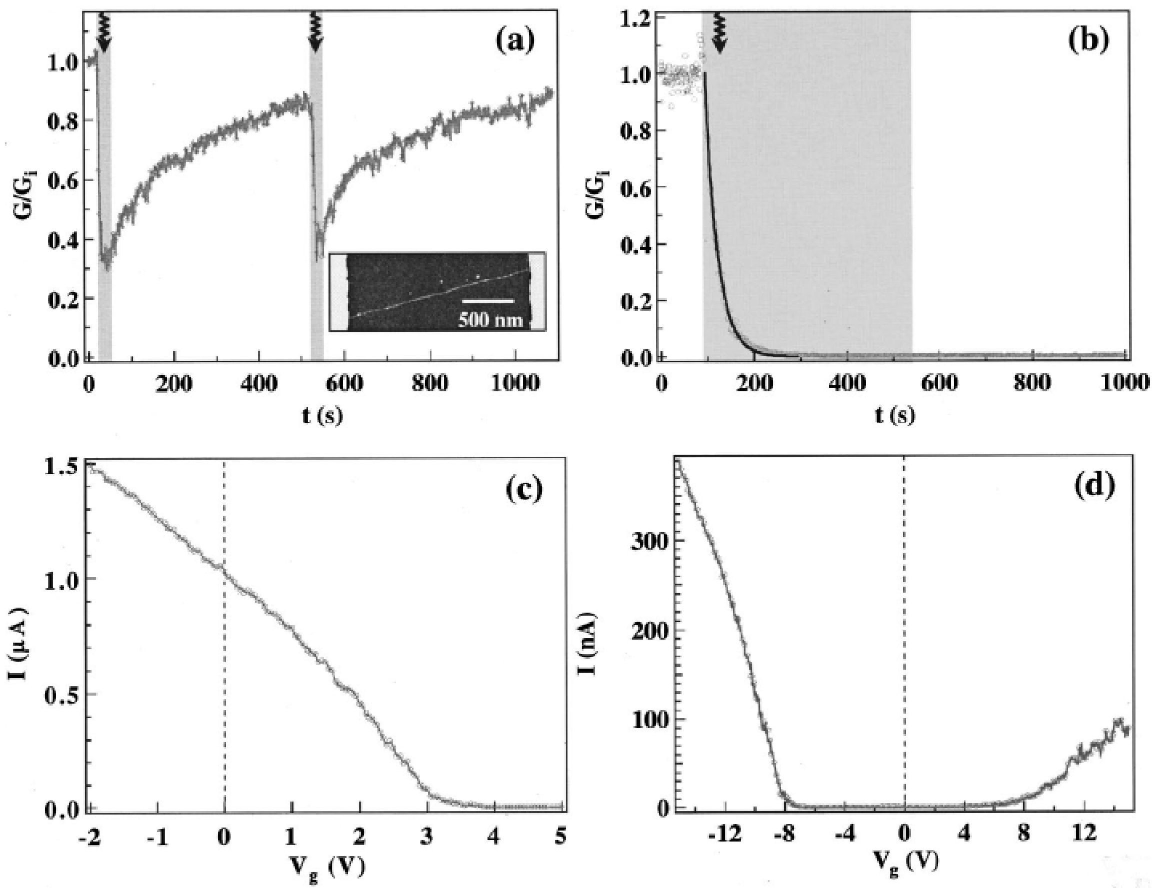
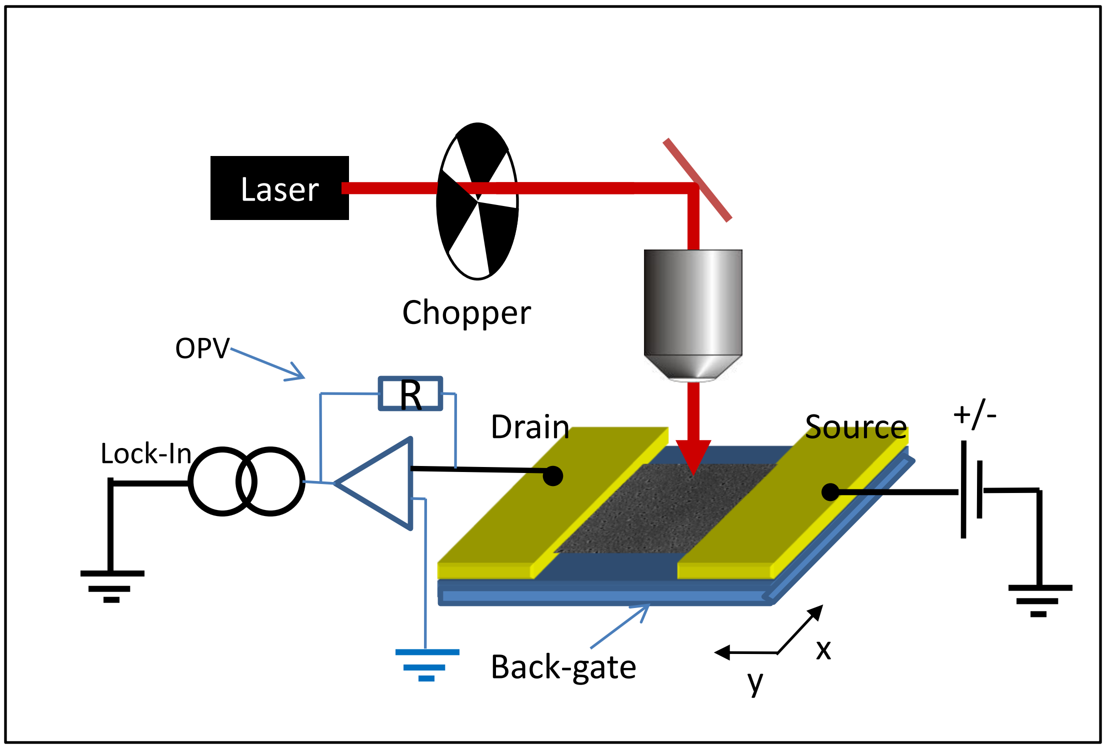
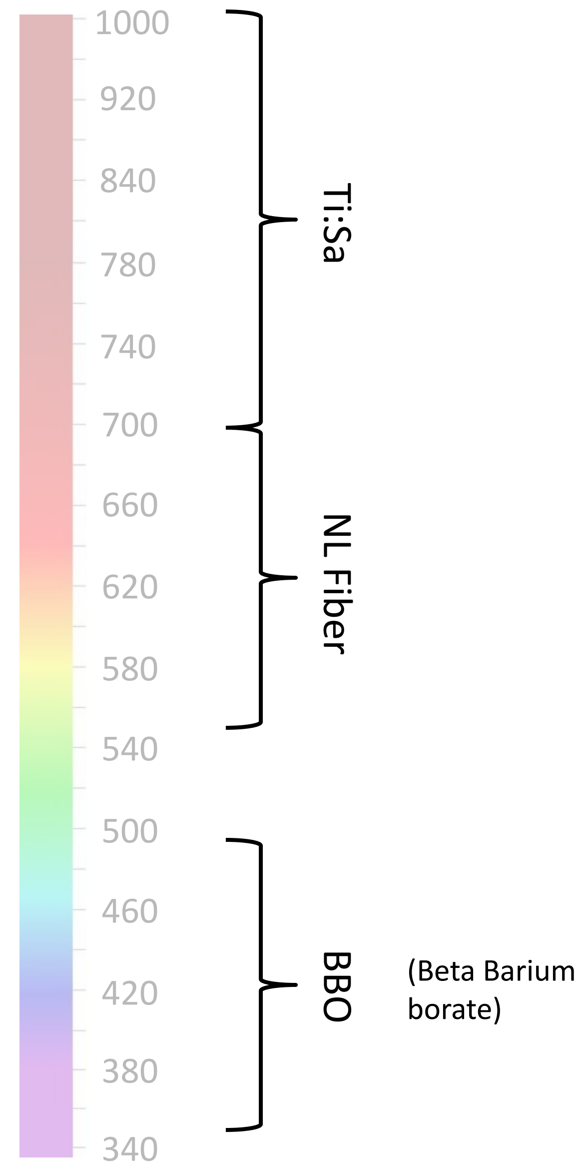


FIG. 1. (a) Normalized conductance [initial conductance $G_i=(1.0\,\mathrm{M}\Omega)^{-1}$] of an individual semiconducting SWNT vs time (t) during UV illumination cycles in air. Shaded and unshaded regions mark the UV-on and -off periods, respectively. The nanotube diameter is ~1.5 nm measured from atomic-force microscopy topography (inset). (b) Conductance response to UV illumination in a 10^{-8} Torr vacuum. Solid line: curve fitting of $G\sim\exp(-\sigma F t)$. (c) Current (I) vs gate voltage (V_g) recorded under a bias voltage of 100 mV in air prior to any UV illumination. (d) I vs V_g of the sample recorded in vacuum after UV illumination.

Experimental setup





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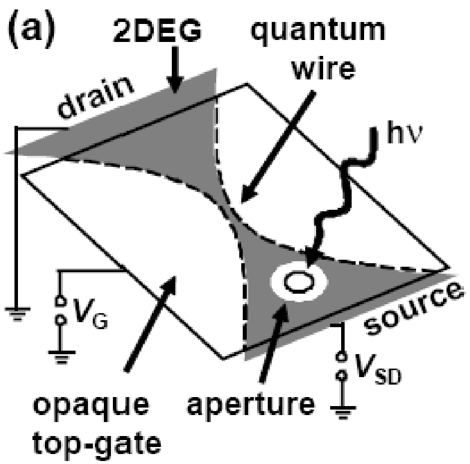
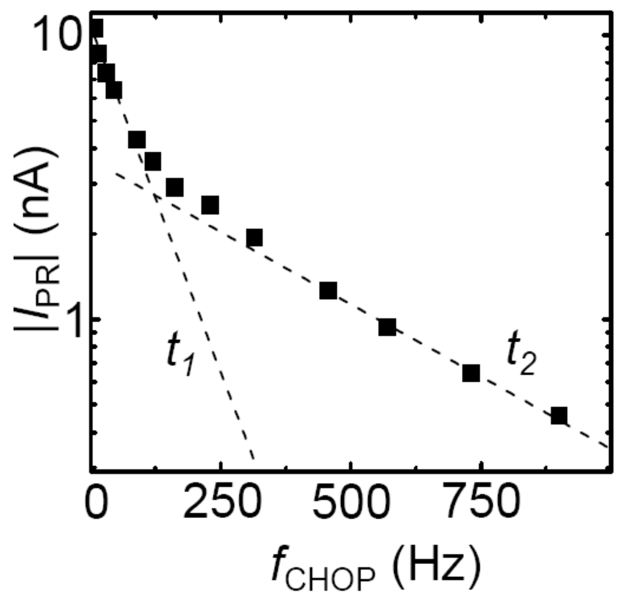
Dynamic photoconductive gain effect

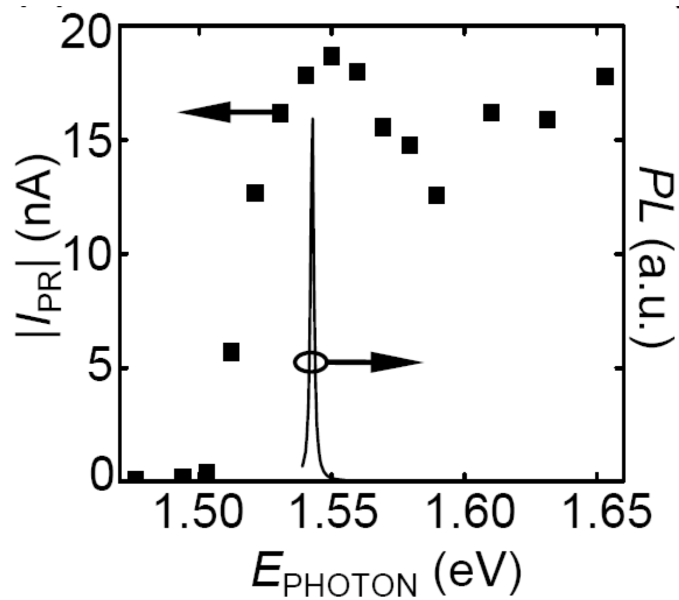
Experimental device



time –resolved measurement



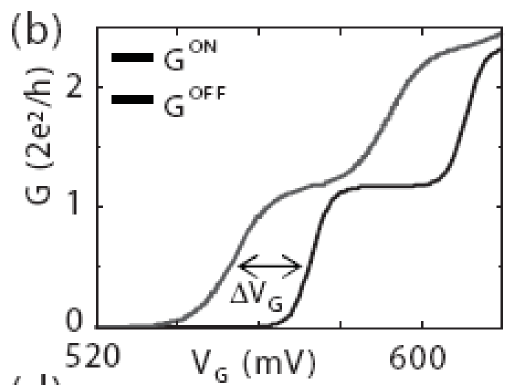
Energy-resolved measurement

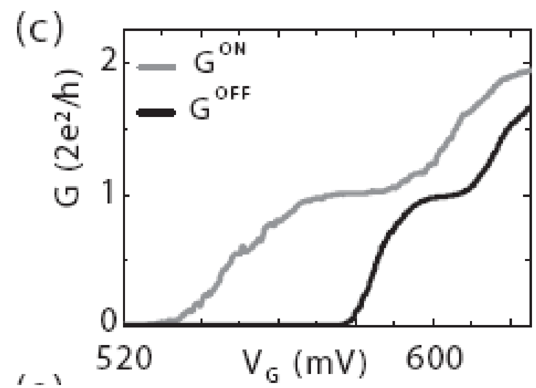


Conductance vs. gate voltage:

b) theoretical model

c) experiment





data from [2]

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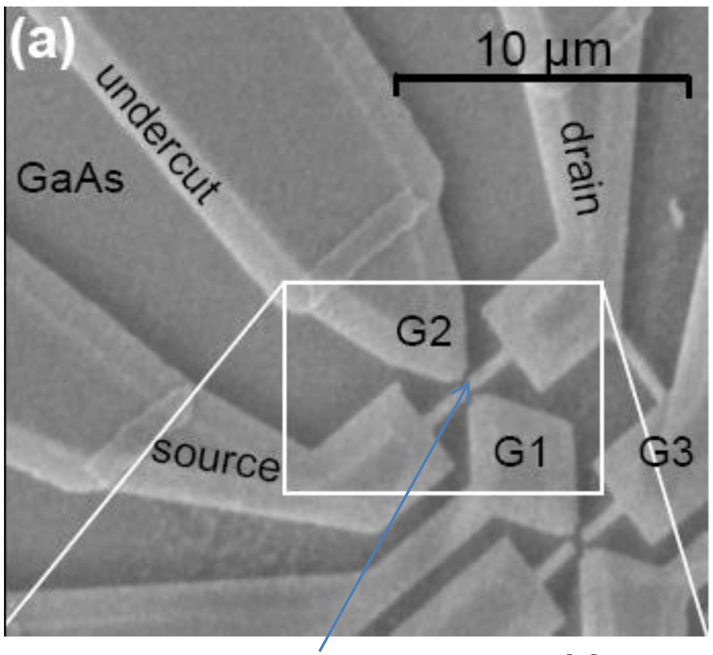
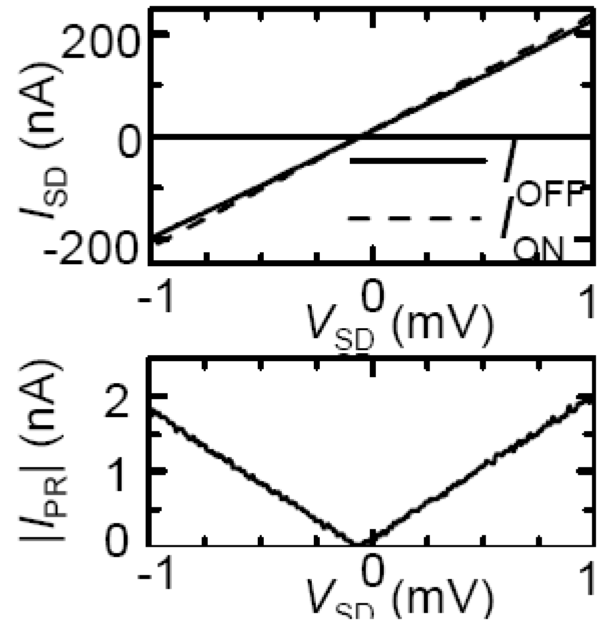
Optically induced transport properties



freely suspended channel, containing a 2DEG [1]



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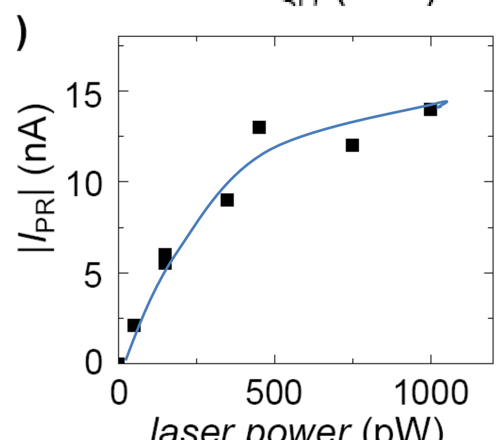
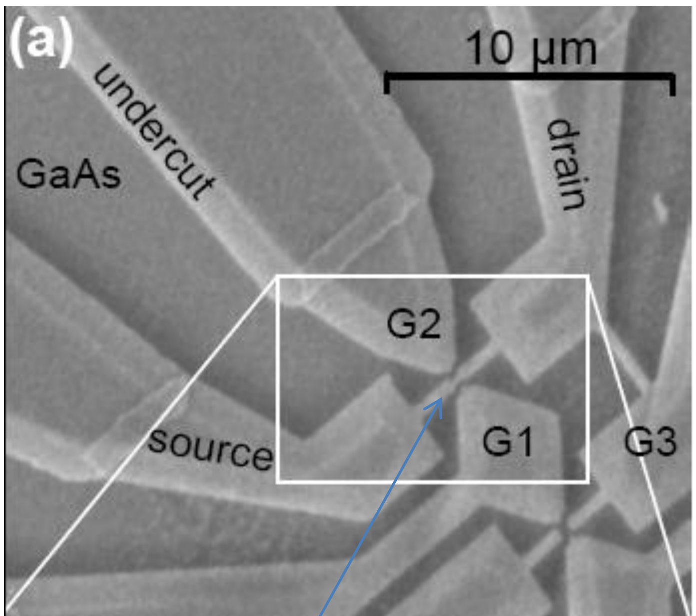


[1]

Spatially resolved measurements

in a freely suspended channel containing a 2DEG



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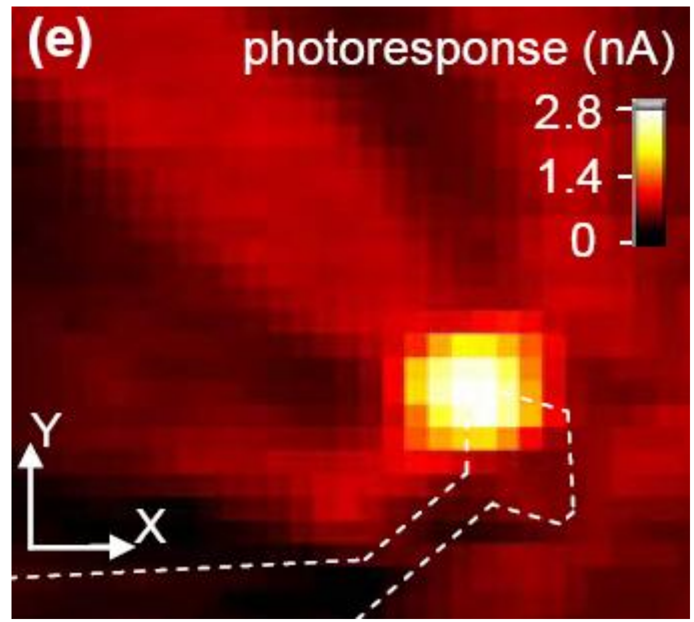

[1]

freely suspended channel,
containing a 2DEG

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Literature

[1] C. Rossler, K.-D. Hof, S. Manus, S. Ludwig, J.P. Kotthaus, J.Simon, A. W. Holleitner, D. Schuh, W. Wegscheider: „Optically induced transport properties of freely suspended semiconductor submicron channels“

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[8] www.wikipedia.org

[9] http://www1.tu-darmstadt.de/fb/ms/fg/ofl/lehre/scripte/schottky.pdf

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!!!   Thank you for your attention   !!!

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