Photocurrent measurement techniques
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
Photocurrent/-voltage (p-n junction)

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

Band alignment after contacting

Distribution of the space charge

Qualitative distribution of donors, acceptors, electrons and holes

Schematic view of a p-n junction in thermal equilibrium

\[ eV_D = E_g + k_B T \ln \left( \frac{n_i^2}{n_{\text{eff}}^2} \right) = E_g + k_B T \ln \left( \frac{n_n^2}{n_{\text{eff}}^2} \frac{p_p^2}{p_{\text{eff}}^2} \right) \]

[5]
Photocurrent/voltage (p-n junction)

forward-biasing

reverse-biasing

\[ J(U) = \left( \frac{eD_p}{L_p} p_n + \frac{eD_n}{L_n} n_p \right) \left( eU/k_B T - 1 \right) \]
Photocurrent/-voltage (Schottky – contact)

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

Band alignment after contacting

\[ J(U) = J_s \left( e^{eU/k_B T} - 1 \right) \]

→ same I-U characteristic as for a p-n junction
Photocurrent/-voltage (Schottky – contact)

a) Radiation produces electron-hole pairs

b) Smaller energy than $E_g$: photoexcited electrons in the metal can surmount the barrier and be collected by the semiconductor “internal photoemission”
What is photoconductance?

→ It is the first derivative of the current $I$ with respect to the Voltage $V$:

$$\frac{dI_{pc}}{dV_{SD}}$$

Here we have a very clear PR $\approx 10^{-2}$, often it is $\approx 10^{-6}$.

[1]
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!

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 increased 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

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

\[ \text{O}_2 \text{ (radical)} \]

\[ \begin{array}{c}
\text{C} \\
\text{C} \\
\text{C} \\
\text{C}
\end{array} \]

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

SWNTs

FIG. 1. (a) Normalized conductance [initial conductance $G_r=(1.0 \text{ M}\Omega)^{-1}$] 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 $1.5 \text{ nm}$ measured from atomic-force microscopy topography (inset). (b) Conductance response to UV illumination in a $10^{-6} \text{Torr}$ vacuum. Solid line: curve fitting of $G \sim \exp(-\alpha F)$. (c) Current ($I$) vs gate voltage ($V_g$) recorded under a bias voltage of $100 \text{ m}\text{V}$ in air prior to any UV illumination. (d) $I$ vs $V_g$ of the sample recorded in vacuum after UV illumination.
Experimental setup

- Laser
- Chopper
- OPV
- Lock-In
- Drain
- Source
- Back-gate
- x-axis
- y-axis
- Ti:Sa
- NL Fiber
- BBO (Beta Barium borate)

Photocurrent measurement techniques (Nanosystems I - Seminar - 1.12.08 @ WSI)

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**Dynamic photoconductive gain effect**

Experimental device:
- 2DEG
- Quantum wire
- Drain
- Source
- Opaque top-gate
- Aperture

**Conductance vs. gate voltage:**
- b) theoretical model
- c) experiment

Data from [2]
Optically induced transport properties

freely suspended channel, containing a 2DEG

[1]
Spatially resolved measurements

in a freely suspended channel containing a 2DEG

freely suspended channel, containing a 2DEG

[1]
Literature


!!! Thank you for your attention !!!

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