Lab 3. Fabrication and characterization of photoactive lateral devices

Organic Materials for Energy and Optoelectronics

Equipment and applicated solutions:

- Plasma cleaner;
- Spin coater NEWBY;
- Evaporator (vacuum chamber) MBraun;
- Keithley 5420A;
- X-Ray Powder Diffractometer (Bruker D8 Advance);
- Monochromatic lasers:
    - Blue (λ = 450 nm);
    - Red (λ = 640 nm);
    - IR (λ = 860 nm).

- Glass substrates;
- Zinc telluride powder (ZnTe) + tungsten boat;
- 15 mg/mL solution of poly(3-hexylthiophene) (P3HT) in chlorobenzene;
- Ag pieces.

This Lab work is devoted to the approaches on fabrication the semiconductor-based lateral devices (Figure 1) and on their photo response discovering. Here, two different semiconductors are presented: ZnTe (inorganic) and P3HT (organic).

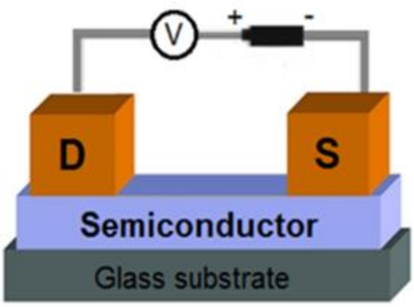

Figure 1. The architecture of lateral device. D is a drain electrode; S is a source electrode.

Progress of Lab work

Step 0. Glass substrates preparation (will be completed and provided to students)

Step 1. Glass substrates cleaning

- Take the substrates out from acetone solution and put them on foil;
- Put the foil inside the plasma cleaner and evacuate the air from it;
- When pressure reduces to 0.2-0.3 mbar; turn on the air flow to keep the pressure constant, then turn on plasma;
- After the cleaning process (10 min) turn it out and fill the cleaner with air. Put the substrate out of the cleaner.

Step 2. ZnTe layer preparation (substrates 1-5)

- Prepare the ZnTe powder for evaporation by placing it on the tungsten boat;
- Close the chamber and evacuate atmosphere inside it;
- Make sure that rotary holder and shutter are turned off (white buttons);
- Turn on the deposition controller (Inficon SQC-310C);
- Wait for the pressure reducing ($2\cdot10^{-5}$ mbar or less);
- Choose the preset program for V_2O_5 evaporation;
- Press "Start layer";
- Increase the power and then regulate %;
- After 20 s continue to slightly increase the power to approx. 13-15% and then regulate it to keep the evaporation rate in range of 0.80-1.50 Å s^{-1};
- Wait the creation of 3-5 nm thickness layer, after:
    - Turn on the rotary holder (green button);
    - Simultaneously press "Zero" button on deposition controller and turn on the shutter (green button);
- Proceed the evaporation process and stop it when the layer thickness reaches 250 nm by turning off the rotary holder and shutter;
- After the evaporation process, heat the substrates on plate for 5 min at 300°C.

- Use Bruker diffractometer to make XRD spectrum of the sample 1 and identify its phase composition using DIFFRAC.EVA soft on the operator's computer.

Step 3. P3HT layer preparation

- Set the following parameters of rotation mode: rpm, 1400 rpm, 30 s;
- Turn on the rotation and drop 65 µL of P3HT solution sharply;
- Heat the resulted substrate for 5 min at 70°C.

Step 4. Ag electrode deposition

- Use the main action sequence for evaporation chamber exploitation using next parameters:
  - Average power of 20-25%;
  - Average deposition rate of 1.0-2.0 Å s^{-1};
  - Aimed thickness of 100-150 nm;
- Turn off the source and fill the chamber with atmosphere.

Step 5. Current-voltage measurements of devices (using and not using lasers)

- Turn on the equipment (Keithley and Advantest) and the software (LabTracer and LabView) for the measurements;
- Put the D and S contacts on the silver electrodes on the device;
- Switch on the laser to the system and adjust it so that the light beam shines on the interelectode channel (surface of semiconductor layer between silver electrodes);

- “Dark regime” measurement parameters:
  - LabTracer: set the linear voltage sweep (0-200 V) with 2001 measurement points;
  - Start the measurement process and then save the data.

- “Light regime” measurement parameters:
  - LabTracer: set the linear voltage sweep (0-200 V) with 2001 measurement points;
  - LabView: set voltage (individual for each laser) and current in range of 25-75 mA depending on laser and preferred intensity of light beam;
  - LabView: set period – 40 s, active time – 39.99 s, number of cycles – 1;
  - First, turn on the laser, then turn on the voltage sweep; save the collected data.

- “Laser pulse regime” measurement parameters;
  - LabTracer: set the linear voltage sweep (100-100 V = const) with 6001 measurement points;
  - LabView: set voltage (individual for each laser) and current in range of 25-75 mA depending on laser and preferred intensity of light beam;
  - LabView: set period – 2 s, active time – 1 s, number of cycles – 30;
  - First, turn on the voltage sweep, then turn on the laser; save the collected data.

Tasks for the Lab analysis

1. Taking the measured I-V data (voltage *Vds_2* [V] – on ***x*** axis; current *Ids_2* [nA] – on ***y*** axis), plot the "dark" and "light" curves on the same graph with different input laser intensity (mA) values for the same device and laser:

- Graph 1 – P3HT-based device, blue laser (4 plots: dark + 3 light);
- Graph 5 – P3HT-based device, red laser (2 plots: dark + light);
- Graph 7 – P3HT-based device, IR laser (2 plots: dark + light);
- Graph 9 – ZnTe-based device, blue laser (2 plots: dark + 75mA-light).

2. Plot the "laser pulse" curves for P3HT-based device (time *Time Ch_2* [s] – on ***x*** axis; current *Ids_2* [nA] – on ***y*** axis):

- Graphs 2-4: blue laser, 3 different intensity values of laser;*
- Graph 6: red laser;*
- Graph 8: IR laser.*

For Graphs 2-4, estimate the difference in current ΔI_{ds} during the switching of laser on and off (induced photocurrent magnitude).

Quantitatively estimate the difference in behavior of P3HT-based device when irradiated by 3 different lasers (Question 1).

3. Plot the "laser pulse" curves for ZnTe-based device (time *Time Ch_2* [s] – on ***x*** axis; current *Ids_2* [nA] – on ***y*** axis):

- Graphs 10-12: blue laser, 3 different intensity values of laser.*

** you can cut some part of plots remaining only first 30-40 s of measurement process.*

Questions for the Lab analysis

1. What causes the difference in photo response of P3HT-based when different lasers are used? Provide the answer with physical parameter(s) of P3HT material.

2. Estimate the wavelength of the laser beam which might theoretically cause the photo response of zinc telluride (ZnTe).

3. What are the general figures of merit using for the photodetectors characterization: photoresponsivity (P) and responsivity (R)? Provide the corresponding formulas of them from literature.