Óbuda University
Kandó Kálmán Electrical Engineering Faculty
Institute of Microelectronics and Technology

Micro- and nanotechnology (KMENT14NEC, KMENT1ETND)

Laboratory program

Measurements guide

5. Study of vacuum photodiode

1. Theoretical background

If the metal is radiated by a proper wavelength light, then electrons will leave the metal surface. This is known as photoelectric effect. The photoelectric effect is characterized by the following facts:

- The photoelectric effect is taking place only if the frequency of the applied light is greater than a given value which is characteristic to the studied metal.
- The electron emission takes place immediately (or never happens) independently on the intensity of the light.
- The number of the emitted electrons is a linear function of the light intensity, but the maximum energy of the electrons depends only on the light's frequency.

This behavior could be explained only by the photon hypothesis of the light. According to Albert Einstein the energy of the light is carried by its photons and its energy quantum is equal to:

$$E_{\text{photon}} = h\nu$$

where h is the Planck constant (6.63x10^{-34} Js) and ν is the frequency of the light.

If the incident photons energy is higher than the work function of the metal (the required energy value of electrons to leave the metal) then the electrons accepting the photons energy could leave the metal with the energy:

$$E_{\text{electron}} = E_{\text{photon}} - W_{\text{metal}} = h\nu - W_{\text{metal}}$$

where W_{metal} is the metal's work function.

Naturally this energy value is the maxima since the electrons could lose some energy colliding with the other electrons in the metal.

To keep the electrons in the metal an extra potential should be applied which is equal to:

$$U_0 = \frac{E_{\text{electron}}}{q} = \frac{h}{q}\nu - \frac{W_{\text{metal}}}{q}$$

where q=1.605x10^{-19} As is the unit charge of the electron.
As we can see, this potential is a linear function of the light's frequency. Getting its value at some different light's frequencies makes the work function's determination to be possible.
To demonstrate the photoelectric effect a vacuum photodiode is applied. The vacuum photodiode (or vacuum photocell) is a vacuum diode with a photosensitive cathode. The Figure 1 is showing the structure and a basic measuring setup of a vacuum photodiode.

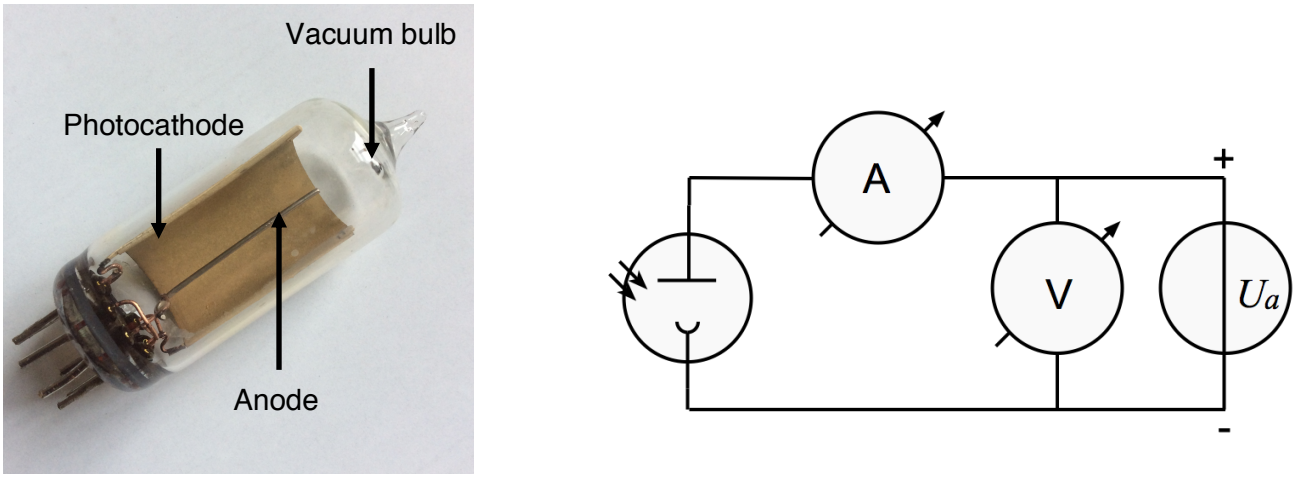

FIGURE 1.

THE STRUCTURE AND THE MEASURING SETUP OF THE VACUUM PHOTODIODE

Usually constant positive U_a applied (about 15V). Due to the incident light the cathode is issuing electrons which are producing anode current proportional to the incident light flux. At a constant light flux (and wavelength) the current — voltage characteristics looks as it is shown in Fig. 2.

In the case of the real vacuum photodiode the materials of cathode and anode are different what results a work function difference between the electrodes. This work function difference results the so-called contact potential (marked with U_{contact} on the Fig. 2).

$$|U_0| = |U_{\text{out}}| + |U_{\text{contact}}|$$

The full switch-off potential can be found as:
At any wavelength of the light the current — voltage characteristics could be measured. Based on them the switch-off potential versus light's frequency plot is obtainable, see Fig. 3. The axis' intersections result the work function of the cathode's material and the minima value of light frequency resulting electron's release.

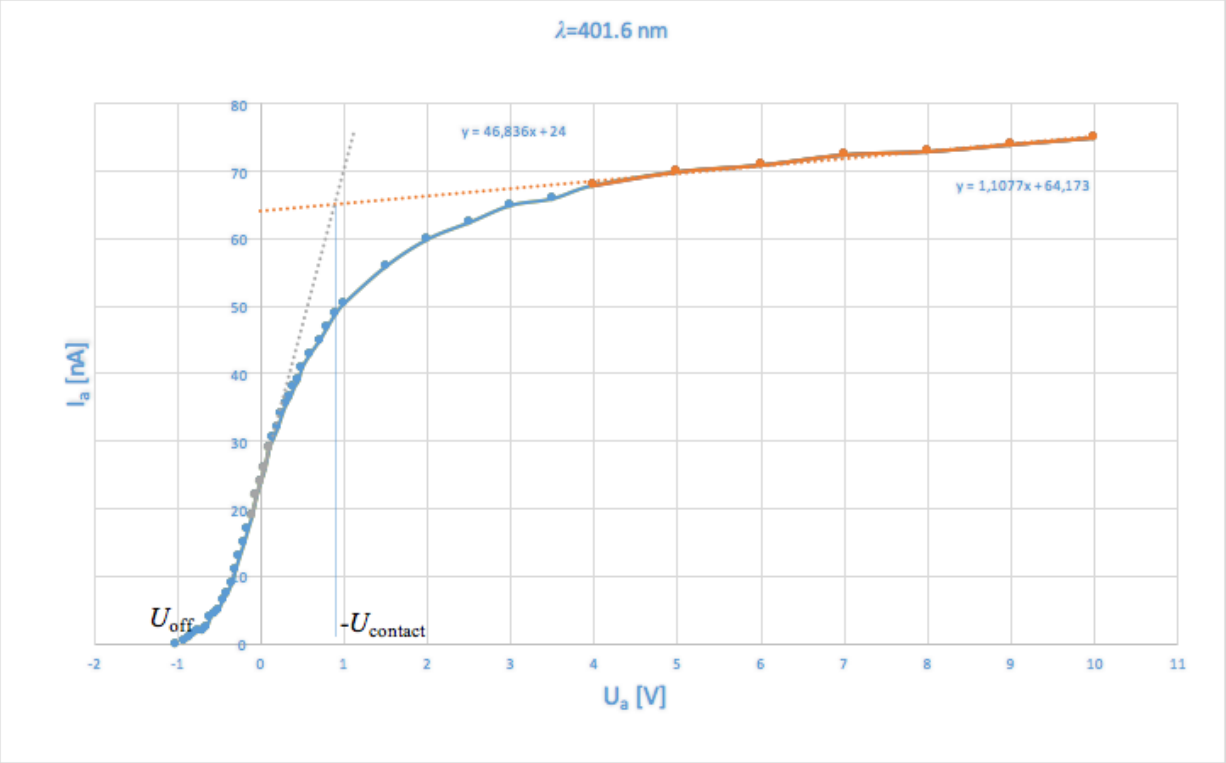

FIG. 2.
CURRENT-VOLTAGE CHARACTERISTICS OF A VACUUM PHOTODIODE

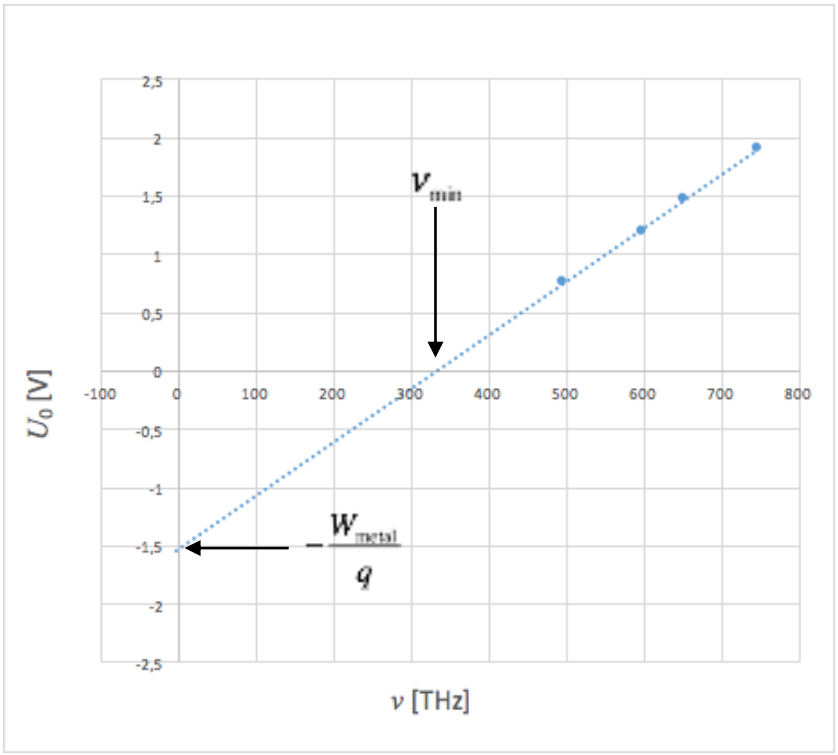

FIG. 3.
DETERMINATION OF THE CATHODE'S WORK FUNCTION

2. The measurement's setup

The light source, the fixture of the color filters and the vacuum photocell itself are mounted into one unit shown in Fig. 4.

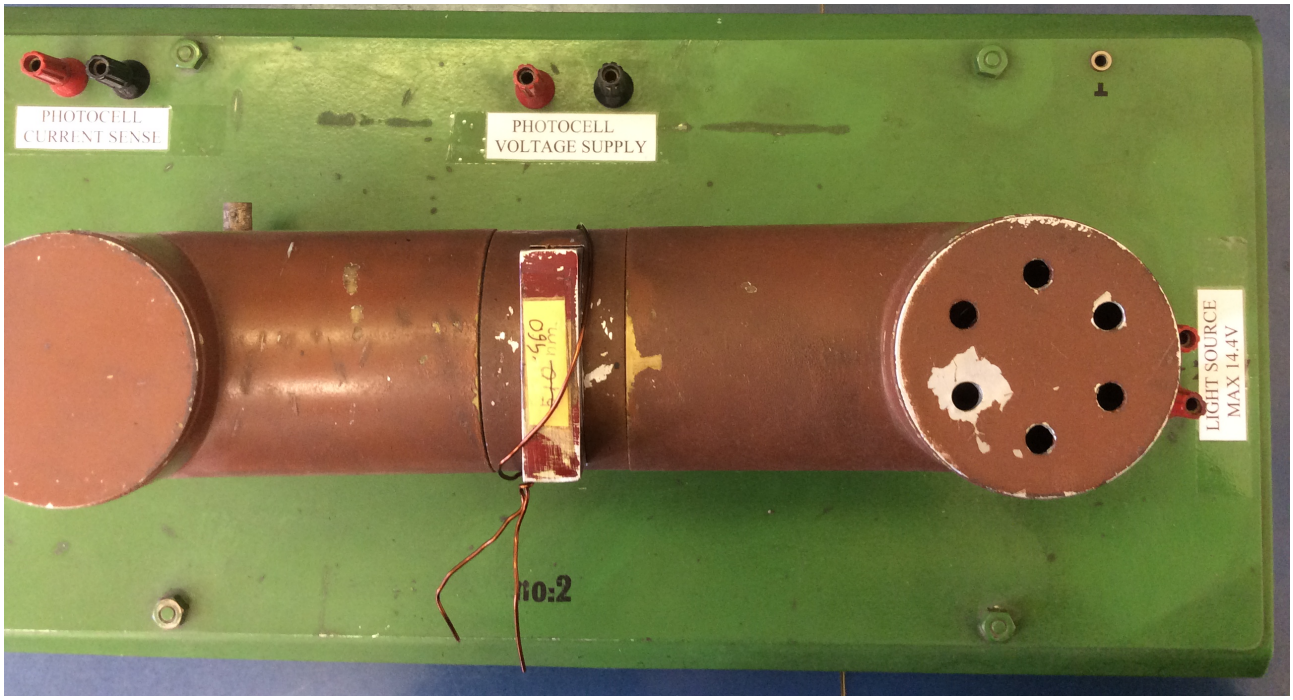

FIG. 4.
THE MEASUREMENT'S FIXTURE (TOP VIEW)

In addition, the measurement requires:

- The different color filters, its wavelength is marked on their frame (4 pc).
- The power supply (QJ-3005SH III) to ensure the necessary biases.
- The nano-ampere meter to measure the anode current (V640)
- The voltage meter to measure the anode bias (HM8012)

3. The test procedure

1. The test circuit should be wired according to the Fig. 5. The power supplies must be switched off!
2. A color filter has to be placed in its fixture. The fixture contains a safety switch which is turning off the lamp's circuit to avoid over-lighting the photocell with white light if the filter would be removed. The filter should be pushed down continuously to operate the system!
3. The bias of the photocell to be sat to 10 V, the light source's bias to be adjusted to reach 75 nA anode current.
4. The current—voltage curve to be measured starting at 10 V till the anode current reaches zero value.
5. Steps 2,3,4 performed for all supplied color filter.
6. The measured characteristics to be documented (tables and graphs!)
7. The switch-off potential to be calculated applying the best fit lines as it is shown on Fig. 2.

8. The work-function of the cathode material and the limit frequency to be calculated, according to Fig. 3.

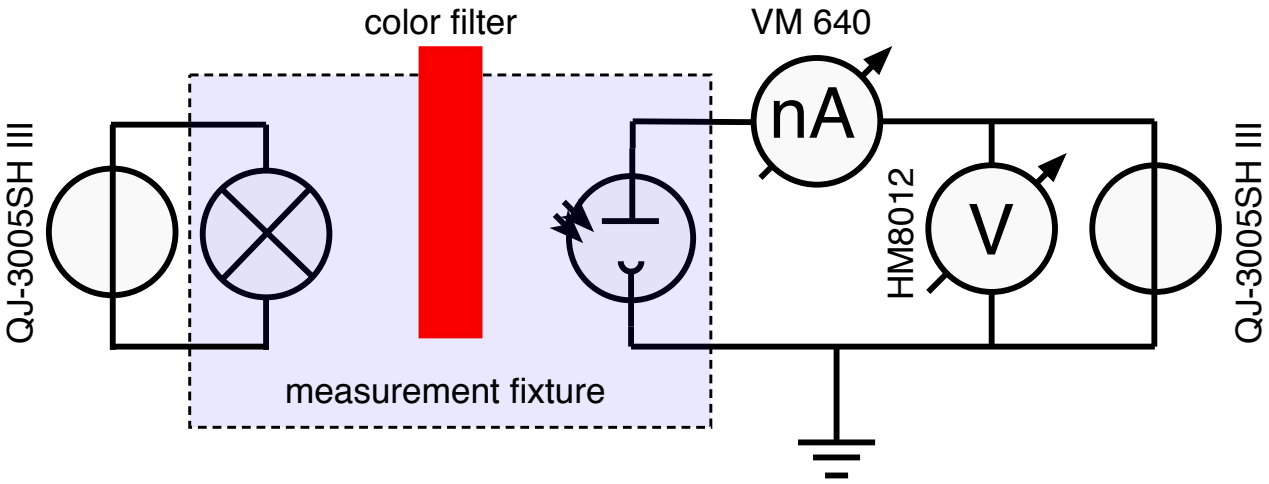

FIG. 5.
THE MEASUREMENT SETUP

4. Review questions

- What is the reason of having contact potential in the vacuum photodiode?
- What is the relation between the wavelength of the light and its photon's energy?
- Sketch the current—voltage characteristics of the vacuum photodiode!
- Why do we need the grounding during the measurement?
- What is the switch-off voltage?
- Why do we use the mirror-scale at the Deprez's unit?

5. Measurement protocol

Each measuring group is asked to give in one protocol. The protocols could be preferably submitted through e-mail latest after two weeks of the measurement performed.

The protocol has to contain:

1. The title of the measurement
2. The names of the colleagues performing the task
3. The date and location of the measurement
4. A declaration stating that the task is performed by the enumerated colleagues
5. The list of applied equipment with types and identification numbers
6. The tabulated list of the measured values, the calculated values, and the requested graphs
7. In the case of calculations, the applied forms
8. Short discussion of the results for each measurement task

PLEASE do not copy previous protocols. Identical protocols will be refused.