Deney 5 Fotovoltaik Hücreler

Chapter 10

PHOTOVOLTAIC CELL

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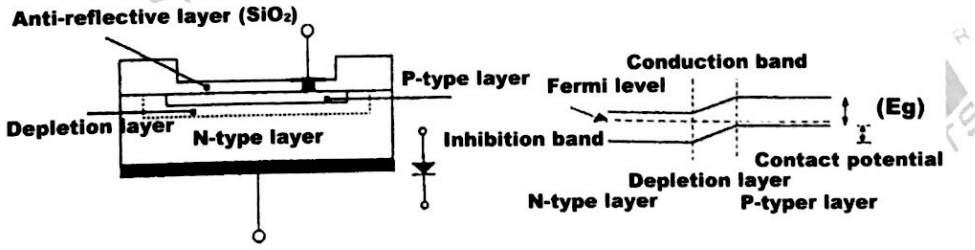
10.1 OBJECTIVES

1. Understanding the characteristics of a photovoltaic cell.
2. Understanding the principle of photo-to-electric conversion.
3. Study the applications of photovoltaic cells.

10.2 DISCUSSION OF FUNDAMENTALS

The photovoltaic cell is unique that converts light energy into electrical energy without the aid of any external excitation power. The magnitude of its light-sensitive electrical output signal (current or voltage) is directly proportional to the light intensity it's exposed to. It is often refer to as "solar cell" because they provide a source of electrical power from exposure to sunlight.

Modern photovoltaic cells are made from semiconductor materials. Different impurities are introduced to opposite ends of materials such as silicon or germanium, making one ends the P-type and the other the N-type. The P-N junction between them is the potential barrier, as shown in Figure 10-1(a). The voltage gradient is formed in the depletion region because the energy level in the P-type layer is higher than the energy level in the N-type layer (see Figure 10-1(b)).



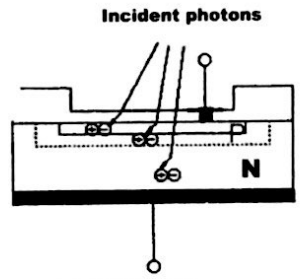
(a) Cross-section view (b) Energy levels

Figure 10-1 Construction of a photovoltaic cell

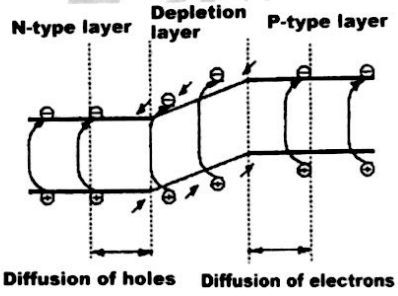
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Most of the silicon photovoltaic cells ("silicon cells") are of the P or N type, as shown in Figure 10-2(a). The upper surface (P-type layer) is a light-transparent layer. The P-N junction acts as a permanent electrical field. When the P-type layer is illuminated, the incident photons cause a flow of electrons and holes. The electric field at the P-N junction directs the flow of electrons toward the N-type layer and the flow of holes toward the P-type layer. The resulting unbalance of charges within the cell will causes an EMF to be developed between two layers (see Figure 10-2(b)).

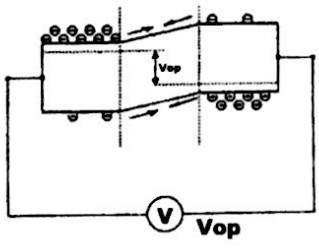
The EMF can be measured with a high-sensitivity voltmeter, as shown in Figure 10-2(c). Vop refers to the open-circuit voltage Vop of photovoltaic cell. When a load resistor is connected across the surfaces, electrons and holes carriers flow through the circuit until a state of balance, called "equilibrium", is achieved. If the load resistor is replaced by a wire, the current in the circuit is called the short circuit current Ish (see Figure 10-2(d)).



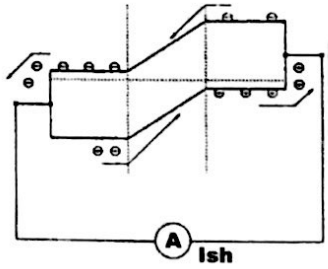
(a) Light illuminated



(b) Carriers diffusion



(c) Vop measurement

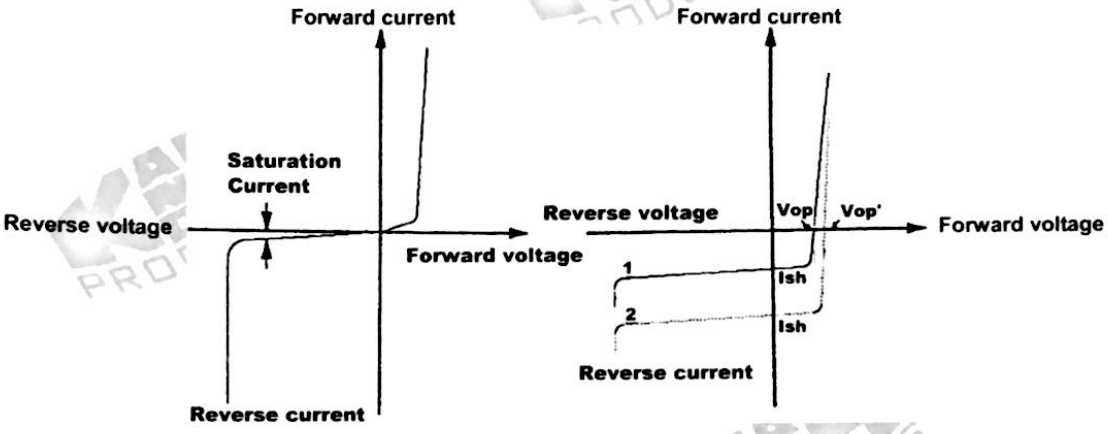


(d) Ish measurement

Figure 10-2 Operation of a photovoltaic cell

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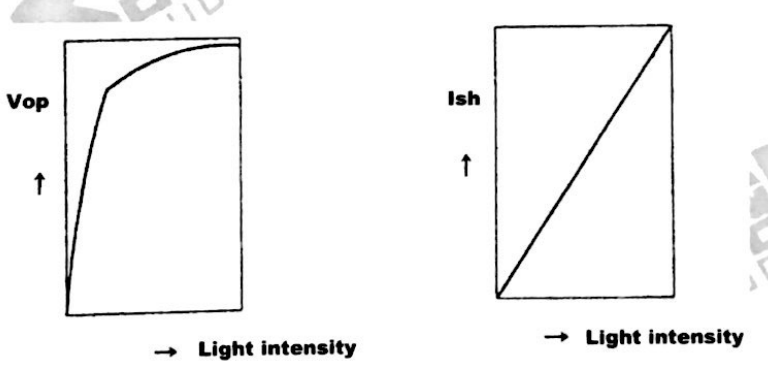
If a photovoltaic detector is not illuminated, the V-I characteristic shown in Figure 10-3(a) is similar to a general-purpose diode. In Figure 10-3(b), the curve no.1 is the V-I characteristic of the photovoltaic cell excited by a weak illumination, and the curve no.2 is of the photovoltaic cell excited by a strong illumination.



(a) Without excitation (b) With excitation.

Figure 10-3 V-I Characteristics of the photovoltaic cell

Figure 10-4 shows the intensity of incident light vs. output signals of a photovoltaic cell. The Vop vs. the light intensity characteristic is a logarithmic curve, whereas the Ish vs. the light intensity is linear.



(a) Vop vs. light intensity (b) Ish vs. light intensity

Figure 10-4 Incident light vs. output signals

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The output current is commonly used for measuring illumination purposes. In many applications, the I-to-V converters are used for converting the output current into an output voltage. A typical I-to-V converter is shown in Figure 10-5. The output voltage Vo can be obtained by the following equation:

$$V_o = - (I_{sh} \times R_f)$$

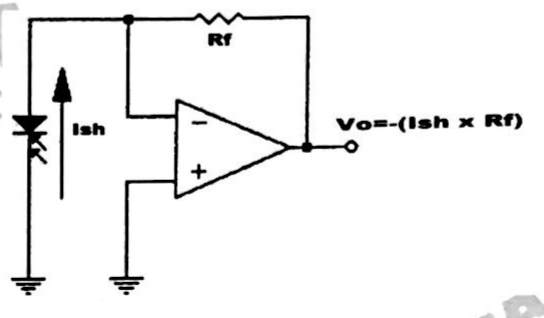


Figure 10-5 A typical I to V converter

When a load resistance is connected across the terminals, the value of resistance will change the linearity of Ish vs. illumination curve as shown in Figure 10-6. With a high resistance, the operating point is located in the nonlinear region.

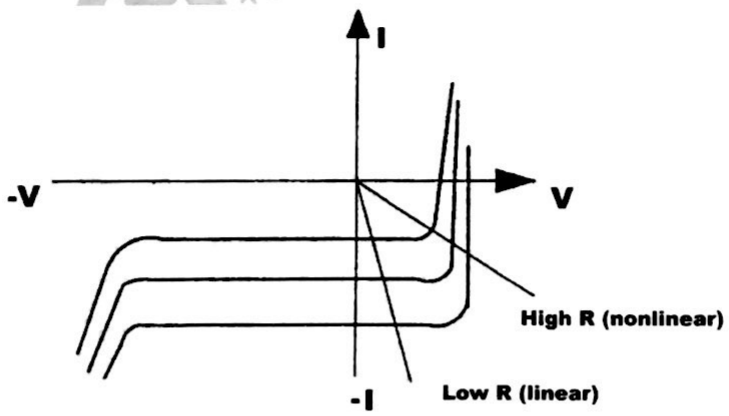


Figure 10-6 Load lines

An ideal equivalent DC photovoltaic circuit cell is shown in Figure 10-7(a). Its voltage and current characteristics are:

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$$I = I_L - I_D$$

$$= I_L - I_S [\exp(qV/nKT)-1] \quad (1)$$

$$I_L = \beta q R_T \quad (2)$$

Where I_S = reverse saturation current of photovoltaic cell

K = Boltzmann's constant

T = Absolute temperature

n = 1 or 2

b = Collective efficiency of electron-hole pairings

q = Electron charge 1.6×10^{-19} Coulombs

R_T = The number of effective photons absorbed by photovoltaic cell

Assume V=0 in Eq.(1), then $1 = I_{sh}$

$$I = I_{sh}$$

$$= I_L - I_S [\exp(0) - 1]$$

$$= I_L$$

$$= \beta q R_T \quad (3)$$

Let I = 0 in Eq. 1, then $V = V_{OP}$

$$0 = I_L - I_S [\exp(qV_{OP} / nKT) - 1]$$

$$V_{OP} = (nKT / q) \ln (I_L / I_S + 1) \quad (4)$$

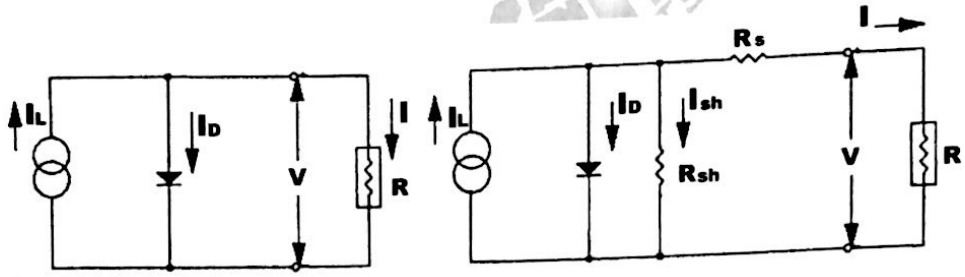
From equations (3) and (4) we find that I_{sh} is proportional to the illumination (linear) and the V_{OP} vs. illumination curve is a logarithmic curve (nonlinear), due to R_T, which is also proportional to the illumination.

The practical equivalent circuit of photovoltaic cell, shown in Figure 10-7(b), which includes the contact resistance, R_S and the inherent parallel resistance R_{sh}. The characteristics of current and voltage are given by:

$$I = I_L - I_S(\exp [q / nKT (V + IR_S)] - 1 (V + IR_S) / R_{sh} \quad (5)$$

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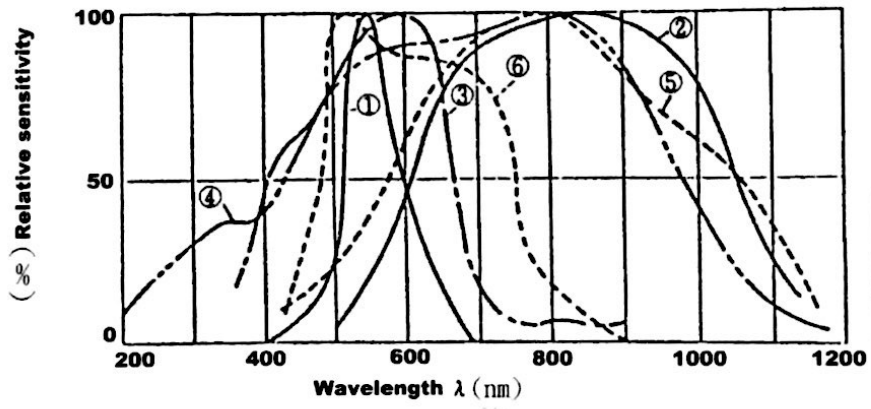
The factors R_{sh} and R_S can be ignored in actual applications since R_{sh} is very large and R_S is very small.



(a) Ideal (b) Actual application

Figure 10-7 Equivalent circuits of the photovoltaic cell

When a photovoltaic cell is illuminated, the magnitude of current is dependent on factors such as wavelength, material, shape, and the location of P-N junction. Figure 10-8 shows the relative spectral response of photovoltaic cell (silicon cell) compared with spectral characteristics of the human eye and various photoconductors. The response peak of the human eye is around 550nm(blue), where as the response of the silicon cell has its peak around 800nm(near IR).



① Human eye
② Photovoltaic cell
③ Photodiode for camera
④ Photodiode for UV
⑤ Phototransistor
⑥ Cds photoconductive cell

Figure 10-8 Relative sensitivity vs. wavelength characteristics

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The unit of luminous flux is the lumen (lm), defined as the flux emitted within a solid angle of one steradian by a point source having a uniform intensity of 1 candela. An unit of illuminance is the lux (lx), which is the illumination of one lumen per square meter($1lx=1lm/m^2$). Other units for illuminance include ph, fc, and W/cm^2. The conversions of various units are shown in Figure 10-9.

ℓ x (ℓ m / m^2)	Ph (ℓ m / cm^2)	Fc (ℓ m / ft^2)	W / cm^2
1	$1.000x10^{-4}$	$9.290x10^{-2}$	$\approx 5.0x10^{-6}$
$1.000x10^{4}$	1	$9.290x10^{2}$	$\approx 5.0x10^{-2}$
$1.076x10^{1}$	$1.076x10^{-3}$	1	$\approx 5.4x10^{-5}$
$\approx 2.0x10^{5}$	$\approx 2.0x10^{1}$	$\approx 1.9x10^{4}$	1

Figure 10-9 Illumination unit conversions

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10.3 DESCRIPTION OF EXPERIMENTAL CIRCUITS

The circuit of photovoltaic transducer is shown in Figure 10-10. This circuit is used to convert the illumination into output voltages. The photovoltaic set combines four identical cells in series has a V_{OP} about 2V and a Ish about 0.08 A/lx.

The OP AMP U1 and resistors R6 and R7 perform the I to V conversion which converts the short-circuit current Ish into an output voltage. The output voltage V_O is given by Ish (R6+R7). R7 acts as a span adjustment to obtain an output voltage of 1mV/lx.

An AC power supply, 110V at 60 Hz, is used for a brightness regulator. A 120Hz ripple will be present at U1 output terminal. The low-pass filter consisted of R8 and C1 is used to filter the ripple. U2 is a voltage follower.

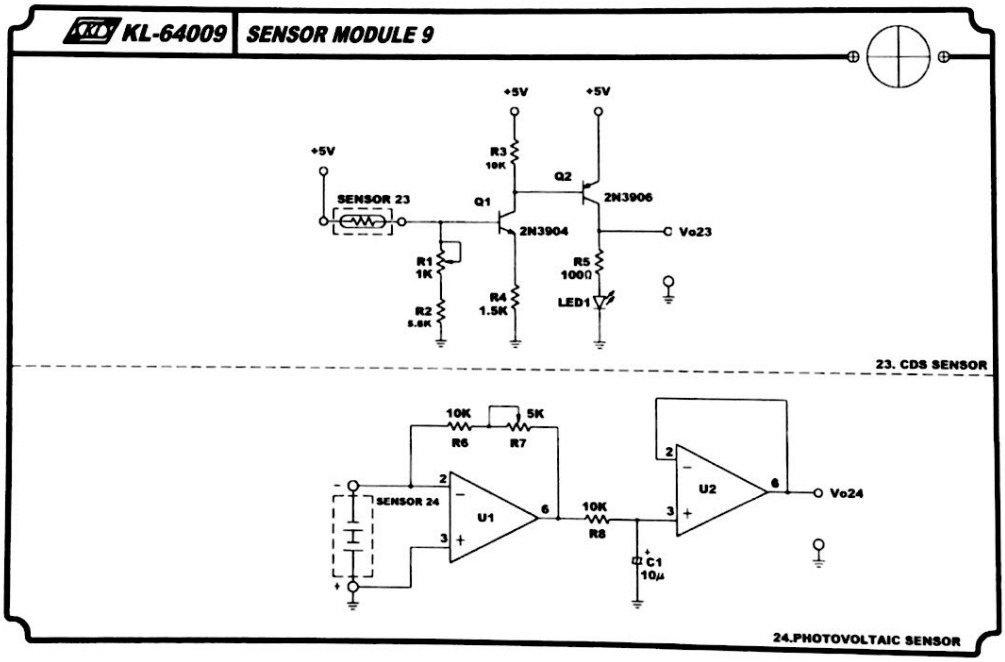


Figure 10-10 photovoltaic transducer circuit

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A digital illuminometer shown in Figure 10-11 is built with the photovoltaic transducer module and the 7135 A/D converter. Since the transduction output of photovoltaic transducer is 1mV/lx, the RANGE switch must be set to LUX position with the unit of lx.

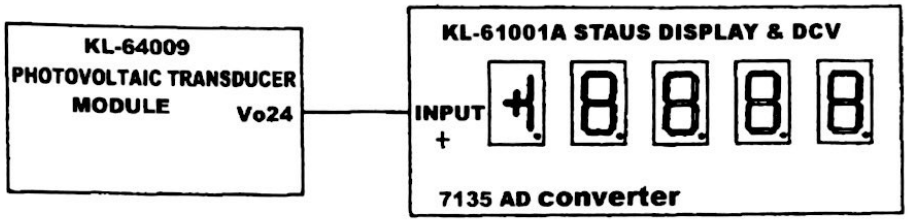


Figure 10-11 Digital illuminometer

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10.4 EQUIPMENTS REQUIRED

1 - DMM

2 - KL-61001A Trainer

3 - Module KL-64009

10.5 EXPERIMENTS AND RECORDS

10.5.1 Photovoltaic characteristics

1. Place module KL-64009 Block 24 on the KL-61001A. (Keep power OFF.)
2. Set each illumination in Table 10-1 with a dimming light. Using the DMM, Measure and record the V_{OP} and I_{sh} for each illumination in Table 10-1.

Table 10-1

Illumination	Dark	Dim	Half	Full
Vop				
Ish				

3. Discuss the relationship between Vop, Ish and illumination.

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10.5.2 Computer control

1. Complete the following connections:

SECTION	AREA	SIGNAL TO SECTION		AREA	SIGNAL
SINGLE CHIP	OUT CONTROL	1	→ AMPLIFIER	ALARM AMPLIFIER	SIN IN
KL-64009	PHOTOVOLTAIC SENSOR	Vo24	→ A/D CONVERTER	CONTROL	A/D IN
KL-64009	PHOTOVOLTAIC SENSOR	GND	→ A/D CONVERTER	CONTROL	GND

2. Place module KL-64009 on the KL-61001A. Supply the power.
3. Complete Table 10-4.

Table 10-4

DIP-switch settings	0819 1000 lx	1638 2000 lx	2457 3000 lx	3276 4000 lx	4095 5000 lx
KL-62001 readout					
OUT CONTROL pin1					
KL-64009 Vo24					

4. When the illumination exceeds the setting, the alarm buzzer should be turned on.
5. Connect the SINGLE CHIP, OUT CONTROL, CTRL to GND.
6. Follow the steps for the USB control in section 4.5.3 and precede the following steps.

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