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Radiation Sensitive Vacuum Electronic Components and Devices

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3.1 Historical Development

The fundamental phenomena, which make possible the function and application of this group of vacuum electronic components and devices, are the external photoelectric effect and secondary electron emission. Electromagnetic radiation with wavelengths in the range of infrared, visible light, ultraviolet or X-rays and particle radiation when hitting the surface of a metal, semiconductor or insulator in a vacuum tube cause the emission of electrons from this surface into the vacuum. By application of electric and/or magnetic fields within the tube, the electron current can be used:

1. for the detection of weak light signals with pulse durations down to the picosecond range and for the detection of particle-, UV- and X-radiation, respectively. In each case the input signals are transformed into small electrical current impulses with subsequent current amplification (secondary electron multipliers);
2. for the conversion and amplification of infrared, visible, ultraviolet or X-ray images into visible intensified light images (image converters, image amplifiers);
3. for the conversion of visible light pictures into electrical currents as input signals for television devices (television camera tubes).

The historical development of these types of radiation sensitive vacuum tubes is characterized by the following detections and inventions:

1887: H. Hertz observes that the ignition voltage of a spark gap decreases when the negative electrode is irradiated with UV light.

1888: W. Hallwachs shows that the effect detected by Hertz is caused by the emission of negatively charged particles from the negative electrode.

1890: J. Elster and H. Geitel, and also P. Lenard show that the charged particles are electrons. Elster and Geitel construct the first vacuum photocells for studying the photoeffect of alkali metals.

1902: L.W. Austin and H. Starke detect the secondary electron emission from metals.
1905: A. Einstein detects the energy equation of the photoelectric effect (Einstein equation).
1928: R. Suhrmann describes the photocurrent amplification by secondary electron emission and the principle of photomultipliers.
1929: V.K. Zworykin invents the first television camera tube (the Iconoscope).
1934: P. Farnsworth and G. Holst describe independently the principle of image converters and image amplifiers.
1950: P.K. Weimer et al. from RCA construct the first photoconductive camera tube (the Vidicon).

3.2 Electrophysical Fundamentals

The function of radiation sensitive vacuum electronic components described in this section is based on photoelectron emission, secondary emission, and electron optics.

3.2.1 Photoelectron Emission

Photons with wavelengths from infrared radiation down to X-rays incident on a solid surface (photocathode) cause the emission of photoelectrons according to the energy equation (Einstein equation)

$$E_\mathrm{k} = hf - W_\mathrm{c}, \tag{3.1}$$

where E_k is the kinetic energy of the emitted photoelectron, h is the Planck constant, f is the frequency of the photon and W_c is the work function of the photocathode. The smallest light frequency f_min or the largest wavelength $\lambda_\mathrm{max} = c/f_\mathrm{min}$ necessary for the emission of photoelectrons ($E_\mathrm{k} = 0$) is defined by

$$f_\mathrm{min} = W_\mathrm{c}/h \quad \text{or} \quad \lambda_\mathrm{max} = hc/W_\mathrm{c}. \tag{3.2}$$

λ_max is the cut-off wavelength of the photocathode. A monochromatic light flux Φ (in lumen, lm) of the frequency f is equal to a power flux Φ_e (in Watt, W) through a cross-section A,

$$\Phi_\mathrm{e} = S_\mathrm{ph} hfA, \tag{3.3}$$

where S_ph is the number of photons incident on the surface per second and cm^2. For the wavelength $\lambda = 555$ nm (maximum eye sensitivity), the relationship between Φ (in lm) and Φ_e (in Watt) is

$$1\ \mathrm{W} = 673\ \mathrm{lm}\ (\lambda = 555\ \mathrm{nm}) \quad \text{or} \quad 1\ \mathrm{lm} = 0.001484\ \mathrm{W}. \tag{3.4}$$

A part r of a light flux Φ_o incident on a solid surface is reflected (r is the reflection factor). The penetrating light flux Φ_a is given by