Photoinjection emission and specific features of plasma–aerosol formations

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Description and elementary theory of a new type of the charged particle emission from the volume-charged emitters under the action of light are presented. I call this type of the emission the "photoinjection emission," which is characterized by variation in the photoeffect cut-off frequency for the emitters made of the same material depending on the excess volume concentration of charged particles in the volume near the surface of the emitter. I isolate the class of processes (injection, photoinjection emission of charged particles and neutral particles) that are caused by the volume-charged state (VCS) of condensed matter. It is assumed that the color shades of the mesospheric clouds are formed owing to the photoinjection emission from the volume-charged aerosols charged by high-energy corpuscular and electromagnetic cosmic radiation at high altitudes in the atmosphere.

Introduction

The basic photoeffect equation establishes the relation between the energy of a quantum producing the photoeffect, photoelectric work function of a metal, and maximum kinetic energy of the resulting photoelectron. The equation has the following form

$$h\nu = E_e + (m_e V^2)/2, \quad (1)$$

where m_e is the electron mass; V is the maximum electron speed, h is the Planck's constant, ν is the light wave frequency.

In this paper I consider the case, when conditions are formed in the volume of the same emitter leading to the change in the maximum wavelength in the spectrum of light absorption and the electron emission ceases above this wavelength (red boundary wavelength). The problem of changing the red boundary for one and the same material is of a pure scientific and applied interest.

As shown in Ref. 1 the excess electron concentration (Δn_e) in the surface layer of the emitter leads to the reduction in the photoelectric work function (E_e) of the emitter by a quantity of the Fermi level energy increase (ΔE_f), according to the expression

$$\Delta E_f = E_{e0} - E_e = E_f(n_{0e} + \Delta n_e) - E_f(n_{0e}), \quad (2)$$

where E_{e0} is the photoelectric work function at $\Delta n_e = 0$, E_e at $\Delta n_e \neq 0$; n_{0e} is the equilibrium electron concentration in the emitter; $E_f(n_{0e} + \Delta n_e)$ is the Fermi level energy at nonequilibrium electron concentration ($n_{0e} + \Delta n_e$), $E_f(n_{0e})$ is the Fermi energy at equilibrium electron concentration (n_{0e}).

As follows from Eq. (2), one can find the photoelectric work function E_e at a nonequilibrium concentration

$$E_e = E_{e0} - [E_f(n_{0e} + \Delta n_e) - E_f(n_{0e})]. \quad (3)$$

From Eqs. (1) and (3), we have

$$E_e = E_{e0} - [E_f(n_{0e} + \Delta n_e) - E_f(n_{0e})] = h\nu - (m_e V^2)/2. \quad (4)$$

As follows from Eq. (4), the E_e value can be positive, zero and negative for the nonequilibrium electron concentrations in the emitter. If positive it causes the property of outer photoemission effect that is allowed for in the formula (1). At minimum light frequency ν_{min}, when kinetic energy of the emitted photoelectrons is equal to zero, we have

$$h\nu_{min} = E_e. \quad (5)$$

From Eqs. (2), (3) and (5), we find

$$\nu_{min} = E_e/h = (E_{e0} - \Delta E_f)/h = C/\lambda_{max}, \quad (6)$$

where C is the speed of light, λ_{max} is the critical light wavelength for the given nonequilibrium electron concentration n_e in the emitter. The photoelectron yield ceases at the light wavelength longer than λ_{max} (λ_{max} can be called red photoeffect boundary at nonequilibrium electron concentration in the near-surface volume of the emitter).

When photoelectric work function takes zero or negative values [from the relation (3)], the electron emission can occur both at any light frequency and without light at all. In this case, the injection emission effect[1] of charged particles is shown from the emitter, when repulsive energy between the particles of excess concentration in the near-surface

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volume exceeds E_{e0} at $\Delta n_e = 0$. Let us note that injection emission can be implemented both for electrons and positive ions of the ion lattice of the emitter, when repulsive energy of the corresponding charged particles becomes higher than their E_{e0} at $\Delta n_e = 0$ and higher than surface tension energy (free energy) of the emitter material being in the condensed state. The emission effect of positive ions from the electrodes was observed when the excess volume charge was acquired by the near-surface layer of the emitted electrons at the expense of the high voltage pulses applied to them with high build-up rate $\sim 10^{14}$ V/s at the potential amplitude $\sim 10^5$ V.[1–3]

In the case of dielectrics and semi-conductors as emitters, the excess volume charge in the near-surface layer as well as the photoinjection emission effect (see above) can cause the development of the internal photoemission effect. It takes place when the field of excess volume charge transfers electrons from the valence band into the conduction band or into the level in the forbidden zone, but close to the upper level of the valence band or to the lower level of the conduction band.

The nonequilibrium volume concentration of elementary charges in different materials in the condensed state can lead to the metals being semi-conductors or insulators at smaller or larger deficiency of the negative volume charge in the metal volume, respectively. Insulators and semi-conductors can prove to be the semi-conductors or conductors, respectively, at smaller or larger excess of the negative volume charge in the volume of insulators and semi-conductors.

The above-mentioned properties of the bodies can be called the "volume-charged states" (VCS). Aerosol particles[4,5] with nonequilibrium volume charge can be considered as the VCS objects.

The properties of VCS at laser sounding of atmospheric aerosols (in the first place, metallic) can be taken into account and used in order to determine the parameters of aerosol particles, for example, their electrization level, Δn_e (excess volume electron concentration in aerosol), refractive index, electric conductivity, etc.).

Actually, the photoinjection emission, as well as ordinary photoemission is the process of absorbing photons by the substance. Energy of these photons exceeds E_{e0} of charged particles (in our case, electrons are meant). Therefore, a sharp drop of the reflected light intensity should be observed in the reflected light spectrum at transition to the incident light wavelengths shorter than λ_{max}. One can determine λ_{max} and E_{e0} by the location of this drop.

As known from the solid-state physics,[6] the Fermi level energy dependence $E_f(n_e)$ on the electron concentration n_e in the substance:

$$E_f(n_{0e}) = (3n_e/8\pi)^{2/3}(h^2/2m_e^*), \qquad (7)$$

where m_e^* is the effective electron mass.

Assuming $n_e = n_{0e} + \Delta n_e$ and using the relations (1) to (7), we shall obtain

$$E_f(n_{0e} + \Delta n_e) = E_{e0} - E_e + E_f(n_{0e}). \qquad (8)$$

If the aerosol substance is known, the values are also known (as reference) E_{e0}, $E_f(n_{0e})$, n_{0e}.

Having determined λ_{max} or ν_{min} by the reflected light spectrum, we shall find E_e from Eq. (5) at their nonequilibrium concentration $(n_{0e} + \Delta n_e)$, equal to $h\nu_{min}$.

From Eq. (8), we shall obtain the value of $E_f(n_{0e} + \Delta n_e)$ for the nonequilibrium electron concentration:

$$E_f(n_{0e} + \Delta n_e) = E_{e0} - h\nu_{min} + E_f(n_{0e}). \qquad (9)$$

Substituting it into Eq. (7), we shall find the value of nonequilibrium electron concentration in the material of volume-charged aerosols:

$$n_{0e} + \Delta n_e = 8\pi/3\{[E_{e0} - h\nu_{min} + E_f(n_{0e})]2m_e^*/h^2\}^{3/2}. \qquad (10)$$

In the first part of expression (10), all the terms, except for $h\nu_{min}$, are the reference data for the given aerosol material. Owing to this, one can easily find their electrization level (excess volume electron concentration Δn_e) and to determine both electrophysical and optical characteristics of the aerosol formations at their laser sounding, using the functional connection between the refractive index and aerosol conductivity with the values of $(n_{0e} + \Delta n_e)$ and Δn_e.

One can assume that aerosol clouds show their properties at photoinjection emission from aerosols, which are volume-charged by the high-energy corpuscular and electromagnetic cosmic radiation at large heights. Various color shades of clouds can be caused by sunlight reflection from aerosol clouds, mainly, in the spectral region at wavelengths exceeding λ_{max}. The radiation of shorter wavelengths should be intensely absorbed due to the loss in photon energy on photoinjection emission of electrons from the volume-charged aerosols similar to losses in the ionosphere.

It should be noted that valid information on aerosol electrization level could be obtained at pulse-periodic laser sounding over the periods sufficient for setting the stationary electrization level after the laser radiation effect. In sounding with constant power of laser radiation, the current of photoinjection emission from aerosols should not exceed the volume charge current of aerosols in the electrization process (electrization).

Henceforth, the VCS properties can be used for control of the electrophysical and optical parameters of different materials such as their reflectivity, extinction, refractive index, dielectric constant, conductivity, photoelectric work function, and in the field of high-voltage, pulsed, and accelerating

technologies and at the development of the photoelectric devices with tunable operation wavelength.

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