N.G. Basov, A.B. Kravchenko, A.F. Plotnikov, and V.E. Shubin, *Self-stabilized avalanche process in a metal-dielectric-semiconductor* (MDS) *structure. Avalanche* MDS *photodetectors*. The avalanche buildup of free-carrier concentrations in solids as a result of impact ionization has attracted the interest of investigators for some time. There are two aspects to the interest in this phenomenon: a physical aspect, determined, among other things, by the importance of this process in the broadly investigated phenomenon of electrical breakdown, and a technical aspect concerned with its successful use in avalance photodetectors and microwave generators. However, it has not yet been possible to produce a spatially uniform, low-noise avalanche with high multiplication coefficients (in the tens and hundreds of thousands). Here the basic obstacles are the extremely high power-source stability requirements and the presence of cord and microplasm spatial inhomogeneities. We have shown that these difficulties can be largely overcome by providing negative feedback between the multiplication factor M and the strength of the electric field E that causes impact ionization in the metal-dielectric-semiconductor structure.

Figure 1 shows a cross section through such a structure. A pulsed voltage source, which creates an electric field of strength E sufficient to trigger an avalance in the subsurface region of the semiconductor, is connected to the structure's metal electrode. Figure 2 shows the volt-ampere characteristic of this structure when a linearly increasing voltage pulse is applied to it and causes nonstationary depletion in the subsurface region of the semiconductor. The current I_{R_L} through the load resistance R_L is determined, when the voltage is $u < u_{ava}$, by the capacitance of the MDS structure, which decreases with increasing applied voltage due to the increase in the width of the semiconductors volume space charge (VSC) layer. Beginning at u_{ava}, the free-carrier concentration in the subsurface region of the semiconductor increases in avalanche fashion, and the current I_{R_L} rises sharply to the saturation value i^1_{ava}. Figure 2b shows that saturation of the current is accompanied by saturation of the semiconductors surface potential Ψ_s at the level Ψ_s^0. Figure 2c shows the multiplication factor M of the avalanche process plotted against voltage. When the multiplication factor reaches saturation, a self-stabilizing avalanche process is established in the

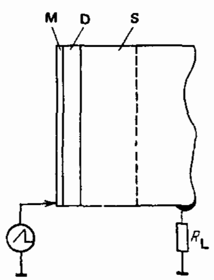

FIG. 1.

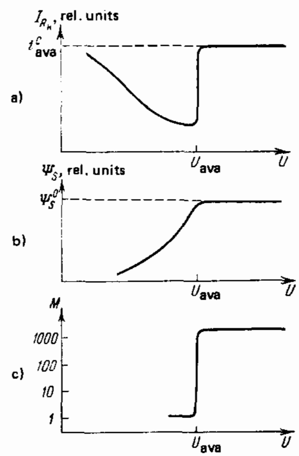

FIG. 2.

structure. Fluctuation of M in the direction of larger (smaller) values results in an increase (decrease) of the current and, consequently, of the charge accumulated at the boundary with the dielectric; this lowers (raises) the surface potential and returns M to the initial steady value.

The avalanche process in the MDS structure is described by the following equations:

$$\Psi_s = u - \frac{Q_\sigma}{\varepsilon_d \varepsilon_0} d + \frac{en\varepsilon_s}{\varepsilon_0 \varepsilon_d^2} d^2 - \frac{en}{\varepsilon_0 \varepsilon_d} d \sqrt{2\frac{\varepsilon_0 \varepsilon_s}{en} u - \frac{2Q_\sigma \varepsilon_s}{en\varepsilon_d} d + \frac{\varepsilon_s^2}{\varepsilon_d^2} d^2} \quad (1)$$

—the solution of the Poisson equation for the semiconductor-dielectric system, where Ψ_s is the surface potential of the semiconductor, Q_σ is the minority-carrier (electron) charge at the semiconductor-dielectric interface, d is the thickness of the dielctric, n is the impurity (acceptor) concentration in the semiconductor, and ε_s, ε_d, and ε_0 are the dielectric constants of the semiconductor, the dielectric, and vacuum, respectively;

$$Q_\sigma(t) = \frac{1}{S}\int_0^t i_{\text{ava}}\, dt \quad (2)$$

is the condition for pure avalanche generation in the semiconductors VSC; here i_{ava} is the avalanche current and S is the area of the structure;

$$\frac{i_{\text{ava}}}{i_0} = \frac{1}{1-(\Psi_s/\Psi_s^{\text{pu}})^{n'}} \quad (3)$$

is the avalanche-breakdown equation, which corresponds to Miller's formula for a sharp $p-n$ junction,[3] where i_0 is the current that initiates the avalanche and Ψ_s^{br} and n' are electrical constants.

In the case that a linearly increasing voltage pulse with a slope a, $u(t) = at$ is applied to the structure, analysis of Eqs. (1), (2), and (3) gives the following expression for the saturation current i^0_{ava} determined from the equilibrium condition $d\Psi_s/du = 0$:

$$i^0_{\text{ava}} = \frac{a\varepsilon_d \varepsilon_0 S}{d} = aC_d, \quad (4)$$

which characterizes the self-stabilized avalanche process. At self-stabilization, the multiplication factor M, defined as the ratio i_{ava}/i_0, takes the form $M^0 = aC_d/i_0$. Figure 3 shows an experimental curve of the avalanche current i_{ava} plotted against the surface potential Ψ_s; it ends at the point with the coordinates Ψ_s^0 and i^0_{ava}, which characterizes the self-stabilized avalanche.

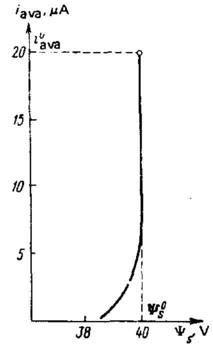

FIG. 3.

The avalanche in the MDS structure can be used to obtain multiplication factors up to 10^5 on a one-square-centimeter area in the absence of microplasmas—an indication that it has a high degree of spatial homogeneity. At the same time, it exhibits high temperature stability in the range from −100° to +40°C. All these properties of the avalanche process in the MDS structure will make it useful in development of a new generation of avalanche devices, e.g., photodectors with unique combinations of parameters and characteristics.

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