Scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the Academy of Sciences of the USSR (24–25 October 1984)

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A joint scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the USSR Academy of Sciences was held on October 24 and 25, 1984 at the P. M. Lebedev Physics Institute of the USSR Academy of Sciences. The following reports were heard at the session:

October 24

1. *A. A. Andronov.* Population inversion and simulated millimeter and submillimeter emission from hot electrons in semiconductors.

2. *A. M. Belyantsev and Yu. A. Romanov.* The classical superlattice—an artificial dielectric, nonlinear hf effect.

3. *S. V. Gaponov.* Ultrathin solid-state films and multilayered structures: methods of fabrication, study, and applications.

October 25

4. *A. F. Bogomolov.* Study of the surface of the northern hemisphere of the planet Venus (radar image and geographical and thermal maps of Venus) and developed radiophysical apparatus.

5. *V. I. Moroz, V. M. Linkin, and D. Oertel.* The results of an infrared experiment on Venera-15 and -16.

The brief contents of three of the reports are published below.

A. M. Belyantsev and Yu. A. Romanov. *The classical superlattice—an artificial dielectric, nonlinear hf effect.* Two new weakly-dissipative types of nonlinear high-frequency conductivity, arising on the basis of classical size effects, can appear in a semiconductor electron-hole plasma, localized in a volume with small linear dimensions. The first type[1,2] is associated with the saturation of the electrical polarization of such a system with the number of plasma particles in the system remaining constant and the second type[3] is associated with the strong dependence of the number of plasma particles on the electric field (voltage drop) due to interband tunneling of electrons. A specific and promising example of such systems is the classical superlattice SL, consisting of thin alternating layers of a semiconductor and a dielectric. The dielectric layers play the role of potential barriers for electrons, localized in the semiconductor layers. They must meet the following basic requirements: low electron transmittance and high electrical strength, high dielectric permittivity, and as small thickness as possible. The thickness of the semiconductor layer d is assumed to be much larger than the characteristic de Broglie wavelength of the electrons; this is not a fundamental requirement, but merely makes it easier to study the properties of the SL of interest to us.

The frequency properties of the SL are determined by three characteristic times of the semiconductor layer: the interband recombination time $\tau_r \sim 10^{-8}$ s, the inverse probability of interband electron tunneling per unit time τ_T, and the time for establishing a quasiequilibrium distribution of electrons and holes in their energy bands over the thickness of the layer τ_D. As d is increased, the relaxation times $\tau_{T,D}$ increase, and this decreases the working frequencies of the SL. For the millimeter and submillimeter ranges the optimal values of d lie in the range $\sim 10^{-5}$ cm, while $\tau_D \sim \tau_T \sim 10^{-12}$s.

The characteristic nonlinear fields E_* are fields which displace the electrons (holes) over a distance of the order of the thickness of the semiconducting layer. For the first type of nonlinearity $E_*^{(1)} \equiv V_*^{(1)}/d = [1 + (d/r_D)^2] W/ed \sim 10^3 - 10^4$ V/cm (r_D is the Debye screening radius, W is the average energy of a charged particle, and V is the voltage drop across the layer), while for the second type $E_*^{(2)} \equiv V_*^{(2)}/d = E_g/ed \sim 10^5 - 10^6$ V/cm (E_g is the gap width of the semiconductor). It is important that the first and second types of nonlinearity occur at different fields.

In the frequency range $\omega\tau_* \ll 1$ (τ_* is the characteristic relaxation time of the dominant mechanism of nonlinearity) the polarization of the SL can almost follow the variations in the field and it can therefore be represented in the form $P(t) \approx P_1(V) - \tau_*(V/V_*) P_2(V)$. The first term determines the reactive current and the second determines the dissipative current. For a single-component nondegenerate plasma and $d \ll r_D$, $P(t) \sim P_0 [L(V/V_*) + \tau_D (V/V_*) L''(V/V_*)]$, where $P_0 = ned/2$, n is the electron density, $V_* = 2kT/e$, adn $L(z) = \coth z - z^{-1}$ is the Langevin function. In the region $V_*^{(1)} \ll V \ll V_*^{(2)}$ the polarization of the SL saturates. As V is increased, interband electron transitions begin to occur, and for $v > E_g/e$ electron tunneling occurs. The number of plasma particles increases rapidly, and this leads to rapid growth of the polarization of the SL. For $V \ll V_*^{(2)} \sim 1$V, $P_1(V) \sim V^{5/4}$. The capacitance of the layer changes in a corresponding manner also. For example, the capacitance of a 500 Å layer of silicon increases tenfold when V varies by 0.1 V near E_g/e.

Thus classical SL with the above-indicated parameters

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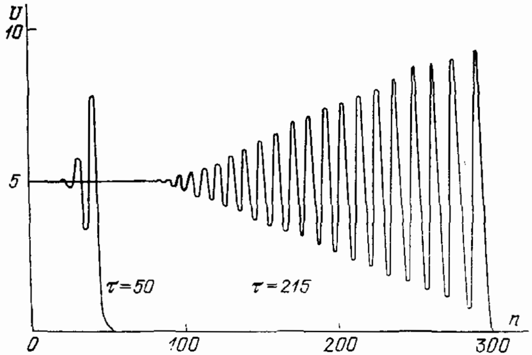

FIG. 1.

are artificial dielectrics with a reactive, strongly nonlinear conductivity up to submillimeter frequencies. For this reason, they are especially promising for producing devices based on a distributed interaction of electromagnetic waves, such as frequency converters and parametric amplifiers, in this range. We present the results of numerical calculations of the parametric processes ($\nu = 1,2,...$) in SL based on GaAs layers with $d = 250$ Å, $n = 10^{18}$ cm^{-3}, and $T = 300$ K. In this SL $E_{*}^{(1)} \sim 20$ kV/cm, and the attenuation length of the pumping wave with $\omega = 10^{12}$s^{-1} is $z_a \approx 2.3$ cm. For a pumping field amplitude of $E_1 = E_{*}^{(1)}$ the parametric gain of a signal with $\omega_3 \sim 2 \cdot 10^{12}$ s^{-1} over a distance of 0.6 cm is equal to 60 dB. The coefficient of conversion of the signal at ω_3 into a low frequency $\omega_2 = 10^{11}$s^{-1} over a distance of z_a is of the same order of magnitude. The coefficient of conversion of the pump into its third harmonic (as a result of parametric generation with $\nu = 6$) over an interaction length of 1 cm is equal to tens of percent.

Since the SL is a strongly nonlinear reactive medium with weak dispersion, by filling a nondispersive transmission line with it, it is possible to realize sharp current and voltage drops with a leading edge of duration $\sim 10^{-12}$ s, and with special dispersion it is possible to achieve efficient generation of oscillations with a period of the same order of magnitude. In particular, a video pulse can be efficiently converted into a radio pulse. A typical picture is presented in Fig. 1 for two values of the dimensionless time τ.

Under the action of an alternating voltage with frequency $\omega \leqslant \tau_T^{-1} \gtrsim \tau_r^{-1} \omega \tau_D \ll 1$ and an amplitude greater than E_g/e it is possible to produce in a classical SL a population inversion in the bands and stimulated emission on interband transitions. This is possible because the conduction band is filled by electrons from the valence band as a result of electron tunneling more rapidly than it is emptied, since reverse tunneling occurs in weaker fields.

Thus the classical SL are promising artificial materials for producing different electronic and optoelectronic devices.

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[3]E. V. Demidov and Yu. A. Romanov, Fiz. Tekh. Poluprovodn. **17**, 1674 (1983) [Sov. Phys. Semicond. **17**, 1066 (1983)].
[4]A. M. Belyantsev and A. V. Okomel'kov, Fiz. Tekh. Poluprovodn. **18**, 1214 (1984) [Sov. Phys. Semicond. **18**, 758 (1984)].
[5]A. M. Belyantsev and V. I. Shashkin, Izv. Vysh. Uchebn. Zaved. Ser. Radiofiz. **25**, 833 (1982).