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Enhancement of Average Velocity of Hot Carriers in Appropriate Heterostructures Due to Inversion of Distribution Functions.

Vladimir A. KOZLOV and Alexander B. KOZYREV

Institute for Physics of Microstructures of Russian Academy of Sciences
46, Uljanov St., 603600, Nizhny Novgorod, Russia

The heterostructures with specific profiles of the internal potential are proposed to enhance the average carrier velocity in strong field in compare to the homogeneous materials. Monte Carlo simulation of the motion of the ensemble of electrons in such heterostructures was carried out. It was shown that at low temperature for some specific conditions the drift velocity can be increased by 1.5 times in comparison with one in homogeneous material at the same value of the average applied field.

1. INTRODUCTION

The response time of many electronic devices is defined mainly by the average electron velocity and by the device dimensions. The ways to reduce the dimensions of electronic devices are well known. In the report we consider some opportunities of the increase of the average velocity of ensemble of electrons in heterostructures (HS). The average velocity of electrons in semiconductors in strong field is saturated due to the scattering with emission of longitudinal optical phonons (LOP). The motion of an electron consists of two stages: acceleration and optical phonon emission. Acceleration of an electron by the electric field gives the increase of energy. Emission of LOP leads to the loss of energy and, hence, to the loss of velocity of electron. Such cyclic motion at low temperatures and strong fields results in the distribution functions of the streaming type [1] and in the occurrence of the inversion [2]. The usage of the peculiarity of these distributions gives an opportunity to increase the average electron velocity at certain conditions. We consider for this purpose the HS with special layers intended for the emission of LOP at assigned places. This gives us an opportunity to reduce sufficiently the time of acceleration of electron and, thereby, to enhance the average velocity of the electron ensemble. Averaged electric field is such that the avalanche breakdown doesn't arise since the regions with high field are spatially localized. Moreover the energy obtained by the electron in the high field layer doesn't exceed the energy of LOP that prevents from the breakdown.

2. STREAMING IN HOMOGENEOUS MATERIAL.

Let us describe qualitatively the process of motion of electron in homogeneous material under streaming conditions which can be realized in comparatively pure semiconductors at lattice temperature less than Debye temperature. The selected trajectory of the motion of electron in constant field is shown in Fig.1. It is convenient to separate the momentum space into two regions: the passive region ($p < p_0$) where emission of optical phonons is impossible and the active region ($p > p_0$) which is located above the dashed line in Fig.1. Here $p_0 = \sqrt{2m^* \hbar\omega_0}$. In the passive region (between solid and dashed line in Fig.1) the electron scattering is weak, so that in a strong field an electron moves in the passive region almost without scattering. In the active region a strong scattering mechanism caused by the LOP emission is switched on. Being scattered with optical phonon emission, the electron jumps back to the passive region and the next cycle of the motion begins.

The dynamical heating of carriers leads to the distribution function stretched in the direction of the electric field (Fig.2.3). Calculations were carried out for two injectors: solid line - $p_t^2 = p_x^2 + p_y^2 \neq 0$ and dashed line - $p_x^2 + p_y^2 = 0$.

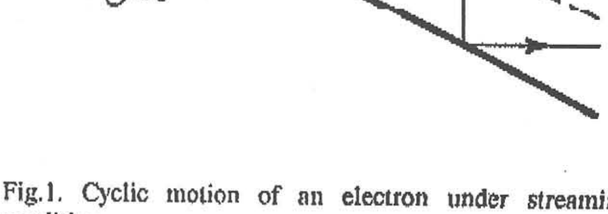

Fig.1. Cyclic motion of an electron under streaming condition.
→ - electron trajectory; ——— - bottom of the conduction band; - - - - - optical phonon energy

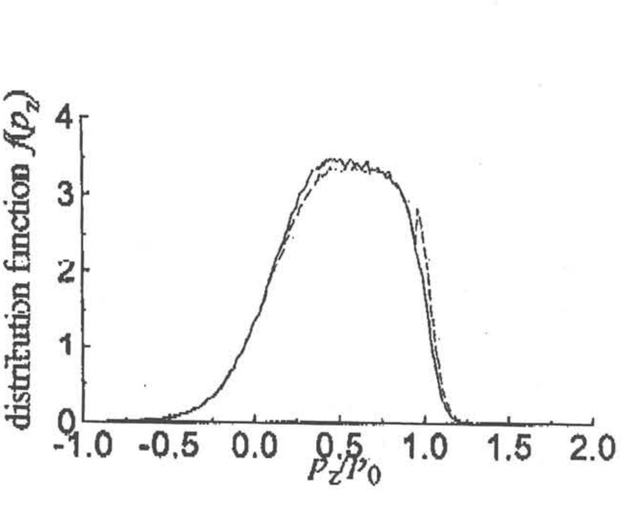

Fig 2. Distribution function $f(p_z) = \int_{p_x,p_y} f(\vec{p})dp_x dp_y$.

3. STREAMING IN HETEROSTRUCTURES WITH STEP LIKE INTERNAL POTENTIAL

Let us consider the motion of electron in heterostructure

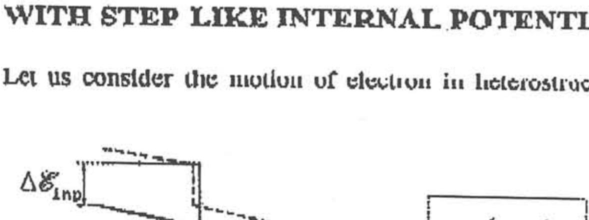

Fig.4. Profile of the conduction band.

(HS) with potential profile shown in Fig.4. At certain

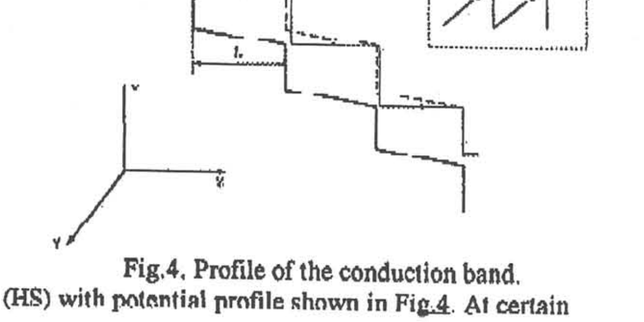

Fig.5. Distribution function $f(p_z) = \int_{p_x,p_y} f(\vec{p})dp_x dp_y$

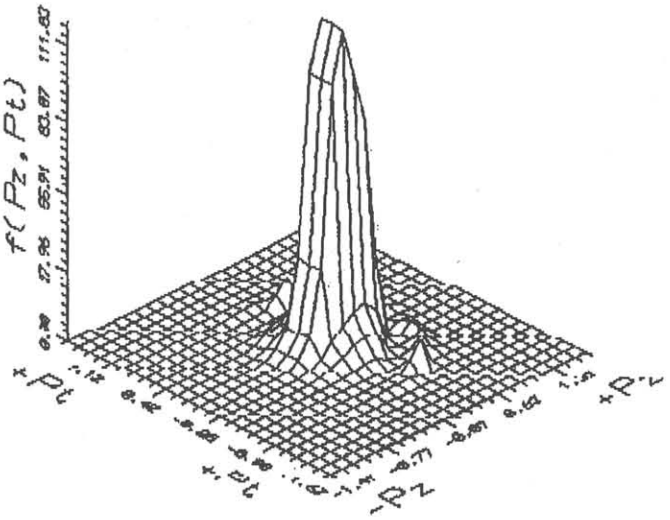

Fig.3. Distribution function $f(p_t, p_z) = \int f(\vec{p})p_t d\varphi$.

values of the jump of the potential (bottom of the conduction band) $\Delta\mathscr{E}$ and the certain value of applied voltage the specific electron trajectory consistent with the period of HS may arise. In this case the time of flight in the energy range near the LOP energy becomes longer in compare with one in the case of the streaming in homogeneous material. This situation takes place at appropriate values of the external electric field E. The total energy obtained by electron in the period of HS should be exactly equal to the energy of LOP. After passing through the heterojunction the energy of electron becomes a little bit less than two-fold LOP energy. So the electron emits an optical phonon during very short time and passes into state with energy a little bit less than the energy of LOP where electron can stay for comparatively long time.

The distribution function $f(p_z)$ for the HS under consideration is shown in Fig.5. The trouble with HS under

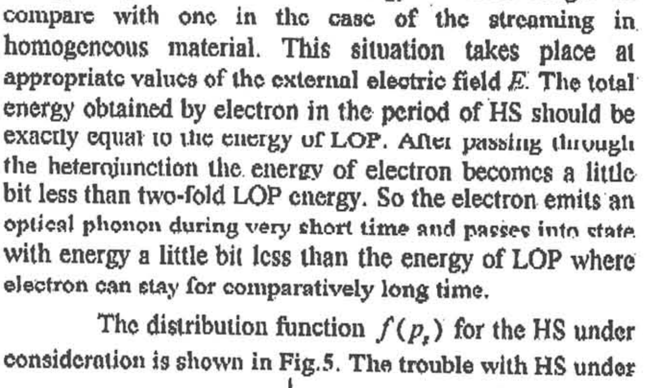

Fig.6. Distribution function $f(p_t, p_z) = \int f(\vec{p})p_t d\varphi$.

consideration is the occurrence of the wide source of electrons appearing after LOP emission. This means that the electrons more probably populate the belt with $p_t \cong 0$ on the monochromatic sphere $\mathcal{E} \sim \hbar\omega_0$. Actually, after the LOP emission electron appears with energy $\mathcal{E} \approx \hbar\omega_0$ and can move in any direction. This leads to the distribution function widely spreaded over energy sphere Unfortunately in this case there is no electron bunching in the momentum space.

4. STREAMING IN HETEROSTRUCTURES WITH SAW SHAPED POTENTIAL

Let us consider the saw shaped HS with the profile of the conduction band shown on the insct in Fig 7. The HS represents itself the pile of thick and thin layers: in the thick layer there is a smooth rise of potential and in the thin layer there is a strict fall of potential. At appropriate applied electric field the potential profile has the form shown in Fig 7. The motion of the electron in the thick layer with high energy of a little bit less than LOP will be approximately free of scattering until electron reaches the thin layer with strong electric field. In the thin layer electron quickly achieves the energy exceeding the energy of LOP and immediately emits the LOP. After the LOP emission electron looses its energy and its momentum becomes equal to zero. But electron is located now in the thin layer of HS with strong field. It means that momentum p_z increases rapidly till electron leaves thin layer and comes to the thick one where electric field is approximately equal to zero so the electron has constant momentum and moves in the vicinity of LOP energy. At the same time the transversal momentum p_t keeps its small value during acceleration so that the momentum p_z in thick layer is of the order of p_0. One can see from Fig.8 and Fig.9 that distribution functions in this case are located in momentum space near the point $p_z \approx p_0$, $p_t \approx 0$. Such self-consistent motion of electron reduces the acceleration time and gives a possibility to transmit the same distance more quickly than in homogeneous materials. The bunching of electrons in the compact region of momentum space produce the inverted distribution of hot electrons which are very attractive for the generation of electromagnetic radiation [3,4].

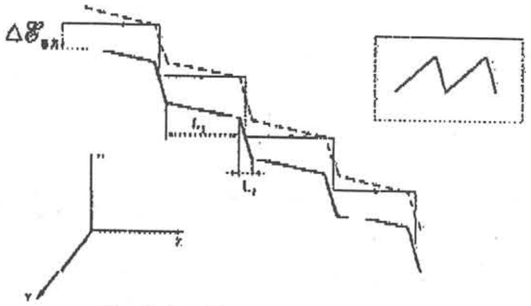

Fig.7. Profile of the conduction band.

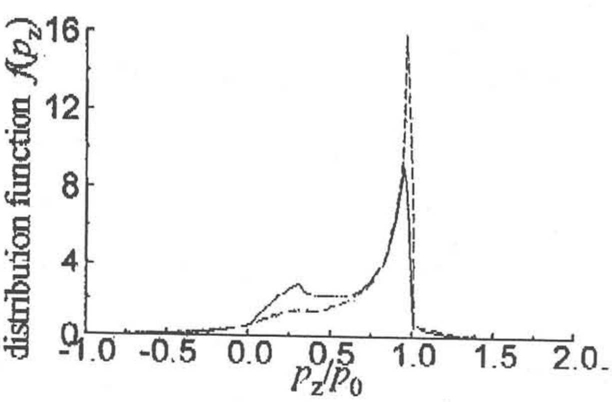

Fig.8. Distribution function $f(p_z) = \int f(\vec{p})dp_x dp_y$

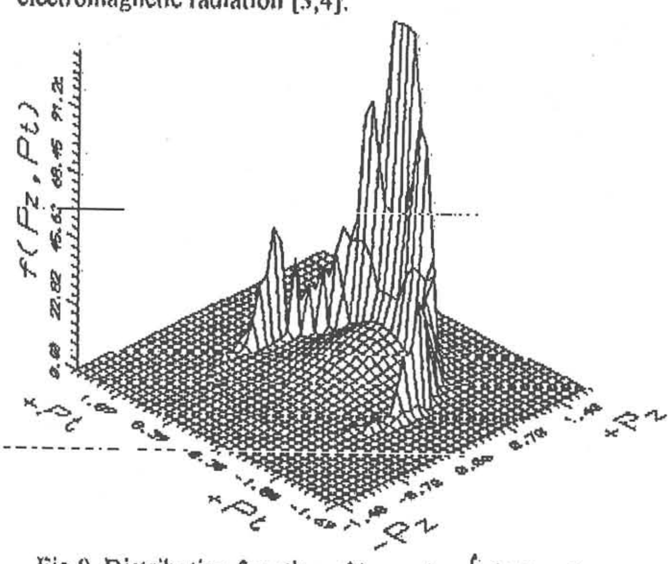

Fig.9. Distribution function $f(p_t, p_z) = \int f(\vec{p}) p_t d\varphi$

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References

1. Kurosawa T., Maeda H. J.Phys.Soc.Japan, **31** (3), 668 (1971).
2. Andronov A.A., Kozlov V.A., ZhETP Lett. **17** (2), 124 (1973).
3. Opt. Quantum Electron. **23**, N2 (1991), Special Issue on Far-infrared Semiconductor Lasers.
4. V.A.Kozlov, Physica Scripta, **19**, 215 (1987).