RESONANT TUNNELING OF ELECTRONS IN A SUPERLATTICE ON SILICON CARBIDE

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Submitted 28 November 1972
ZhETF Pis. Red. 17, No. 1, 22 - 24 (5 January 1973)

Theoretical and experimental studies of superlattices are of great interest, since these structures constitute a new class of semiconductors with controllable properties. The presence in the crystal of additional modulation of the main crystal field with a large period a leads to breaks in the quasi-continuous spectrum of the electrons at the points $n\pi/a$ and to formation of narrow energy subbands (minibands). Theoretical calculations show that the current-voltage characteristics of such structures in strong fields can have resonant singularities due to Bragg reflections from the miniband boundaries [1 - 3] and to tunneling of the electrons between the different minibands [4]. However, in spite of the strong efforts to produce and investigate artificial superlattices, these singularities have not yet been observed experimentally.

It was shown in [5] that different polytype modification of silicon carbide constitute natural one-dimensional superlattices, and the self-stabilization of different structures during the course of growth determines the ideal repetition of a definite superperiod through the entire crystal.

We have measured the current-voltage characteristics in strong fields on various modifications of SiC crystals. The samples were selected by x-ray structure analysis. The carrier density was determined from electric measurements.

The measurements were made at T = 77°K in the pulsed regime, with approximate pulse duration 1 μsec and repetition frequency 1 - 2 pulses/sec. These conditions, and also the maximum amplitude of the applied field, were determined by the relatively high conductivity of the samples. In sufficiently strong fields and at a long pulse duration (as well as in direct current), heating by the current is observed in most samples, with resultant nonlinearity of the current-voltage characteristics, due to thermal ionization of the impurities.

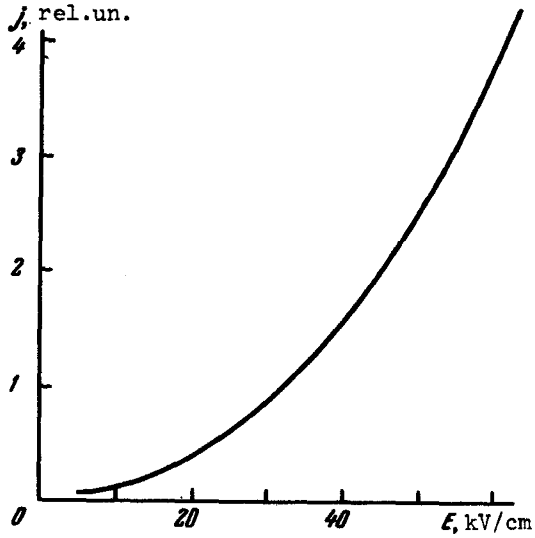
The current voltage characteristics of samples with small superlattice periods (4H, 6H, and 15R) were linear up to fields corresponding to the start of the heating, for current directed along the crystal c axis (i.e., in the superlattice direction) as well as in a perpendicular direction. Estimates based on calculations of the band structure of these SiC modifications have shown that in order to obtain the negative differential conductivity due to the Bragg reflections it is necessary to have in these structures fields that exceed by at least one order of magnitude those at which heating takes place. Thus, to observe this effect in the SiC modifications mentioned above, it is necessary to have much purer samples or else measurements with shorter pulses and at a temperature below 77°K. Resonant tunneling is apparently impossible in principle in these samples, owing to the large energy gap between the first and second minibands (for example, ΔE in 6H-SiC is approximately 1 eV [5]).

To observe resonant phenomena in relatively weak fields, we performed measurements on the 297R modification of SiC. If, as in most multilayered SiC structures, the 297R structure is based on the (33) phase [6], then the energy spectrum of the electrons in it should be analogous, for a current along the c axis, to the 6H spectrum [5], but with 33 additional weak energy discontinuities. The "microbands" produced thereby are separated by very small gaps, and the energy interval between the points $k = 0$ and $k = \pi/a$ is less than 10^{-2} eV.

The results of the measurements on the 297R structure are shown in the figure. It is seen from these data that when the current is directed along the c axis one observes a clearly pronounced nonlinearity of the current-voltage characteristic, with a sharp increase of the current, although there are no peaks whatever on the curve. At the same time, a pure ohmic dependence is retained for the current across the axis.

The anisotropy of the current-voltage characteristic is undoubtedly the result of the presence of a one-dimensional superlattice in the crystal. The most probable mechanism of the nonlinearity in this case is the resonant tunneling of the electrons [4].

Using the transverse relaxation time $\tau = 10^{-14}$ sec estimated for SiC in [7], we obtain for the energy uncertainty a value of $\delta E = 0.07$ eV, which is much larger than the widths of the microbands. Thus, the individual resonances cannot be resolved in this structure, and this explains the absence of peaks on the current-voltage characteristic. The increase of the current with increasing field is determined only by the increase of the density of states in the succeeding microbands with increasing energy.



Current-voltage characteristic of SiC crystal 297R in a direction parallel to the crystal c axis. The current-voltage characteristic in the perpendicular direction is linear.

At helium temperatures it is apparently possible to obtain in such a structure Bragg reflections from the boundaries of the microbands already at fields on the order of 10^3 V/cm.

The authors thank N.F. Kartenko for performing the x-ray structure analysis of the samples, G.A. Lomakina for measuring the concentrations, and Yu.V. Shmartsev and A.G. Ostroumov for interest in the work and numerous useful discussions.

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QUANTUM DIFFUSION OF He^3 IMPURITIES IN SOLID He^4

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Submitted 29 November 1972
ZhETF Pis. Red. 17, No. 1, 25 - 28 (5 January 1973)

The purpose of this study was to observe and investigate He^3 impurity behavior features connected with the quantum nature of solid helium.