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13. ABSTRACT *(Maximum 200 words)*

In this period the main focus of the work was dedicated to the study of a superlattice under bias. Most of the previous experiments could not investigate the bias dependence of the superlattice current since the applied electric field was not varied in a controlled way. Our structure has the specific advantage that a defined voltage can be applied between base and collector. Therefore our work represents the first defined experiment of superlattice transport as a function of electric field across the superlattice.
As a result we find that for negative bias the current is quenched quite rapidly and decreases to zero at the expected value of the localization electric field (5kV/cm). For positive bias a very promising behavior is found: up to an electric field of 1kV/cm a nearly constant current is observed which is an indication for electric field induced miniband transport. This observation which has to be confirmed with several samples, could be the first signature of a Bloch-type current in the superlattice.

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THz RADIATION SOURCE THROUGH PERIODICALLY MODULATED STRUCTURES

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6th Interim Report

Ballistic electron spectroscopy of biased superlattices

In this report we present results on the transport in biased superlattices. This is the next step towards the realization of a source based on superlattice transitions. A bunching of carriers in a superlattice requires the presence of an electric field. On the other hand the wavefunctions get localized in the electric field. So there is probably just a small window where bandtransport in the superlattice is present. To study this situation the current transfer ratio α of a biased 10 period superlattice was

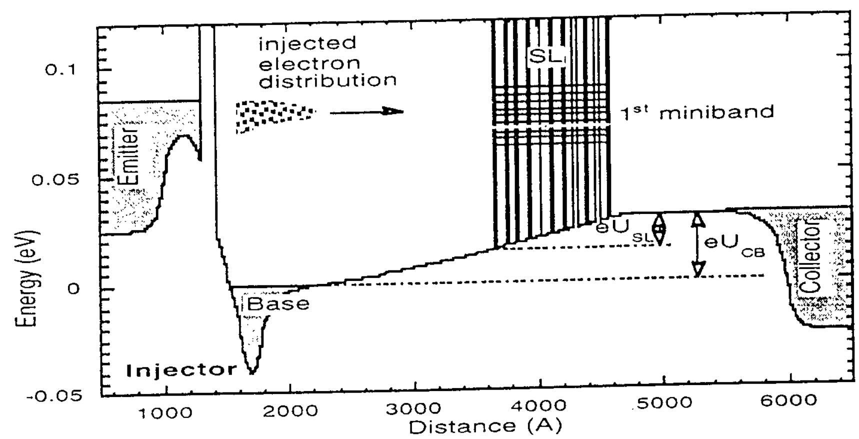

Figure 1: Bandstructure of a three terminal device with a biased superlattice in the drift region.

studied and compared with a self consistent calculation based on the transfer matrix approach.

A ten period superlattice with barriers of 25Å thickness and 65Å well width was embedded into the drift region of a three terminal device. We have grown a 1900Å GaAs drift region between the base layer and the superlattice, and a 1400Å drift region between the superlattice and the collector. The band structure for typical bias conditions is shown in Fig. 1.

The measured transfer ratio a as a function of the normal electron injection energy at different collector-base biases is shown in Fig. 2a and Fig. 2b respectively. It can be seen that the onset of the transfer ratio shifts with the applied collector-base bias with the lower edge of the first miniband due to the superlattice bias. The observed transfer ratios decrease quite dramatically with the applied electric field. Longitudinal optical phonon replicas, which are shifted 36meV to higher injection energies can be observed at all biases.

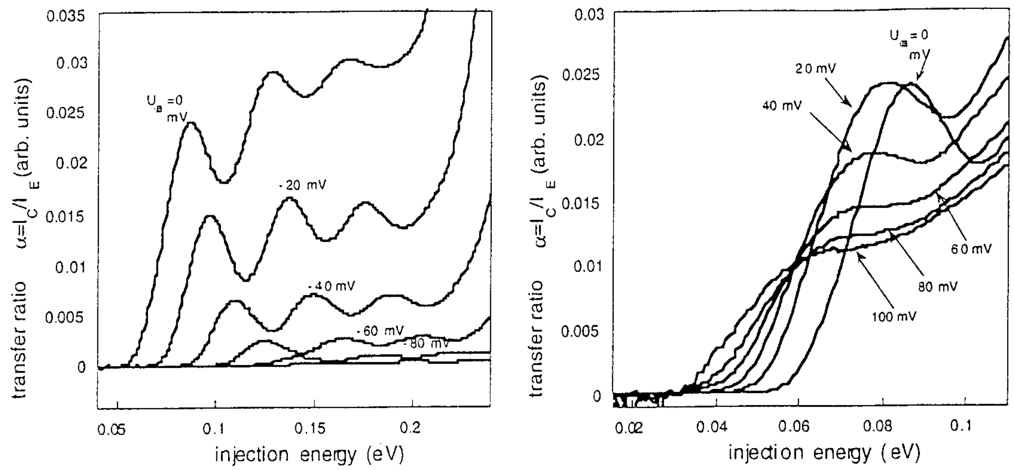

Figure 2. Measured transfer ratios at different collector-base biases(a) for negative (b) for positive vs. injection energy

In Fig. 3, the calculated positions of the five lowest superlattice states for a structure shown in the insert of Fig.3 with respect to the Fermi level of the base are plotted versus superlattice voltage. To evaluate the onset of the theoretical transmission for different electric fields (transfer ratio), we have to consider the wave functions of each state as a function of the applied bias. In the second inset of Fig. 3

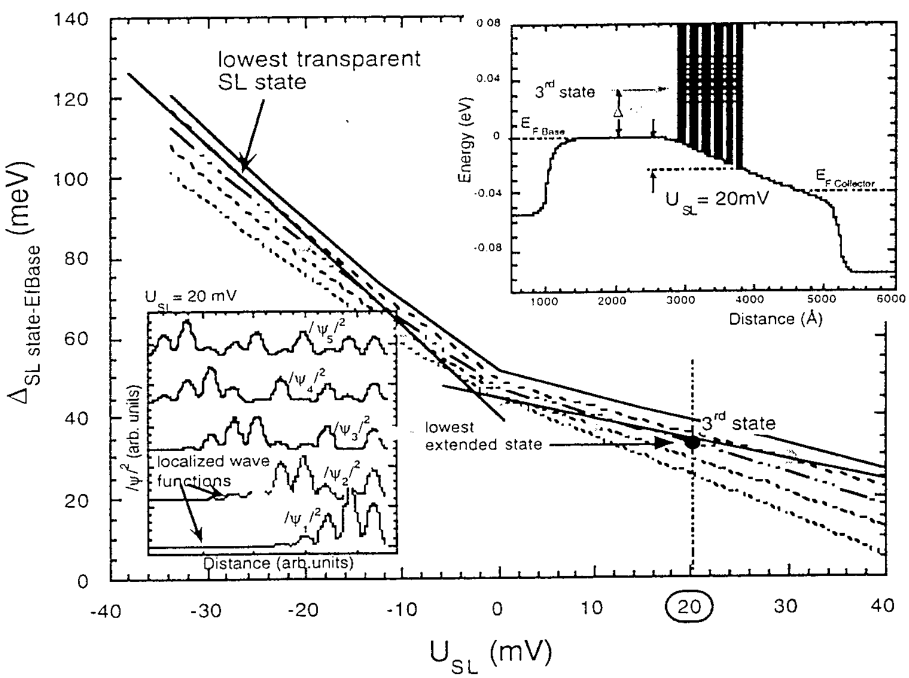

Figure 3. The energy position of the five lowest superlattice states with respect to the Fermi level at the base are plotted against superlattice voltage. The insets show the squared wave functions of the corresponding states, and the band structure at U_{SL}= 20mV. The solid line represents the lowest transparent superlattice state.

the extended wave functions of the five lowest states for a superlattice bias of 20mV are shown. It clearly evident that the wave functions of the first and second state are strongly localized. Consequently these states will not contribute to the transport of ballistic electrons. This means that the first transparent state is state 3. The solid line in Fig. 3 represents the lowest transparent state of the first miniband as a function of superlattice bias. It has to be pointed out that this line represents the theoretical onset of the current of the biased structure.

The main question here is up to which bias will band-like transport be present in the superlattice. Only the existence of several extended states allows the formation of wavepackets , which are an essential requirement for bunching of carriers.

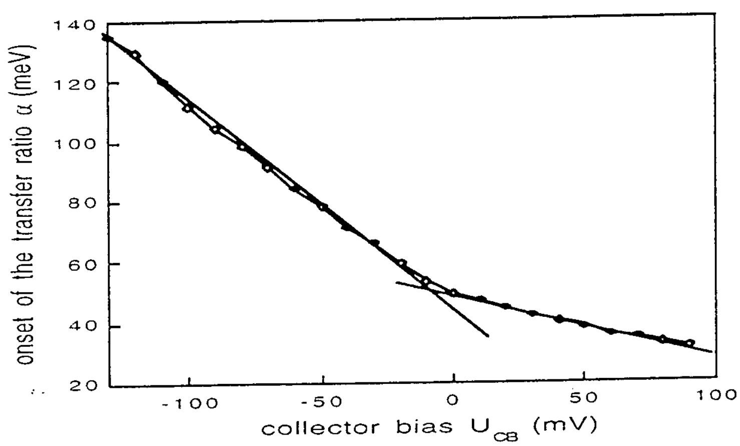

Figure 4: Measured onset of the transfer ratio vs. collector-base bias

In Fig.4 the position of the experimentally derived onset of the current (transfer ratio) is plotted versus collector-base (U_{CB}) bias. The onset is measured at 10 % of the maximum transfer ratio. A very linear but asymmetric behavior can be observed. The asymmetry is due to the asymmetry of the structure, since the drift regions on both sides of the superlattice are of different lengths. Comparing the slopes of the theoretical derived onsets to the slopes of the measured onsets of the heterostructure one gets a relation between the applied collector-base voltage to the real voltage drop at the superlattice. Consequently it is possible to scale the collector voltage to the voltage at the superlattice itself, which is an important requirement for the analysis of the data as a function of the real internal field.

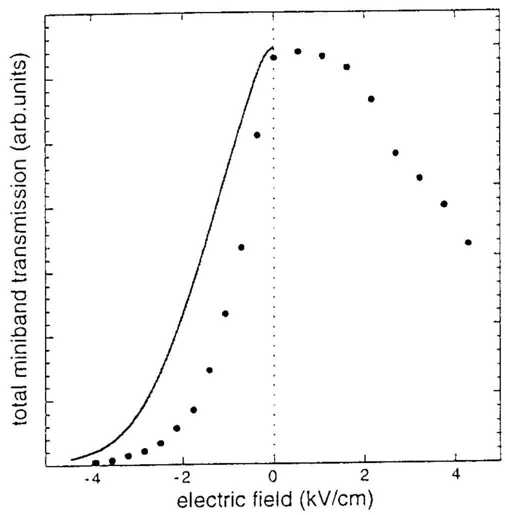

Figure 5: Measured transfer ratio at peak position vs. superlattice electric field

Fig.5 shows the absolute transfer ratio at the peak position as a function of the superlattice voltage. This transfer ratio is a measure of the transmittance of the superlattice at different biases. It can be seen that the transmittance is vanishing when the applied voltage exceeds 40 mV. That means that all states are localized for voltages higher than 40 mV which fits very well with the theoretically derived cut off of the transmittance. With decreasing voltages (below 40 mV) the superlattice states becomes extended again (one after the other) over the whole superlattice dimension and thus transparent leading to current. At zero bias the transfer ratio has its maximum since all states are extended over the whole dimension of the superlattice and contribute to current. The peak is highly asymmetric, what gives us a confirmation that the positive bias has a different effect on the transport through the superlattice than negative bias. The drift region is pinned at the collector side for negative collector-base voltages and at the base side for positive voltages. It is assumed that the slope of the biased drift regions is about the same as the slope within the superlattice. The decay of the current is quite weak for small positive biases. This region corresponds to an electric field of about 1kV/cm. This behavior has been observed for the first time. The full curve is a calculation of the transmittance for negative bias.

Further detailed studies with changing sample parameters are necessary to make some conclusions from this behavior. This is also the field region where Bloch- type oscillations are expected

In summery we have shown the quenching of miniband conduction of a biased superlattice using the technique of hot electron spectroscopy. For voltages across the superlattice higher than 40 mV (corresponding to 5kV/cm) the superlattice becomes non transparent. A sharp drop of the transmittance even at very small electric fields can be observed for negative bias, while constant transmittance is observed up to 1kV/cm for positive bias which is followed by a sharp drop. This is the first clear indication of electric field induced superlattice current which is compensating the field localization.