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Unmonotonous variation of oscillation threshold with in-plane magnetic field in resonant-tunneling diode

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Abstract. Current oscillations in the negative differential conductance region of resonant tunneling diodes with different lateral pattern and size versus perpendicular to the tunneling current magnetic field have been studied. It is revealed that the value of the critical negative differential conductance or oscillations threshold, that is the value of conductance when the oscillations in measurement circuit are arisen, unmonotonically depends on magnetic field. The relation of the observed dependence with inhomogeneous distribution of the tunneling current is discussed.

Current instabilities have been investigated in semiconductor devices for over 50 years [1]. Inhomogeneous instabilities such as domains and filaments have attracted much attention and have been revealed in a wide range of the devices. As far as we know, a resonant tunneling diode (RTD) becomes experimentally investigated for the presence of the *inhomogeneous instabilities* very recently [2]. By inhomogeneous, we mean instabilities or charge inhomogeneties in the plane of the barrier and quantum well. Some theoretical works have already predicted this kind of instability in the RTD [3–7]. In particularly it was shown that increasing of the lateral size of the diode above some critical value leads to a significant inhomogeneous current distribution along the RTD structure when the diode is biased in the negative differential conductance (NDC) region.

A local probe technique has already been successfully exploited in Gunn diodes to determine the inhomogeneous current distribution [8]. However, for the RTD, this technique is not applicable, not only because of the relative small lateral size of the predicted current inhomogeneities but also because of inaccessibility of a local external probe to the barrier and quantum well region of the diode where the inhomogeneity is expected to occur. Another way to test for an inhomogeneous current distribution is to compare experimental data with those calculated from widely used RTD models derived on the assumption of a homogeneous current distribution along the tunnel junction. Features that cannot be explained by these models can then be searched for experimentally as evidence of current inhomogeneity.

In this work we present studies of the current oscillations excited in measurement circuit when RTD is biased to the negative differential conductance region in magnetic field parallel to the barriers focusing on the variation of the oscillation threshold conductance with magnetic field. The oscillations appear when negative differential conductance exceed some critical value — threshold conductance. In the approximation of homogeneous current distribution the threshold conductance is related with other measurement circuit parameters by stability condition. The in-plane magnetic field strongly effects and change

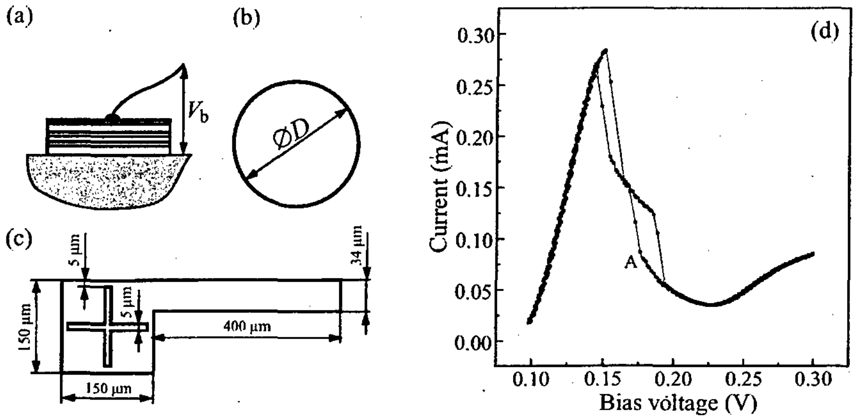

Fig. 1. (a) Resonant tunneling diode with ohmic metallization and applied bias voltage. (b) Circular mesa structure. The diameter D of the structure is equal to 200 μm for sample A and 400 μm for sample B. (c) Mesa structure of stripe-like sample C. (d) Current-voltage characteristic of the RTD measured with dc voltmeters. The point A is a transition point between stable current region and unstable current region at backward sweep of bias voltage. The threshold conductance is a differential conductance at point A.

dc current-voltage characteristic (I–V curve) of the RTD [9, 10]. It changes mainly differential conductance and remains other internal parameters of the diode almost unchanged. Evidently one could expect that threshold conductance measured without changing in the external circuit should remains almost the same at different magnetic fields. Contrary to this expectation we have found remarkable dependence of the threshold conductance on magnetic field.

The resonant tunneling diodes were fabricated from double barrier heterostructure grown on n^+ GaAs substrate. The heterostructure consisted of 11.8 nm wide QW sandwiched between two $Al_{0.4}Ga_{0.6}As$ 8.3 nm thick barriers. Undoped 30 nm spacer layers separated the barrier/well region from the n-doped contact layers. The diodes had different lateral sizes and forms of the mesa structure made by conventional wet etching (see Fig. 1(a)). Sample A had circular mesa of 200 μm diameter (see Fig. 1(b)). Sample B had circular mesa of 400 μm diameter. Sample C had mesa of stripe-like form and the area of the sample was equal the area of a square with 300 μm side (see Fig. 1(c)).

The I–V curves were measured with dc voltmeters. Since the dc voltmeter measures an average value of real voltage sudden appearance of nonlinear voltage oscillations cause an appearance of current steps and jumps in the NDC region (see Fig. 1(d)). The oscillations excitation was controlled by measurements with high sensitive oscilloscope. The oscillations were observed inside the voltage range of current step and they were absent out of this range.

Thus when the voltage is swept from stable region of the I–V curve to unstable one the differential conductance at point of the stable-unstable transition is equal to threshold conductance which could be determined from the data. So measuring the dc I–V curves at different magnetic fields one can get the dependence of the threshold conductance on magnetic field. In this work we have investigated stable-unstable transition in NDC region near current minimum (see Fig. 1(d), point A) for reverse bias sweep direction. Near the current peak the differential conductance changes very quickly with voltage therefore this

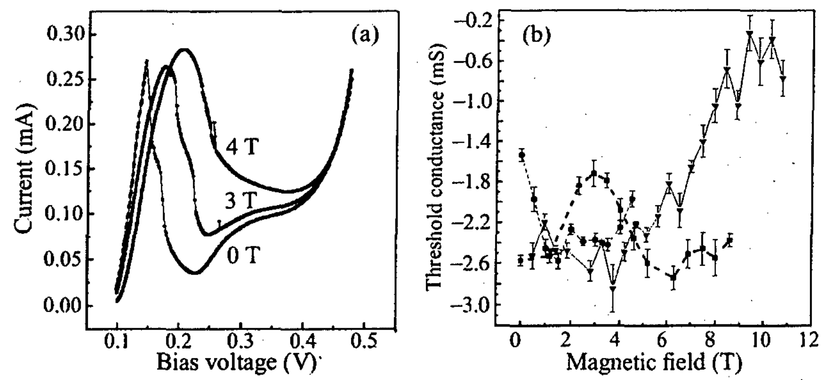

Fig. 2. (a) Current–voltage characteristics of the RTD at different in-plane magnetic fields. (b) Threshold conductance versus in-plane magnetic field. Circles with dotted line correspond to data measured on sample A. Squares with dash line correspond to sample B. Triangles with solid line correspond to sample C. Lines is used only as viewguide.

region is not convenient for the measurements. The I–V curves are shown in Fig. 2(a) at different in-plane magnetic fields. The in-plane magnetic field causes the broadening of the resonant peak and shifts it to higher voltages [9, 10]. The dependences of the threshold conductance on magnetic field are plotted in Fig. 2b for different samples.

As it was mentioned above the magnetic field effects only parameters of the RTD while other parameters of the measurement circuit remain the same. Furthermore in magnetic field the differential conductance changes more drastically then other parameters of the RTD, e.g. differential capacitance. From Fig. 2(b) one can see that threshold conductance is constant $\sigma_T \approx -2.5$ mS in the magnetic field range from 1 T to 2 T for all samples. In addition the σ_T has the same values for samples A and C from 1 T to 5 T. It is worth to note that capacitance of the sample C is twice larger than that of the sample A, which is four times less of capacitance of the sample B. The same relations should be valid for contact resistances of the samples. This is very surprising that the values of the threshold conductance are so closed for such different samples. It can be so when the σ_T is determined mainly by the external circuit parameters, which doesn't depend upon the magnetic field, and one should observe no dependence upon the magnetic field and no significant difference between different samples. On the other hand if we suppose inhomogeneous lateral current distribution the effective area of the samples will be determined by lateral size of the inhomogeneity that may be the same for the samples with different lateral sizes. The inhomogeneous current distribution should be very sensitive to the in-plane magnetic field and thus one should expect nontrivial dependence upon the magnetic field.

In summary, we have investigated the current oscillations in the NDC region of the RTD in the in-plane magnetic field. The samples of different size and form have been investigated. We have measured the differential conductance at transition point from stable current region to the region where the oscillations are exited. The threshold conductance is found to have a peak in its dependence on magnetic field. The peak positions and threshold conductance differ for the samples of different size. However the value of threshold conductance out of the peaks are the same for all samples. The observed features cannot be explain assuming homogeneous lateral current distribution in the NDC region of resonant tunneling diodes.

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