ACOUSTOELECTRIC EFFECTS IN Ge/Si NANOSYSTEMS WITH Ge QUANTUM DOTS

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Introduction

Acoustic techniques [1] allow one to study mechanisms of AC conductance and provide independent contactless methods to determine material’s parameters. Here for the first time we apply these methods to Si samples with high-density (n=3×10^{11} cm^{-2}) arrays of Ge quantum dots (QD).

Experimental

A sample with a QD array “embedded” close to its surface lays on a piezoelectric substrate. A surface acoustic wave (SAW) in the frequency range 30-300 MHz propagating along the surface of the substrate creates a wave of electric field. This wave acts on the QD array causing an additional SAW attenuation, Γ, and change in the sound velocity, V. Such “sandwich” geometry allows finding electrical AC conductance, σ^{AC}, of a non-piezoelectric material by acoustic methods. We used 18T SC magnet (NHMFL DC facility) for measurements the ∆Γ=Γ(H)-Γ(0) and ∆V/V_0=[V(H)-V(0)]/V(0) as functions of an external magnetic field, H, perpendicular to the sample's surface, in the temperature interval T=1-20 K.

The samples were grown by MBE method on the (001) Si-substrate, on which an intrinsic Si buffer layer was placed followed by a B delta-doped silicon layer with NB=6.8×10^{11} cm^{-2}, NB=8.2×10^{11} cm^{-2} and NB=11×10^{11} cm^{-2}. Then a 10 nm undoped Si layer was grown, on top of which 8 Ge monolayers were placed. This structure was covered by a 200 nm i-Si layer. The self-organized Ge QDs had pyramidal shape with height of 20 Å and square 120×120 Å base.

Results and Discussion

The measured magneto-attenuation ΔΓ as a function of H for different temperatures is shown in Fig. 1 for the sample with NB=6.8×10^{11} cm^{-2}. One can see that at temperatures lower 6 K attenuation decreases with magnetic field, ΔΓ<0, then saturates at H>10 T. At higher temperatures ΔΓ changes its sign, while dependence ΔΓ(H) becomes non-monotonic. Similar behavior is also observed for the higher doped samples, and the higher doping – the lower temperature the ΔΓ changes sign at.

Fig. 1. ∆Γ(Η) at different T, f=28MHz.

Fig. 2. ∆V/V_0(Η); T=4 K, f=28MHz. Field sweeps up and down are shown.

We believe that at T≤4 K under the experimental conditions acoustoelectric effects are determined by AC hopping conductance between different QDs under condition ωτ>>1, τ is the typical relaxation time for the population of relevant pairs of QDs. It is also evidenced by temperature dependence and absence of frequency dependence of σ^{AC}, derived from acoustics.

From simultaneous measurements ∆Γ and ∆V/V_0 one can determine real σ_1 and imaginary σ_2 components of AC-conductance.

It turns out that at T≤4 K there is transition from σ_1~H^2 (the weak MF condition) to σ_1~1/H^2 (the strong MF condition). That enables to estimate the localization length ξ=100Å. Temperature dependence follows σ_1(0)~T^{-2.5}, that is in accordance with the T^3 prediction of Galperin for this mechanism.

The sign change of ΔΓ at higher temperatures is associated probably with contribution of the holes that are in delocalized states due to activation or impurity breakdown. These results are under the scrutiny at the present time.

References