The Effect of Depletion Layer Charge on Rashba Polarization in Inversion Layers on HgCdTe

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To realize the spin-polarized field-effect transistor [1] based on the Rashba effect [2], at least two requirements should be satisfied: high enough value of Rashba polarization $P_R = (n^- - n^+)/(n^- + n^+)$ and the possibility of a gate voltage control of the Rashba polarization. The largest values of Rashba splitting are expected and observed experimentally in MIS structures based on narrow-gap semiconductors (NGS) [3]. However, in inversion layers on low-doped NGS, the Rashba polarization and effective Rashba α-parameter (in NGS, this parameter is not a good enough quantity for the performance of Rashba effect) are weakly sensitive to a gate voltage at the typical experimental conditions. The noticeable variations of the Rashba polarization are observed only in the narrow range of small 2D concentrations. The analysis shows that this interval corresponds to a circumstance when the charge in the depletion layer contributes appreciably to an electric field in inversion channel. It is hoped that this concentration range can be extended by increase in doping level of substrate. For this goal, we investigated experimentally (by magneto-capacitance spectroscope method) and theoretically (in 6x6 and 8x8 Kane approximation) the Rashba effect in the inversion layers on zero-gap HgCdTe with different doping level N_A-N_D = $3x10^{15}$÷$3x10^{18}$ cm^{-3} what corresponds to the depletion charge density N_{dep} ranged by (0.1÷5)$x10^{12}$ cm^{-2}. The MIS structures with anodic oxide film as insulator were investigated.

For all samples investigated the measurements show the well-resolved split of Fourier spectra into two lines in each a 2D subband in wide range of subband densities (see insert in Fig. 1). Measured and calculated carrier distribution on the Rashba spin-split subbands for ground subband is shown in Fig. 1 as a function of subband concentration. For the low-doped samples, the experimental data are in a good enough agreement with the self-consistent calculations we performed in the Hartree approximation for 8x8 Kane model assuming an infinite potential barrier at the interface and zero boundary conditions for components of wave function corresponding to the light branch of Γ_8 band (in a scale of Fig. 1, the theoretical curves for different samples are slightly distinct). The 6x6 Kane approximation corresponding to the infinite spin-orbit splitting of valence band overestimates the Rashba splitting even in the case of HgCdTe.

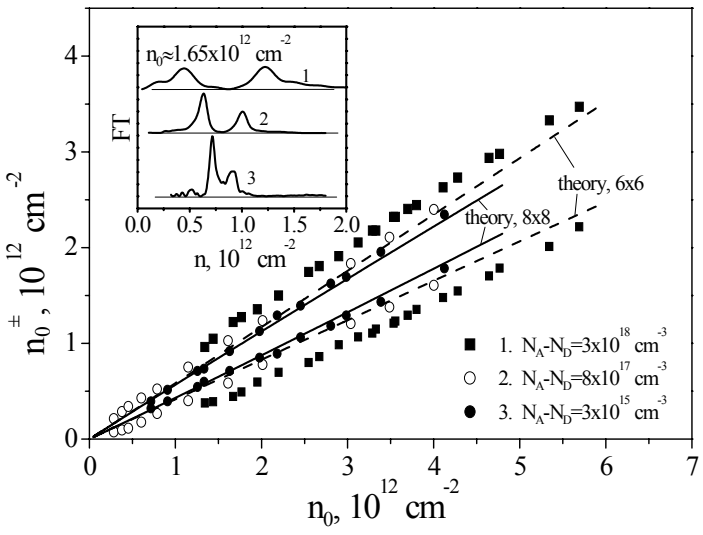

Fig. 1

The Rashba polarization decreases with increasing subband concentration and increases with N_{dep} (see Fig. 2). Increasing in N_{dep} leads to the extension of concentration range, in which the concentration dependence of Rashba polarization is observed. The width of this interval corresponds to an approximate condition $n < N_{dep}$. At large N_{dep} and small n the Rashba polarization reaches such high

value as $P_R = 0.5$. At $n > N_{dep}$ the polarization is saturated at the same for all samples values of $P_R = 0.18$ which is close to the value calculated for non-doped material.

The calculations predict a qualitatively proper behavior of the dependence of P_R on N_{dep} and n. However, the theory underestimates strongly the effect of the charge in the depletion layer. The discrepancy is aggravated with increasing N_{dep}/n ratio. There are several mechanisms, which can make for magnification of Rashba effect. The Rashba splitting can increase because of electron - electron interaction, as it takes place in two-dimensional systems for g-factor. However, in view of smallness of parameter of electron-electron interaction this mechanism can not play an appreciable role in studied materials. The calculations performed in framework of an approach of a work [4] show that the magnification of Rashba splitting via this mechanism does not exceed 5-7 %.

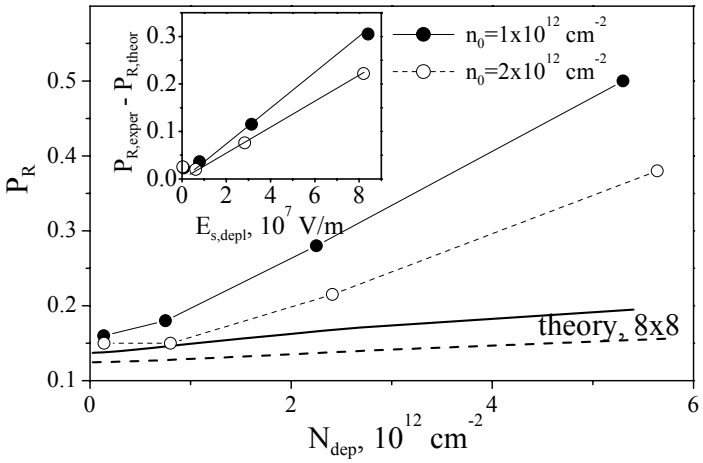

Fig. 2

The zero boundary conditions approximation we used takes into account the contribution in Rashba splitting originating from a spatial charge region in semiconductors alone. However, generally there are two contributions in the Rashba splitting: the pure field contribution induced inside the surface quantum well and interface contribution, which is a result of the spin-dependent boundary conditions. As is seen from insert in Fig. 2 that the additional contribution in the Rashba polarization is linear (if additive) in the additional interface electric field due to the depletion charge. Just such behavior is predicted for interface contribution in [5]. Quantitative calculations would require extensive knowledge about the region near interface. In contrast to heterostructures, in the case of MIS structures such estimations are hampered because there are no reliable data on the basic energy parameters of actual interfaces with oxide. Furthermore, the description of the energy spectrum of the (semiamorphous) oxide on the basis of the Kane symmetry classification (used for matching of Kane components of wave functions at interface in heterostructures) seems to be doubtful.

It is important to point out that in MIS structures the charge in depletion layer (and so the Rashba polarization) can vary at the same subband density by application of a voltage between the inversion layers and the bulk. The possibility to drive polarization without changing electron concentration is one of the most important features for spintronic devices.

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