Photo-ESR of Self-Organized SiGe Islands and High Frequency Effects on a Si 2DEG

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Photo-ESR on Self-Organized SiGe Islands

Introduction

Currently, there is much research activity on electron spins confined in zero dimensional structures [1], as they present a promising candidate for future spintronic and quantum computation applications [2] – [4]. In III-V compounds, the high degree of confinement leads to a significant increase in spin relaxation times [2], [3]. Earlier, we investigated self-organized Ge islands embedded in a Si buffer in photoluminescence (PL) and electron spin resonance (ESR) experiments in continuous wave (CW) and in time resolved mode [5] and found a single ESR line with a g-factor of g = 1.998, corresponding to electrons confined in the strained Si regions directly above the locations of the Ge islands [6]. This line appears only under the illumination with white light, which creates electron-hole pairs. The holes are localized inside the Ge islands, and the electrons in the strained Si regions nearby. Transitions between these two states are observed at 0.85 eV in PL experiments [5].

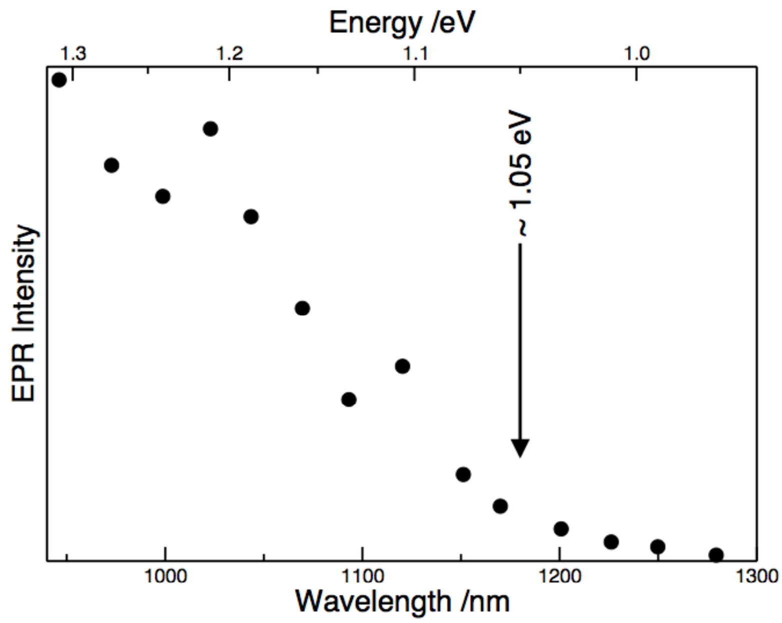

Fig. 1: ESR intensity as a function of wavelength/energy. A clear onset of ESR intensity is observed at 1.05 eV.

Experiment

During CW ESR at 2.5 K the sample is illuminated with monochromatic light from an optical parametric oscillator (OPO) source (details on the ESR experimental setup and the sample structure are found in Ref. [5]). At wavelengths around 1450 nm, corresponding to the transition energy from the Ge valence band (VB) to the strained Si conduction band (CB) states at 0.85 eV, no ESR intensity is detected. We find a strong increase of the ESR signal in the range of 1300 nm to 950 nm, with an onset at 1.05 eV, shown in Fig. 1.

Results and Discussion

The excitation from the Ge VB to the strained Si CB states at 0.85 eV in a photo-ESR experiment with monochromatic light is rather unlikely. For these transitions to occur, the OPO wavelength (energy) has to match the transition energy exactly, although there is a certain spread in transition energies due to fluctuations in Ge island sizes and locations [5].

Excitation from the Ge VB states above the band-gap, followed by relaxation into the strained Si regions, is much more probable. Such an excitation process is shown in Fig. 2. The observed onset at 1.05 eV appears quite realistic for it.

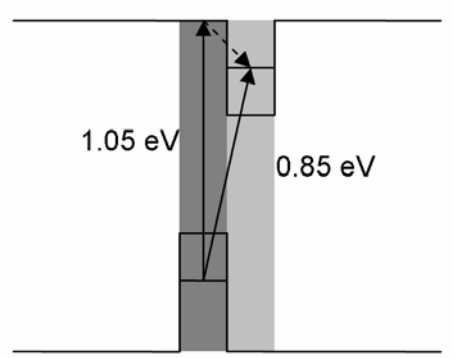

Fig. 2: Schematic sketch of the band structure variation along growth direction, through the center of a Ge island. The excitation from the Ge VB to the strained Si CB states at 0.85 eV is indicated, as well as the excitation from the Ge VB above the conduction band, followed by a relaxation into the strained Si CB (dashed arrow).

High Frequency Effects on a Si 2DEG

Introduction

Confinement of electrons in 2D structures, in particular in 2D electron gas (2DEG) in a Si/SiGe heterostructure has been extensively studied previously by us [7], [8]. We found that both the g-factor and the ESR line width are governed by the Bychkov-Rashba (BR) effect, arising from a structure inversion asymmetry introduced by the one-sided Sb modulation-doping layer in these structures. In the low field regime, the BR effect manifests itself by an effective magnetic field $\boldsymbol{B}_{BR}$ that is parallel to the 2DEG plane, perpendicular to the electron momentum. Recently, we reported on the direct observation of this BR field in the presence of an electric current that causes an additional contribution to the electron momentum vectors [9], [10]. When the sample is oriented in such a way that this BR field is parallel to the external field, it can be simply observed as a shift in the ESR line. Rotating the sample around an axis perpendicular to the external field gives exactly the expected anisotropy: the effect vanishes for $\boldsymbol{B}_{BR} \perp \boldsymbol{B}_{ext}$ and is maximized for $\boldsymbol{B}_{BR} || \boldsymbol{B}_{ext}$.

A high frequency (hf) current thus is expected to produce a hf BR field, which can be utilized directly for spin excitation and spin manipulation [11]. This effect is observed as an increase in ESR signal when the sample is moved towards a position where the electric mode of the resonator has its maximum [12].

Experiments

This effect is observed indirectly in our sample structures as well [8]. The observed ESR signal is a complex superposition of three components: the antisymmetric absorption signal (AS), corresponding to magnetic dipole transitions in the sample at resonance (the traditional ESR signal), the symmetric dispersion signal (DS), arising from the frequency dependence of the electric conductivity, and the antisymmetric polarization signal (PS) which appears due to the dependence of the conductivity on spin polarization.

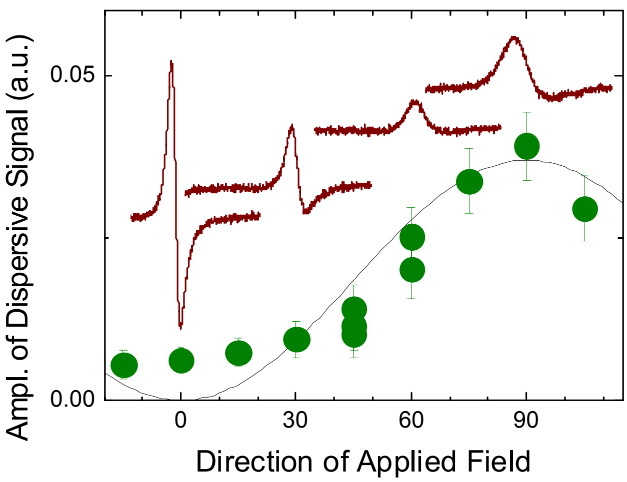

Fig. 3: Amplitude of the DS component of the ESR signal as a function of sample orientation with respect to the external field. The overall ESR line shape is shown qualitatively as insets.

When the sample is rotated around the direction of the magnetic component of the microwave (MW) radiation inside the resonator, $\boldsymbol{B}_1$, perpendicular to the external field it is found that the ESR signal is mostly antisymmetric when the external field is perpendicular to the 2DEG, and becomes more symmetric when the sample is rotated towards an orientation where the field is in-plane (see Fig. 3). This is due to the finite dimensions of the 2DEG. The electric component of the MW radiation, $\boldsymbol{E}_1$, vanishes completely exactly in the center of the resonator only. For in-plane orientation, it is parallel to the 2DEG, which gives rise to hf currents, leading to an increase in DS amplitude by a factor of ~30. When the 2DEG is oriented perpendicular to $\boldsymbol{B}_1$ ($\boldsymbol{E}_1$ in-plane), the DS amplitude is increased by a factor of ~100.

Acknowledgements

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