Demonstration of the Electrical Detection of Spin Coherence of Phosphorous Donor Electron States in Isotopically Pure Crystalline ^{28}Si

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Introduction

Phosphorus doped silicon (Si:P) is a technologically important material with possible uses in spintronic and quantum information processing devices [1]. One way to understand the properties of this material is by investigation of spin-dependent electronic transitions which influence transport and recombination and thus, the conductivity of the silicon host material. Whilst numerous studies of this type have been performed on Si:P at low magnetic fields [1,2], and a single cw-EMDR spectra at 7.1 T reported [3], no systematic investigation has been undertaken at high magnetic fields. The goal of the work presented here was to carry out pulsed electrically detected magnetic resonance experiments on phosphorous in a crystalline silicon host matrix in order to better understand the nature of electronic processes that may be utilized for coherent electrical spin readout devices.

Experimental

The samples used in this study (displayed in Fig. 1a) consisted of (111) crystalline bulk silicon wafers with a phosphorous doping corresponding of ~10^{17} P/cm^2. A number of interdigitated contacts (10 µm width, 20 µm pitch) were fabricated on the wafer surface, consisting of Cr (10nm) /Au (190nm) (Fig. 1b). A native oxide was formed by exposing the wafer to air following etching of the wafer in hydrofluoric acid. We used the quasi-optical homodyne and heterodyne spectrometers in the EMR facility to perform spin resonance on the device at B ~ 8.5 T (frequency = 240GHz), operating in a microwave chopping mode. The change in voltage across a device on resonance was recorded using a lock-in technique. The measurement circuit is shown in Fig. 1c. One of the challenges for such an electrically detected high field/ high frequency magnetic resonance experiment was to establish sufficiently high radiation fields (B_1 fields) in a sample consisting of conducting materials. This problem was solved by means of a sophisticated design of the sample and contact geometry as well as the use of quartz layers on both sides of the silicon wafer as anti-reflection coatings.

Results and Discussion

Fig. 1d shows the EDMR signal recorded at a temperature of 12 K. An EPR measurement is also shown to demonstrate the ability to resolve the two hyperfine split P resonances. Additionally, the EDMR signal shows a large resonance attributed to the P_b defects at the Si-SiO_2 interface, which is not visible in the ESR spectra. The absence of the P_b resonance in the conventionally detected EPR spectrum is expected due to the minute absolute numbers of P_b centers within the sample due to their exclusive occurrence at the silicon to silicon dioxide interface. Hence, the visibility of this resonance demonstrates the high sensitivity of the EDMR method.

Conclusions

We have demonstrated EDMR at the highest magnetic fields reported to date. This allows a systematic investigation of EDMR at high magnetic fields to be undertaken with much higher sensitivities for certain paramagnetic centers than with conventionally detected EPR measurements. Future work will also focus on implementing pulsed EDMR at these high fields.

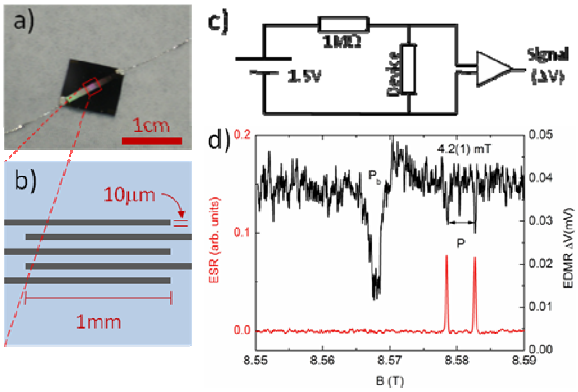

Figure 1: a) Photo of the Si:P sample used in this study. b) Contact arrangement on the surface of the sample (asymmetric scale). c) Circuit diagram of the measurement setup. d) ESR and EDMR signal at 12K.

Acknowledgements

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References

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