Eötvös Loránd University (ELTE)

Faculty of Natural Sciences

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OPTICALLY DETECTED MAGNETIC RESONANCE SPECTROMETER IN A CONFOCAL MICROSCOPE IN THE STUDY OF SOLID-STATE QUANTUM BITS

4th semester research report

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Introduction The goal of the research to develop solid state defect quantum bits in ultrasmall silicon carbide (SiC) nanocrystals and observe them by optically detected magnetic resonance (ODMR) technique. Single defect quantum bits might be observed with using a confocal microscope setup where only single digit nanocrystals could be engineered in the confocal volume spot. Ádám Gali's group already developed a synthesis method to generate vacancies in few-nanometers-sized SiC nanocrystals that can be converted to divacancy defects with observable ODMR signals at ensemble level. My research task is to participate in the improvement of the ODMR setup in Ádám Gali's ODMR laboratory as well as to optimize the formation of vacancies and divacancies in SiC nanocrystals in the synthesis process developed in the group. These approaches may culminated to the observation of ODMR signal of single divacancy or related quantum bits in few-nanometers-sized SiC nanocrystals.

Summary of work in the previous three semesters I started to work in the ODMR laboratory. I tested diamond nitrogen-vacancy centers, a well-known ODMR center and quantum bit, by the ODMR equipment in the group and learnt to observe ODMR signals. I learnt to use Raman spectroscopy, photoluminescence (PL) spectroscopy, electron spin resonance (ESR) spectroscopy, FTIR vibration spectroscopy and the analysis of the results including the software environment at Wigner Research Centre for Physics. Then I focused on the materials science to search for parameters in the synthesis method of SiC to control the hexagonal stacking sequences and hexagonality in the SiC crystals. I started the synthesis with Si and black carbon source, and the reaction took place in an induction chamber (Stanelco STX25-DF1). I also tested other synthesis processes with using silicon-dioxide as a starting material with Carbolite high temperature horizontal tube furnace (CTF/18/300). Finally, I concentrated on the defect creation in the synthesized SiC crystals by adding aluminum (Al) precursor in the synthesis process for introducing silicon-vacancies (Si-vacancies) in the SiC crystals.

Summary of work in the 4th semester I realized in the previous works, that the basic challenge in the synthesis process of defective SiC is to find the optimum parameter for the concentration of Al precursor and the reaction time. Since the SiC synthesis process occurs at elevated temperatures (above 800 °C) this may annihilate the desired Si-vacancies as Si-vacancies anneal out at such temperature according to the literature. Aluminum plays multiple roles in the synthesis process of SiC: the presence of Al will increase the hexagonality of SiC crystal and removes Si in the reaction process with leaving Si-vacancies behind. On the other hand, too high concentration of Al would significantly degrade the quality of SiC crystal. The crystal quality of SiC was studied by Raman spectroscopy and X-ray diffraction (XRD) where Gábor Bortel helped me to analyze the XRD spectra. Since Si-vacancy is paramagnetic (it has S=3/2 ground state) the change in the concentration of Si-vacancies could be monitored by ESR spectroscopy. ESR spectroscopy also reveals whether other paramagnetic centers are present in the samples. We note that the PL signals of Si-vacancies were found but could not be used for quantitative analysis for the concentration of Si-vacancies in the samples.
Our results demonstrate that (i) ESR signal of Si-vacancy shows weak dependence of Al concentration in the precursor. (ii) There is strong dependence between the concentration of Si-vacancy and reaction time. There is a very small reaction time window to maximize the concentration of Si-vacancies with keeping the good quality of SiC crystallinity.

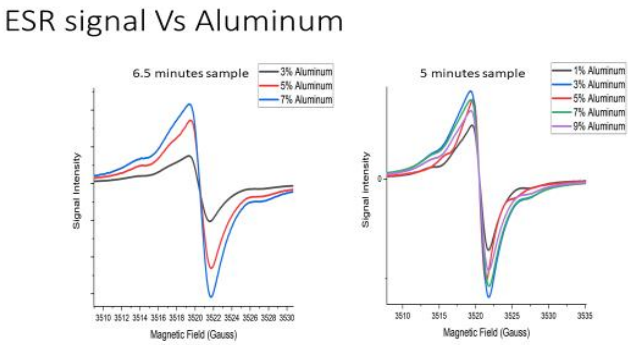

Figure 1: ESR spectrum vs. Al content in the precursor at room temperature

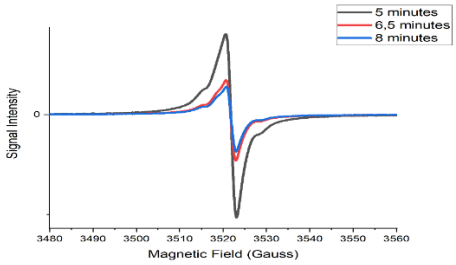

Figure 2: ESR spectrum vs. reaction time of SiC synthesis with Al content at 5% at room temperature

Publications: Because of pandemic situation, the work in the laboratories were restricted that significantly affected the progress of the research. In addition, the territory of analysis of PL and ESR signals from SiC nanocrystals with hexagonal inclusion is unprecedented in the literature, and we have to gain experience in these issues. Nevertheless, we think that the already achieved results are publishable this year where two scientific articles will be submitted in this topic (tentative titles: "Silicon vacancy generation in SiC via aluminum SiC reaction" and "Silicon vacancy and divacancy in porous 3C-SiC"). We demonstrated the introduction of vacancy quantum bits by non-destructive methods which is of great interest because no other (paramagnetic) defects are formed in the SiC lattice, so the properties (e.g., coherence time of the electron spin, etc.) of the vacancy quantum bits in our sample will be superior over those which are created by irradiation techniques.

Studies in current semester at ELTE or other courses attended I participated in two courses: Technology of materials (8 credits) and Physical material science (8 credits).

Conferences: Because of pandemic situation, we were not allowed to travel conferences and many conferences were cancelled. We plan to show our results at conferences next year.

Future plans We expect that we find new results in a much shorter research period in the future because all the synthesis and measurement method, evaluation protocols are almost completely developed. After producing a larger number of samples, we plan to measure the ODMR signals at ensemble level first, then to disperse the nanoparticles and observe the ODMR signals from single defects.