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Single Photon Ge Vacancy Centers in Heteroepitaxial and Homoepitaxial Diamond Grown by HFCVD

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Abstract: Epitaxial diamond films containing single photon emitting Ge vacancies (GeV) were grown on both diamond seeded Si substrates and single crystal (100) diamond wafers. Photoluminescence (PL) measurements showed a zero phonon line near 602 nm.

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1. Introduction

Data that is encrypted using conventional methods and then sent over communications networks is theoretically indecipherable to any eavesdropper without knowing the encryption key. However, all conventional encryption methods are vulnerable to brute force attacks in which every possible encryption key is used to decrypt the data [1]. Therefore, the effectiveness of any encryption method depends on the number of possible keys. To complicate matters, advances in computing have significantly reduced the amount of time it takes to perform an exhaustive search over the key space of longer encryption keys. Thus the conventional encryption methods in use today will not be secure in the near future.

Quantum key distribution (QKD) has the ability to guard against eavesdropping, which in turn guards against unauthorized access to transmitted data. An encryption key consisting of a sequence of polarized photons is exchanged between the sender and receiver. If a hacker attempts to eavesdrop, the photons are changed, which corrupts the key exchange. The sender then knows not to transmit the data over the compromised network. Therefore, no unauthorized access to the data is possible either at the time of communication or in the future. Clearly, QKD is superior to the conventional encryption methods currently in use.

The underlying communication network suitable for use with QKD consists of a fiber optic network, a light source that can output single photons and a receiver sensitive enough to detect the transmitted photons. Therefore, if QKD is to become a viable alternative to traditional encryption, reliable single photon emitters must be available.

Although previous research has focused on using atoms, molecules and quantum dots, each has it's drawbacks [2]. Recently, vacancy center defects have received much attention as single photon sources. Iwasaki *et al.* [3] showed that germanium vacancies (GeV) in diamond are a single photon sources. However, they used non-scalable methods, namely implantation and microwave plasma CVD growth, to obtain the GeV. Therefore, it is the goal of this work to grow germanium vacancy centers in diamond using the more scalable hot filament CVD method.

2. Methods

The heteroepitaxial and homoepitaxial diamond films were grown in a hot filament chemical vapor deposition (HFCVD) system from Blue Wave Semiconductor. The HFCVD reactor we used has 3 tungsten filaments that were maintained at 2300 °C during growth. Hydrogen (H_2) and methane (CH_4) were used as source gases. The pressure during growth was 20 Torr, and the flow rates for H_2 and CH_4 were 80 SCCM and 1 SCCM respectively. A mixture of 1% germane (GeH_4) in 99% $H_2$was used as the Ge source and was introduced into the growth chamber at 5 SCCM for 1 h in the middle of the growth cycle. The substrate temperature was 700 °C. A 250 nm buffer layer was first grown for 2 h, then a 125 nm Ge doped layer was grown for 1 hour, and then a 125 nm cap layer was growth for 1 h, which produced films about 500 nm of total thickness.

For the heteroepitaxial growths, single side polished p-type silicon wafers were used. The wafers were first cut into 1 cm^2 pieces and then cleaned by sonicating the pieces in an acetone bath followed by a sonication in a methanol bath. The wafers were then rinsed in DI water and dried with nitrogen. The surface oxide of the Si pieces was removed using an HF dip. Finally, the Si pieces were sonicated in a diamond nano-particle slurry for 10 minutes and then dried with nitrogen. The average crystal size in the diamond slurry we used is 5 nm.

For the homoepitaxial growth, type Ib high pressure high tempertur (HPHT) synthetic diamonds were used. The diamonds were first cleaned by boiling them in a 1:1:1 mixture of nitric, sulfuric and perchloric acids for three hours. Then the diamonds were sent to an outside company to be polished. Before growth the diamond wafers were again cleaned agin using the same acid mixture.

3. Summary of Results and Discussion

Photoluminescence (PL) measurements were performed on the samples at room temperature and at 4K. The germanium vacancies (GeV) were excited using a 532 nm laser, and the data was collected using a confocal microscope that simultaneously saved both the Raman and PL data. The Raman/PL data are shown below in Figure 1.

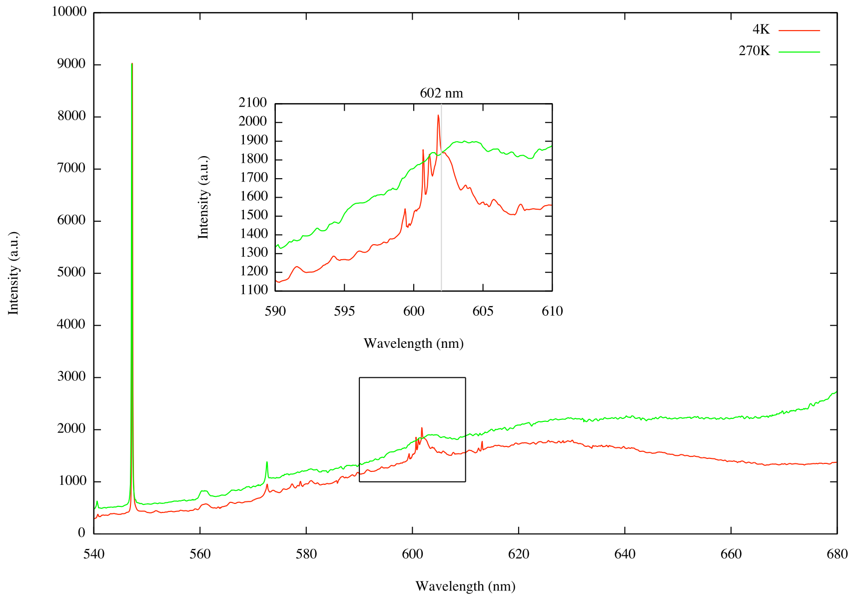

Fig. 1. Photoluminescence spectrum of the observed germanium vacancy center in the heteroepitaxial polycrystalline diamond diamond films at room temperature and at 4 K. Zero phonon line peaks are observed at 601.8 nm, 601.1 nm and 600.7 nm. The room temperature graph is scaled and offset for clarity.

As shown in Figure 1, the zero phonon line (ZPL) for the GeV in the heteroepitaxial diamond film that we grew was detected at 601.8 nm, 601.1 nm, and 600.7 nm. All of these values are slightly lower than the 602.14 nm mean that was reported by Iwasaki *et al.* However, we believe that these results are consistent. We attribute our lower observed values to a shift in the ZPL due to the stress in the epitaxial film generated by the large mismatch between the Si and diamond lattices.

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