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Sharp and intense Si-vacancy center emission from diamond cube selective-grown on Si (100) substrate

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Abstract

Sharp and intense emission from the Si-V center in a diamond cube grown on Si was demonstrated. The cavity mode emission was also observed. Possibility of the Si-V luminescence center as a light source for integrated quantum photonics on Si chip is suggested.

1. Introduction

Diamond has excellent characteristics such as high thermal conductivity and wide band gap, as well as high hardness. Recently nitrogen-vacancy (NV) centers in diamond are attracting much attention to apply to single photon emitters and fluorescent biomarkers [1]. Emission of NV center shows zero-phonon line (ZPL) at 637nm accompanied by the vibronic band from 637nm to around 800 nm. On the other hand, a silicon-vacancy defect (Si-V center) in diamond has indicated ZPL at 738nm without vibronic band and high emission rate [2]. Therefore the Si-V luminescent center is expected to be a new light source for quantum photonics. Taking into account of the integration on Si chip, it is necessary to achieve diamond growth on Si substrate.

Diamond hetero-epitaxial growth on Si substrate has been investigated for long time. Recently we have demonstrated highly oriented diamond growth on Si substrate [4]. In this paper, diamond cube selective-growth on Si (100) substrate by two-step MP-CVD is demonstrated, and emission properties of the Si-V luminescent center from the diamond cube are evaluated.

2. Experiments

Two-step diamond growth on Si (100) substrate was performed by microwave-plasma-assisted chemical vapor deposition (MP-CVD) using CH_4, H_2 as source gases. The first process is highly oriented diamond nucleation using the bias enhanced nucleation method with atomic Si micro addition [3,4]. Mono-methyl silane (MMS: $Si(CH_3)H_3$) was used as an atomic silicon source. Then microwave power is 500W, and the atomic Si induced nucleation is dominant under this condition. The second step is the epitaxial lateral over growth (ELOG) of diamond using the cylindrical resonant microwave plasma system (CYRANNUS®), which makes the diamond selective growth against Si possible. Then the deposition rate is about 5μm/h. The crystallinity was evaluated by Raman scattering using second harmonic generation (SHG) of Nd-YAG CW laser (532nm).

In order to characterize luminescence properties of the diamond cube, μ-photoluminescence (PL) was performed by using SHG of Nd-YAG CW laser (532nm) as an excitation light. Spot size of the excitation light was about 3μm. The collected light vertical to the surface by an objective lens was detected using a conventional Si-CCD spectrum analyzer through an optical fiber.

3. Results and discussions

Figure 1 shows a SEM image of the diamond cube formed on Si (100) substrate after 12-h growth. Isolated diamond cube with 60-μm square oriented to Si (100) substrate is clearly seen. Micro-Raman scattering spectrum of the diamond cube is also shown in figure 2. The Raman peak at 1333-cm^{-1} with linewidth of 4.5-cm^{-1} indicates good crystallinity equivalent to homo-epitaxial diamond.

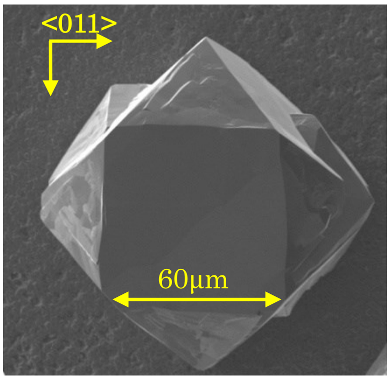


Fig.1 SEM image of a diamond cube grown on Si (100) substrate.

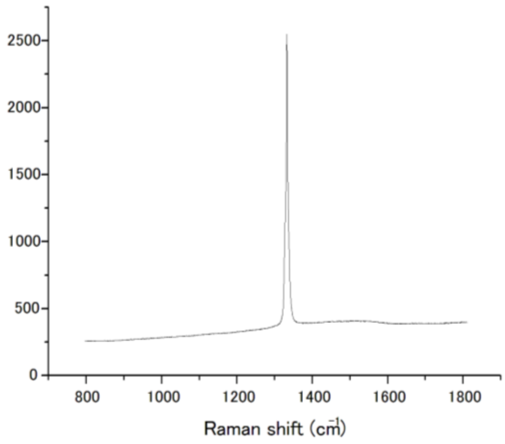
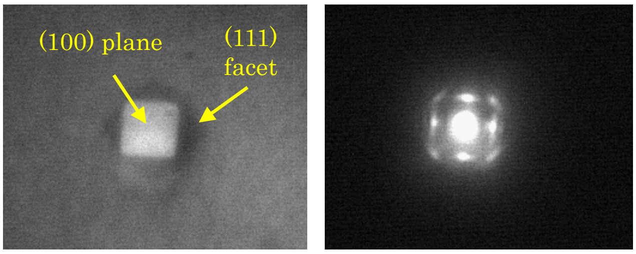


Fig. 2 Micro-Raman scattering spectrum of the diamond cube.

Figure 3 shows a micro-photograph (a) and an emission image (b) of a diamond cube grown on Si (100) substrate. Size of the diamond cube is 10-μm square oriented to Si (100) substrate. A diamond (100) top plane and four (111) facets of the diamond cube are clearly seen in Fig.3 (a). Several emission spots corresponding to the each facet of the diamond cube are observed in Fig.3 (b). The most intense emission spot is at the center of the (100) top plane and corresponds to the excitation point. The second most intense spots are at the (111) facets. These facets can make optical cavities. We consider that the emission spots are originated from the cavity mode.



(a) (b)

Fig. 3 Micro-photograph (a) and emission image (b) of the diamond cube.

Figure 4 shows a room temperature μ-PL spectrum of a diamond cube grown on Si (100) substrate. Then excitation power is 1mW. A sharp and intense peak at 738 nm with FWHM of 5nm (11.4meV) is observed, which indicates the zero-phonon line (ZPL) of Si-V center in diamond cube [2]. Note that no vibronic emission related to the Si-V center emission is observed. Moreover the resonant peaks are also observed. They are indicated in the viewgraph by arrows which are calculated under the condition of a diamond cavity with a length of 17-μm. The cavity length corresponds to the cavity with (111) facets. The PL emission mainly comes from the (100) plane, but the vertical resonant mode is not dominant because of the higher refractive index of Si at silicon-diamond interface on the opposite side.

We have made the selective growth of diamond cube on Si substrate possible. Also dry etching process to make diamond nanostructures can be performed easily [5]. It is expected that the Si-V center is used as the coherent light and single photon sources for integrated quantum photonics on Si chip, because of the excellent emission properties. Now we have attempted to make the diamond emitter coupled with silica waveguide, and to observe the single photon emission from the Si-V luminescent center.

4. Conclusion

Diamond cube selective-growth on Si (100) substrate by two steps MP-CVD is demonstrated. Emission properties of the Si-V luminescent center from the diamond cube are evaluated. Sharp and intense emission is observed. The observed ZPL of the Si-V center shows FWHM of 11.4meV at room temperature. From this result, an application of the Si-V center to single photon sources is expected. The cavity mode resonance originated from the facing diamond (111) facets is also observed. This result suggests a possibility of the diamond micro-cavity laser to apply to the coherent light for integrated quantum photonics on Si chip, as well as single photon sources.

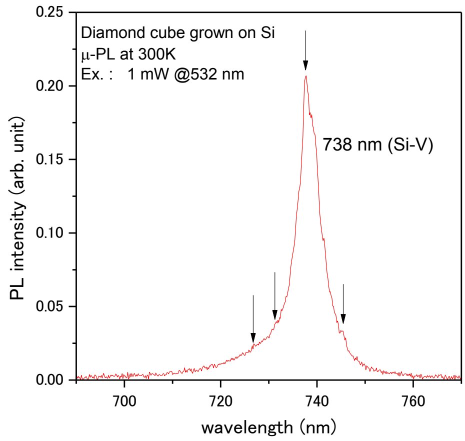


Fig. 4 Room temperature μ-PL of SiV center from diamond cube grown on Si substrate.

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