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Single photon generation from an impurity center with well-defined emission energy in GaAs

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1. Introduction

A single photon source is essential for the optical quantum information technology, such as quantum cryptography and quantum computation. Semiconductor quantum dots (QDs) have been extensively studied as an important candidate. However, the emission energies of QDs are undesirably inhomogeneous due to the large size distribution. In recent years, single impurity centers in bulk semiconductors have attracted considerable attention, because they are free from size distribution and have well-defined emission energy in principle. Single photon generation has been realized from several single impurity centers, such as nitrogen-vacancy centers in diamonds [1]. By nitrogen doping in a III-V semiconductor, isoelectronic trap centers can be formed. Nitrogen pair centers in GaP:N have been proved to be useful for the single photon sources with well-defined energy [2, 3]. Another promising candidate, GaAs:N, have been studied by several research groups, and sharp luminescence lines are observed in the bandgap. Recently, single photon generation has been also demonstrated for the nitrogen isoelectronic trap center with high emission efficiency in GaAs:N [4]. However, the emission energies from those centers were not identical with each other.

In this work, an attempt was made to obtain energetically well-defined single photon source in the nitrogen doped GaAs sample grown under a different growth condition from our previous report [4]. Optical properties of the individual luminescence centers with identical energy were investigated, and single photon emission from the center was clearly observed.

2. Sample and experiment methods

The sample was grown by a low pressure metal organic chemical vapor deposition (MOCVD) on a Cr-O doped semi-insulating GaAs (001) substrate. The nitrogen doped layer was sandwiched between a GaAs buffer layer and a GaAs cap layer. From secondary ion mass spectroscopy, the nitrogen concentration was estimated to be 1.8×10^{12} cm^{-2}. Unintentional carbon impurity was also observed at the delta-doped layer with a sheet density of 8.5×10^{10} cm^{-2}. The detailed growth condition will be reported in elsewhere.

In the single impurity center study, the sample was cooled to 5 K in a liquid helium continuous flow cryostat. To improve the spatial resolution and collection efficiency, a hemispherical solid immersion lens was attached onto the sample surface. The luminescence signal of sample was collected with a microscope ×40 lens (NA=0.5) and was focused onto the entrance slit of a spectrometer with a focal length of 92 cm equipped with a charge-coupled device. A continuous wave 532 nm solid-state laser was used for excitation. Polarization measurements were carried out for many single impurity centers by rotating a half-wave plate placed in front of the polarized beam splitter. Single Photon generation was studied for several single impurity centers by a Hanbury-Brown and Twiss (HBT) setup with two silicon avalanche photodiodes.

3. Experimental results

We obtained a luminescence distribution map by scanning the sample with a narrow bandpass filter (~400 μeV) at the center photon energy ~1.475 eV. As shown in Fig. 1, the most of luminescence centers isolatedly distributed in the nitrogen doped layer, and each intense spot is caused by an impurity trap center. The emission energy of these cen-

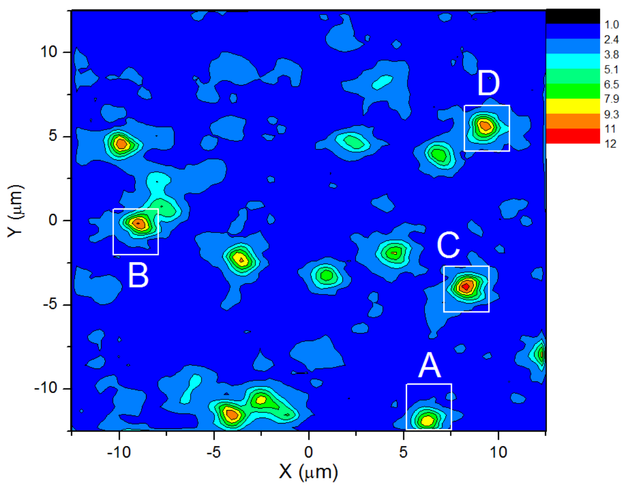

Fig. 1 A luminescence map of GaAs:N in the scanning area about 25 μm × 25 μm at the center photon energy ~1.475 eV.

ters must be approximately identical because they pass through the narrow bandpass filter. According to Makimoto's report [5], the origin of the luminescence peak at 1.475eV is the nitrogen pair [0,0,0]-[4,2,0]. However, we think that there is a possibility that other impurity such as carbon is involved in the luminescence center.

To obtain the detail optical properties of these centers, we individually implemented the polarization measurement for many luminescence centers. The results of four centers, marked by A, B, C, and D in Fig. 1, are shown in Fig. 2. We found the emission energies of the four centers are almost identical with the energy fluctuation less than 100 μeV in contrast to our previous work [4]. Photon correlation result of a single impurity center is shown in Fig. 2 inset. The strong reduction at zero delay time demonstrated that the single photon is indeed generated from this single impurity center.

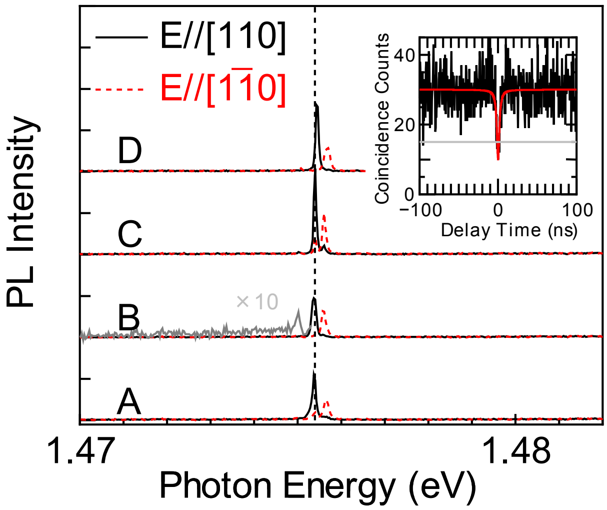

Fig. 2 Polarization measurements and single photon generation at 5 K. Polarized spectra of the four centers marked by A, B, C and D in Fig. 1 are displayed. This black solid lines show the [110] polarization components and the dotted red lines show the [1$\bar{1}$0] polarization components. The grey solid line is magnified ten times of the red dotted line for center B. The inset shows a result of HBT measurement for a single impurity center.

We found that not only the emission energy but the polarization properties of the luminescence center were also identical. As shown in Fig. 2, two distinct emission components have been observed from all of the luminescence centers. The two components are linearly polarized, and they are orthogonal to each other. The polarization directions of the intense component at low energy side and the weak component at high energy side are along to [110] and [1$\bar{1}$0] crystal axis, respectively, for all of the examined centers in the sample. The polarization characteristics of the impurity centers are very similar to that of the [110]-oriented NN pair centers in GaP:N [3]. It seems reasonable to suppose that the luminescence center studied here are due to [110]-oriented impurity pair. Strictly speaking, we also observed slightly tilted polarization direction from [110] crystal axis for several luminescence centers. The luminescence center studied in our previous work [4] showed similar [110]-polarized luminescence, though only one component was observed. The atomic configurations of these nitrogen luminescence centers should be studied further.

4. Conclusions

A kind of impurity luminescence centers in GaAs with well-defined emission energy has been realized in this work. We studied the optical properties of these single luminescence centers in a micro-spectroscopy system. All of luminescence centers show the same polarization characteristic, and the emission energy fluctuations are less than 100 μeV. The single photon emissions from these single impurity centers have been demonstrated.

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