Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 104-105

E-1-3

First Demonstration of Electrically Driven 1.55 μm Single-Photon Generator

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1. Introduction

We have successfully observed of single-photon generation from an electrically driven 1551.2 nm single-photon generator by using InAs quantum dot (QD). In the previous work, single-photon generation at 1.55 μm with QD is only demonstrated by photo excitation method [1] even though the 1.55 μm is the most important wavelength in telecommunication because of the lowest transmission loss.

An electrically driven single-photon generator (ESPG) has an advantage over the photo excitation method, because the ESPG does not need a pump laser and extra optics. In general, it is difficult to obtain high quality QDs for telecom single-photon generator (SPG), and so most of ESPGs with QD was presented below 1μm [2, 3]. More recently, the longest wavelength ESPG has been demonstrated at ~1.3 μm [4].

2. Experiments and Results

Our ESPG consists of InAs QDs, a *p-i-n* diode and an optical mesa structure. We have grown QDs by using metal organic chemical vapor deposition. Figure 1 (a) shows that InAs QDs are embedded in an InGaAsP layer on an *n*-type InP buffer. The InAs QDs and InGaAsP layer have a smaller lattice mismatch than other QD structures [2-4]. Therefore we can easily control the size of QDs for 1.55 μm photoemission. The density of InAs QD is about 2.7×10^{10} cm^{-2} and the typical lateral size of the QD is about 30 nm from an atomic force microscope (AFM) image (Fig. 1 (b)).

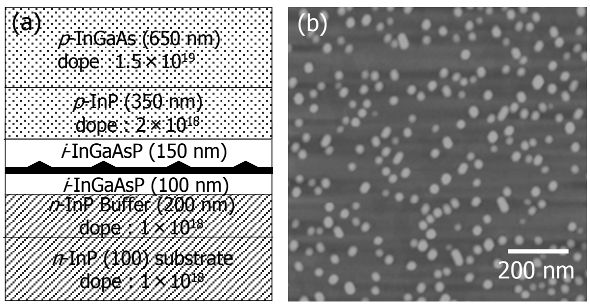

Fig. 1 (a) Epi structure of ESPG. (b) AFM image of QD.

Figure 2 (a) shows the scanning electron microscope (SEM) image of the surface of ESPG. We fabricated the *p-i-n* diode into the optical mesa structure. Hole-carriers are injected into top *p*-InGaAs layer from an electrode and they diffuse in *p*-InP layer of the mesa structure. The top *p*-InGaAs layer was etched except for the area below the contact hole and used only ohmic contact with electrode. Clear diode characteristic was observed from I-V curve (fig. 2 (b)). For electrical pulsed injection into InAs QD, we used a pulse pattern generator (PPG, MP1570A, Anritsu) which can produce the 80-ps width electrical pulses on demand. The generated electrical pulses were merged with the DC voltage using Bias-T (5575A, Picosecond Pulse Labs.) and transmitted to the electrode through coaxial cable.

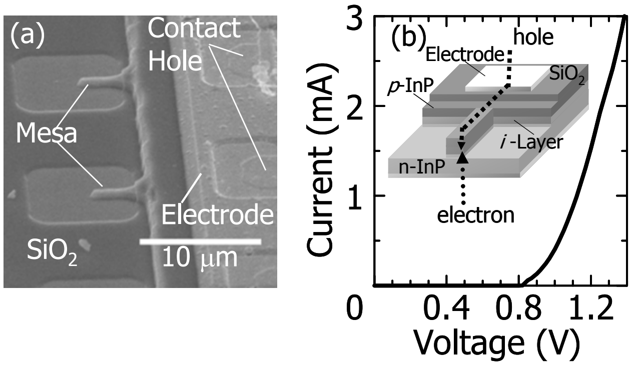

Fig. 2 (a) SEM image of surface of single QD device. (b) I-V characteristics of *p-i-n* diode at 8 K. Inset shows schematic illustration of carrier injection.

We then selected the brightest single exciton line from QD as a photon source around 1.55 μm. Figure 3 (a) shows the selected line from electroluminescence (EL) spectrum at 1551.2 nm using 0.3-nm width band pass filter and 1500-nm low pass filter. Inset shows the EL spectrum before selection. The current were injected with 80-ps width and 2.5-V height electrical pulses with 80 MHz repetition rate and 1.22-V DC voltage for this measurement.

The single exciton line shows the clear single exponential decay which was observed by time-resolved EL (fig. 3 (b)) using a single-photon detector (id 200, id Quantique). The time difference between a signal from the detector and a gate signal from PPG were accumulated with a time correlated single-photon counting board (TCSPC, TimeHarp 200, PicoQuant). The obtained lifetime of 1.59 ns is equal to that of single InAs/InP QD with optical excitation [5] and is longer than that of single InAs/GaAs QD [6]. This suggests that the selected EL line originates only from the single exciton in single QD.

Selected single exciton line shows clear antibunching dip at a zero-time delay by using a photon correlation setup [1]. The time delay between two signals which were generated by 5ns-gated two detectors, were accumulated by a TCSPC. The photon correlation experiment was executed 40 times for 30 min accumulation and the total event number was 32556 for 19 time bins when the pulse rate was set 4 MHz. The sum of the counts at a zero-time delay was 1513 counts which was lower than the average counts at a non-zero time delay 1725.

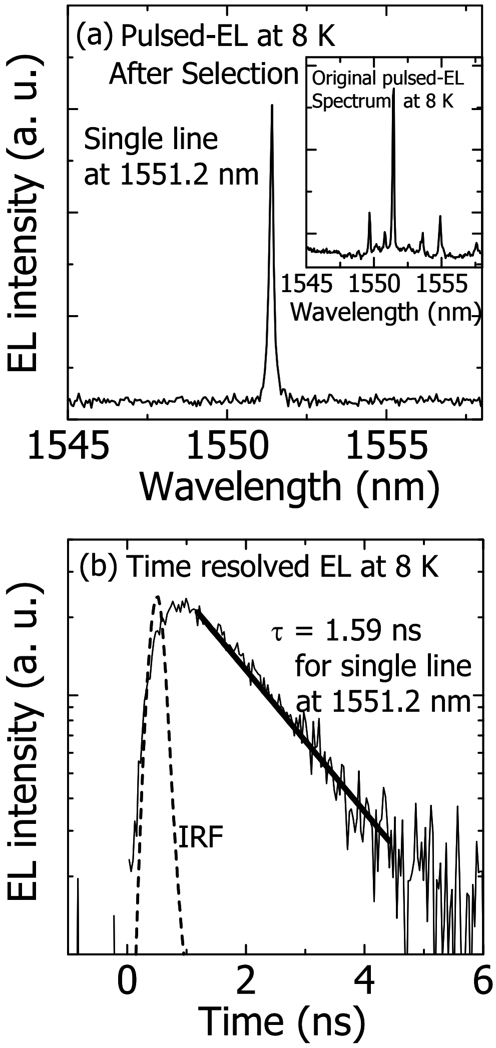

Fig. 3 (a) Selected EL line of InAs QD at 8 K. Inset shows EL spectrum before selection. (b) Time-resolved EL signal of the selected EL line at 8 K. Dotted line shows instrument response function (IRF) of our setup.

The estimated second-order correlation function $g^{(2)}(\Delta t)$ indicates the single-photon generation by current injection (fig. 4). Figure 4 shows the estimated $g^{(2)}(\Delta t)$, where the error bars for zero-time bin indicate the 95% confidence interval given the statistically variance of the data from 40 trials. By subtracting the noise counts, the estimated $g^{(2)}(0)$ is about 0.36. Since the selected exciton line contained only the luminescence of the single exciton in single QD besides the noise, this antibunching behavior means the single-photon generation.

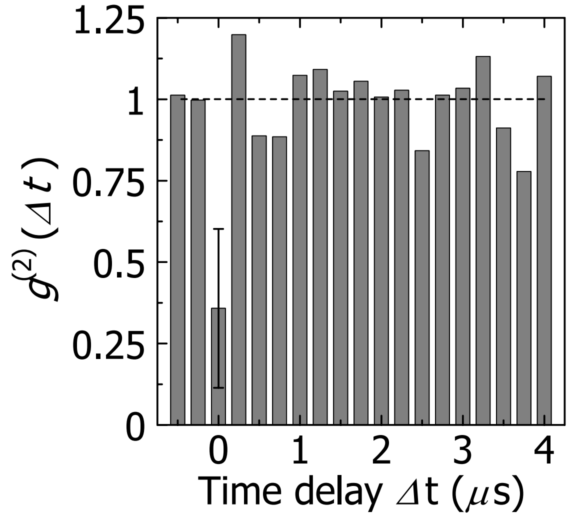

Fig. 4 Antibunching behavior of photon correlation function $g^{(2)}(\Delta t)$ by current injection at 1551.2 nm. Dotted line shows average count of $g^{(2)}(\Delta t \neq 0)$.

3. Conclusions

We succeeded in demonstrating single-photon generation from InAs QD at 1551.2 nm by ESPG for the first time. This result suggests that our realistic semiconductor technology can be used to integrate SPGs into electrical devices. In realizing the practical quantum communication over the optical fiber network, this technology is important and essential itself.

Acknowledgements

This work was partly supported by Special Coordination Funds for Promoting Science and Technology. The authors would like to thank Dr. N. Hatori and Dr. T. Nakaoka at the University of Tokyo as well as Dr. M. Ekawa and Dr. N. Harada at Fujitsu laboratories for helpful discussion and continuous support.

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