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Voltage-controlled Emission Wavelength Switching in a Pseudomorphic $Si_{1-X}Ge_X$/Si Double Quantum Well

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1. Introduction

Controlling or tuning the emission wavelength of a light emitter is a basic demand that arises in the design of device architecture, and a prerequisite for viable devices as well. Among a rich variety of technical schemes to this end, application of external electric field seems to be the optimal choice from the standpoint of device operation. As opposed to quantum wells (QWs) of compound semiconductors, pseudomorphic $Si_{1-X}Ge_X$/Si QWs are characterized by their type-II potential line-up which diminishes otherwise useful electric-field effects such as Stark effect [1]. As such, it is necessary to explore a novel capability if one wishes to achieve voltage-controllability over wavelength with pseudomorphic $Si_{1-X}Ge_X$/Si QWs.

In this report, we demonstrate that electron population in a pseudomorphic $Si_{1-X}Ge_X$/Si QW can be controlled by applying longitudinal electric field, paving a way towards voltage-controlled emission wavelength switch operation using QWs with different emission wavelengths.

2. Experimental

The sample was a nominally-undoped pseudomorphic $Si_{1-X}Ge_X$/Si DQW grown on an on-axis p-type Si(001). The well widths and Ge contents are $Lz^{(1)}$=34Å, x=0.15 for the buried well (QW1) and $Lz^{(2)}$=126Å, x=0.30 for the near-surface well (QW2), respectively. The two wells are separated by a 0.8-μm-thick Si barrier. Time-resolved photoluminescence (PL) was monitored under longitudinal electric field in the time-correlated single-photon-counting mode using an InGaAs-based photomultiplier (Hamamatsu 5509-71). Bias voltage was applied through Al electrodes deposited on both wafer faces which allow optical access.

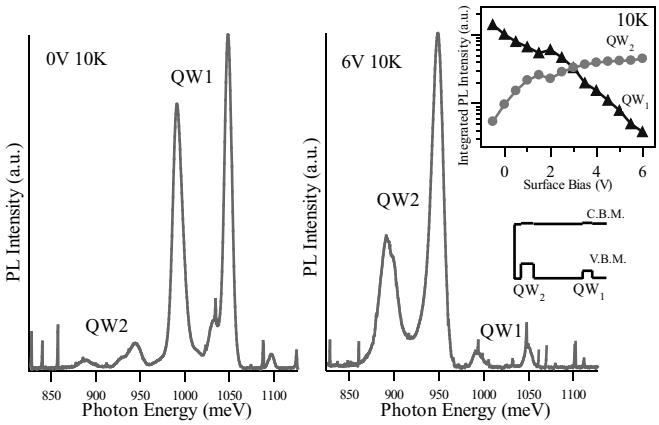

FIG.1 10-K PL spectra at bias voltages of 0 and 6V. Upper inset: voltage dependence of PL intensity of DQWs. Lower inset: schematic band line-up of strained $Si_{1-X}Ge_X$/Si DQWs

3. Results and discussion

Under cw excitation, a clear spectral dominance switch was observed between the two wells with varying bias voltage as visible in Fig.1. Luminescence from the near-surface (buried) QW is significantly enhanced when the surface is positively (negatively) biased [2, 3]. Although quenching of luminescence is not complete at the maximum bias voltages shown in Fig.1, an extinction ratio more than 100 was achievable at further increased voltages.

As illustrated in the inset of Fig. 1, the appropriate band line-up is of type-II so that holes are confined in the QW at the bias voltages studied while electrons are bound to the holes only through the Coulomb interaction. As such, the electrons are susceptible to electric field and excitons are prone to field-ionization at relatively low electric field strength.[4] This is why Stark shifts are not observed in pseudomorphic $Si_{1-X}Ge_X$/Si QWs [1]. Likewise, population of the electrons in the QW and

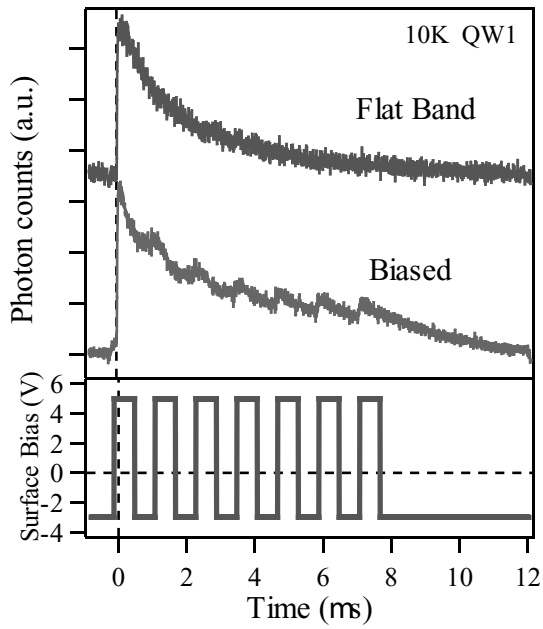

FIG.2 Upper panel compares PL decays of buried QW under flat band and biased conditions. Bias voltage waveform is shown in lower panel.

accordingly the PL intensity of the two well are expected be controlled by longitudinal electric field, which was observed experimentally (Fig.1). Voltage-controlled emission wavelength switch as confirmed in Fig.1 shows that the electrons are the minority carriers.

The switching operation was analyzed in the time domain. Figure 2 shows PL decays of the buried well along with bias voltage waveform. Note that the sample is both forward and reverse biased before the excitons decay radiatively so that the electrons are pushed away from and pulled back to the buried well. As seen in Fig.2, the decay undulates synchronously with voltage pulses. This is what was expected and can be interpreted in terms of dynamic localization [4] of the electrons such that electron residence time in the QW can be modulated by longitudinal electric field. The sharp rise upon application of forward bias voltage promises switching operation with a bandwidth more than 100MHz or higher.

3. Conclusions

Voltage-controlled emission wavelength switching operation was demonstrated in a pseudomorphic $Si_{1-X}Ge_X$/Si DQW. Oscillatory PL decays with period synchronized with polarity switch of longitudinal electric field were observed, wbich indicates that dynamic localization dominated by the electrons occurs alternately in the buried well and the near-surface well.

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