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(In)GaSb/AlGaSb quantum wells grown on Si substrates

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Abstract

We have successfully grown GaSb and InGaSb quantum wells (QW) on a Si(001) substrate, and evaluated their optical properties using photoluminescence (PL). The PL emissions from the QWs at room temperature were observed at around 1.55 μm, which is suitable for fiber optic communications systems. The measured ground state energy of each QW matched well with the theoretical value calculated by solving the Schrödinger equation for a finite potential QW. The temperature dependence of the PL intensity showed large activation energy (~77.6 meV) from QW. The results indicated that the fabricated QW structure had a high crystalline quality, and the GaSb QW on Si for optical devices operating at temperatures higher than room temperature will be expected.

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1. Introduction

Antimony-compound-based semiconductors have attracted much attention recently because of their narrow band-gap properties and high carrier mobility [1–3]. The GaSb are of particular interest because of their potential application in the development of high-performance devices for optical communications systems. Since their energy band gap of 0.726 eV is equivalent to a wavelength around 1.55 μm, these semiconductors are considered suitable for use in fiber optic communications systems. Therefore, GaSb based optical devices, such as GaSb/AlGaSb quantum well (QW) lasers, using a GaSb/AlGaSb heterostructure have been suggested. In addition, the use of ternary alloys, such as InGaSb and InAsSb, enables us to control the operation wavelength of these optical devices to longer wavelengths. A research has also shown that long wavelength lasers have practical applications in gas sensing [4]. However, it is difficult to grow high quality antimony-compound-based semiconductor crystals because there are few substrates whose lattice constants match these materials.

The GaSb or InAs substrates were not initially considered as potential candidates because these substrates are expensive and are not normally used. Furthermore, it is difficult to obtain large GaSb or InAs substrates because they are more fragile than the other traditionally used substrates. The use of Si wafers is a possible way to overcome these problems. However we expect that growing GaSb films on Si substrates is difficult because of the lattice mismatch between GaSb and Si is significantly large (12.2%). Nevertheless, the growth of GaSb films on Si substrates is attractive because it achieves monolithic integrated high-performance electro-optical devices, antimony-compound-based semiconductors. To this end, we have developed a technique to grow GaSb films on Si substrates [5].

The growth of high quality GaSb films on Si substrates is based on the introduction of a thin AlSb initiation layer on a Si surface. This layer significantly improves the GaSb film growth on Si substrates without the need for a low-temperature buffer layer. This method enables the fabrication of a GaSb/AlGaSb QW, and an emission at 1.55 μm from the fabricated QW has been previously reported at room temperature [6]. However, the detailed optical properties for the (In)GaSb/AlGaSb QW fabricated on Si substrates have not been investigated. Therefore, we investigated the optical properties and the effects of well structure and temperature on these properties of GaSb/

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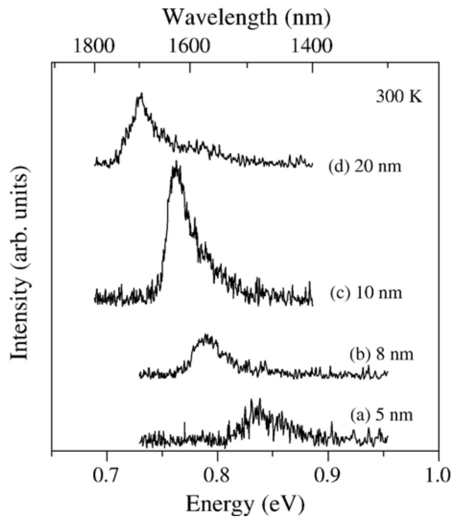

Fig. 1. PL spectra from GaSb/AlGaSb QWs with (a) 5, (b) 8, (c) 10, and (d) 20 nm well width at room temperature.

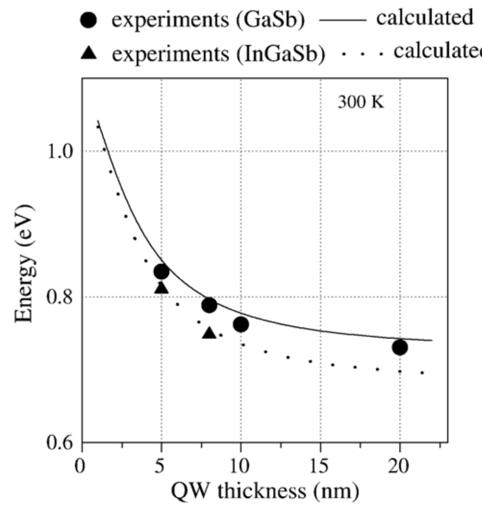

Fig. 3. Emission energy dependence on GaSb QW and InGaSb QW well width. Circles and triangles represent experimental results for GaSb and InGaSb QWs. Solid and dotted lines represent theoretical curve calculated by solving Schrödinger equation for a finite potential GaSb and InGaSb QW in envelope function approximation.

AlGaSb and InGaSb/AlGaSb QWs required to achieve longer wavelength emission.

2. Experimental

All samples were grown using solid source molecular beam epitaxy (Veeco Gen II). A valved cracker cell generated the Sb flux. The n-type Si(001) substrates were used to grow the GaSb and InGaSb QW structures. The Si substrate was etched in HF/$H_2O = 1{:}39$ solution for 3 min at room temperature and rinsed in de-ionized water. After HF etching, the surface of the Si substrate was terminated by hydrogen [7,8]. Then, the substrate was loaded into the MBE chamber. First, a thermal cleaning of the Si substrate by heating up to 760 °C was performed in the growth chamber to remove the hydrogen terminating at the Si surface and any other gases present. After cleaning, the reflection high-energy electron diffraction (RHEED) exhibited a (2×2) reconstruction pattern. The substrate temperature was set to 500 °C, and the Sb beam was irradiated on the substrate for 5 min at a 2×10^{-6} Torr equivalent beam flux before the growth. Then, a 5-nm-thick AlSb initiation layer was grown at 0.1 monolayer per second (ML/s). After growth interruption under the Sb flux for 5 min, a 500-nm-thick GaSb buffer layer was grown at 0.5 ML/s. Then a 2-µm-thick $Al_{0.3}Ga_{0.7}Sb$ layer was grown at 1.0 ML/s. Finally, five pairs of a *d*-nm-thick (In) GaSb QW and a 20-nm-thick $Al_{0.3}Ga_{0.7}Sb$ barrier layer were grown and capped using a 5-nm-thick GaSb. The QW thickness increased from 5 to 20 nm. The photoluminescence (PL) measurement was performed by using the 532-nm second harmonic line of an Nd:YVO_4 laser exited using a semiconductor laser diode, a 250-mm monochromator and an electrically cooled PbS detector to evaluate the QW's optical properties.

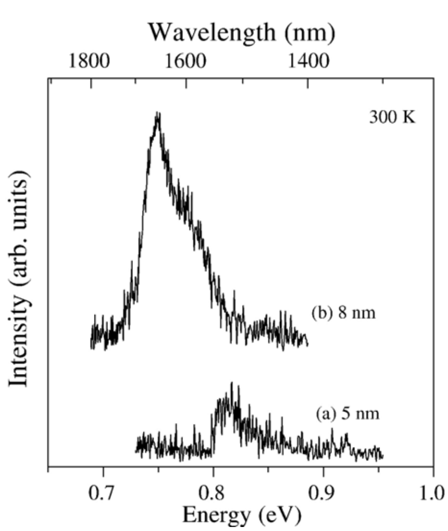

Fig. 2. PL spectra of $In_{0.05}Ga_{0.95}Sb$/AlGaSb QWs with (a) 5 and (b) 8 nm well width at room temperature.

3. Results and discussion

The PL spectra from five-stacked multi-quantum wells (MQW) with well widths of (a) 5, (b) 8, (c) 10, and (d) 20 nm are shown in Fig. 1. All samples showed a clear emission around 1.55 µm, even at room temperature. Therefore, these results indicate that high quality AlGaSb and GaSb crystals were grown on the Si substrates. Indeed, the PL intensity of the 8-nm-thick GaSb wells grown on the Si substrate was in the same order of that grown on the GaAs substrate. The emission energy and the

Table 1
The potential profiles and effective masses using in calculation

	ΔE_v (eV)	ΔE_c (eV)	m_e	m_{hh}
GaSb	0.12531	0.23451	$0.041m_0$	$0.4m_0$
$In_{0.05}Ga_{0.95}Sb$	0.13735	0.268357	$0.039m_0$	$0.43m_0$

ΔE_v, ΔE_c, m_e, m_{hh}, and m_0 represent valence-band offset, conduction-band offset, electron effective mass, heavy hole effective mass, and electron mass in vacuum, respectively.