論 文 の 内 容 の 要 旨

Heteroepitaxial metal-organic vapor phase epitaxy of III-V semiconductors on Si for high efficiency and low-cost solar cells

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金　ボラム

III-V compound semiconductor based tandem solar cell integrated on Si substrate is a promising structure for realizing high efficiency solar cell with low production cost. In the III-V on Si structures, GaAs/Si(1 0 0) is the most widely targeted for optical devices and CMOS uses as well as two-terminal tandem solar cell. Heteroepitaxy by metal-organic vapor phase epitaxy (MOVPE) is regarded as the most suitable method for industrial fabrication because the epitaxy process is simple comparing to mechanical bonding, and it has large scale epitaxial chamber than molecular beam epitaxy. For these backgrounds, in this research aims at fabrication of GaAs(P)/Si by MOVPE for solar cell application.

The major challenge for GaAs(P) heteroepitaxy on Si(1 0 0) is reducing the threading dislocation density (TDD) on the epitaxial layer. The threading dislocations in the grown epitaxial layer causes the degradation of open circuit voltage of the cell, so that degrades the energy conversion efficiency. To suppress performance degradation of the cell due to TDD, it should be 10^6 cm^{-1} or less in the epitaxial layer. However, to obtain high quality of GaAs(P) heteroepitaxial layer on Si is very difficult due to the material property differences, such as lattice constant, thermal expansion coefficient, and polarization, between GaAs(P) and Si. In this study, new concept for reducing the burden for heteroepitaxial growth is suggested and fabricate the target structure which is designed.

To yield the ideal bandgap of 1.73 eV which is considered current matching with active Si bottom cell, a big lattice-mismatch had to be considered. Here, we propose a new structure for a two terminal III-V/Si tandem solar cell which bases on strain-balanced multi-quantum wells (MQWs) embedded in a GaAsP top cell. Strain-balanced MQWs extend the absorption edge to a longer wavelength and enable a reduction of the arsenic contents in the GaAsP metamorphic top cell matrix. The accumulation of carriers in MQWs favors radiative recombination, which is beneficial for high efficiency while deep quantum well lowering the carrier collection efficiency. In this research, the solar energy conversion efficiencies over 42.6% with an entire MQW as thin as 500 nm is predicted by calculation. The applied model takes into account the drawbacks of MQWs, such as limited light absorption and the bottleneck of carrier collection from the confinement in the wells.

In the heteroepitaxy of Ⅲ-Ⅴ materials on a Si substrate, antiphase domains, which induces threading dislocations and degrade the device performances, need to be suppressed in order to obtain high quality epitaxial layers. Antiphase domains results from the coexistence of polar Ⅲ-Ⅴ semiconductor and non-polar Si. For reducing the antiphase domains, Si surfaces should be prepared to have double-layer steps. In contrast to the initial achievements of double-layer step formation by high-temperature annealing (>1000°C) under H2 ambient, exposure of Si surface to an arsenic precursor can reduce the annealing temperature and make the process relatively robust against reactor contaminations. In this study, the relationship between surface reconstruction parameters and surface state under arsenic ambient is verified with in-situ measurement by reflectance anisotropy spectroscopy (RAS) in the MOVPE reactor. In the succeeding growth of GaP heteroepitaxial layer on double-layer stepped Si(1 0 0) surface, the clear RA peak for the P-rich (2×2)/c(4×2) surface was observed and XRD measurement suggested single-crystalline GaP.