別紙４－１（課程博士（英文））

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Abstract (Doctor)

Title of Thesis	"Phosphide based type-II stacked quantum dot arrays enhancing carrier spatial separation for multi-junction III-V/Si photovoltaic application"

Approx. 800 words

GaP based III-V-N materials have attracted attention as absorber layer in solar cells for their large tunable band gap which cover 1.5-2.0 eV under lattice matching conditions to silicon. Despite this advantages III-V-N growth on Si remains as a complicated task to overcome due to the generation of structural defects, such as threading dislocations, stacking faults and antiphase domains. Optimization of growth conditions and understanding of GaP epitaxy is essential for the integration of III-V-N materials and Si substrates by GaP/Si heteroepitaxy. Along with the crystal defects originated from the interface carrier recombination due point defects and N-composition inhomogeneity result in poor conversion efficiency.
Accomplish high crystal quality epitaxy of GaP on Si substrate has been achieved through great effort. Diffusion length of adatom on the grown surface is one of the decisive factors to understand the growth mechanism since for techniques such as MBE it operates outside the thermodynamic equilibrium and the interaction between the adatoms, for growth temperature of 550°C and 600°C it seems that the diffusion mechanism is affected by the interaction of the Ga adatom and the dimers of the (2×4) surface reconstruction. We conclude that the GaP (001) exhibits similar diffusion mechanism as the GaAs (001) for some growths conditions This behavior is also important in the formation of nanostructures such as quantum wells and quantum dots.
The goal of this work is to contribute to the achievement of efficient III-V-N photovoltaics on Si substrates. First, we focus on the diffusion mechanism of GaP homoepitaxy growth by the estimation of the diffusion lengths of two principal axes and its relation to the growth temperature. Directional anisotropy was observed along the <110> and <1$\bar{1}$0> directions. This anisotropy is highly consistent with the surface morphology, this that if islands are formed elongation of the growth island along <1$\bar{1}$0> is also consistent with larger diffusion length along the <1$\bar{1}$0> direction. This

anisotropy is useful for the self-annihilation of the antiphase domains in the GaP/Si heteroepitaxy. In our results for low growth temperature there is not strong anisotropy of diffusion lengths, so the self-annihilation of antiphase domains is less likely to occur.
The next part for the improvement of III-V-N solar cells efficiency, we proposed the type-II band alignment QDs in a InP/GaAsPN stacked structure for the improvement of the carrier recollection. Type-II band alignment produce the carrier spatial separation, by this we expect to recollect carriers with the QDs, and with a stacked QD structure been able to extract them from the GaAsPN solar cell. First we focus on the formation of self-assembled InP Quantum dots (QD)s on GaP. Several growth conditions were studied. For most of the studied conditions two types of QDs were observed characterized by their geometry. It was found that for low growth rate and V/III ratio more uniform and smaller QDs can be produced, a transition in QD size was observed for specific conditions. since the nucleation of larger QDs tends to generate crystal defects, these conditions should be avoided. The InP QD growth conditions used in the present work were far from typical ones for InP homoepitaxy, i.e., very low growth rate and very low P overpressure. Considering these situations, the effect of the V/III ratio and/or growth rate on InP QD size can be dominated by the rate of P desorption from the various facet surfaces that form the InP island.
Capping process and stacking of QDs was studied. Growth interruption process during the capping of the QDs was used to improve the homogeneity of the stacked QDs. Optimized growth condition of 0.025ML/s and V/III ratio of 20 together with a two-step growth interruption consisted of a removal of excess In atoms from the top of the QD by the growth interruption of the partial capped QD, and the posterior flattening of the GaP capping layer by a second growth interruption process. Two samples were prepared for the two-step growth interruption evaluation, One included the growth interruption process and the second was grown without that process. For the sample without the growth interruption, the size of stacked QD increased and defects appeared in route of stacking. In contrast, sample with the proposed method, clear stacking of the InP QDs through the layers was present. In this case, the height of the QDs was slightly increased from 3 to 4 nm from the bottom to the top layers proved to control the QDs size and uniformity. Achieving a good quality 30 period InP/GaP structure without the implementation of any strain compensation layers.
These results can be applied in the following GaAsPN material. And may help in designing more efficient GaP-based III–V–N solar cells on Si substrates.