博士論文(要約)

Use of Erbium for Enhancement of GaAs Based Solar Cell Performance

（GaAs 系太陽電池における Er 添加・化合物の利用に関する研究）

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This work investigates the properties of various Er-V/III-V and Er doped III-V semiconductors grown by molecular beam epitaxy (MBE) and applies the material in tunnel junction (TJ) and intermediate band solar cell (IBSC), respectively. The various electrical and optical properties of these composite materials are found to be dependent on the growth conditions. In both cases, incorporation of Er related material substantially improves performance.

In chapter 1 the basics of solar energy and the motivation are introduced. In chapter 2, some equipment used in this study and its theory are introduced. In chapter 3, ErAs nanodots (NDs) grown on GaAs (001) substrate by using MBE was investigated. Atomic force microscope images indicate that the size of ErAs NDs increases with deposition time and growth temperature. A calibration was performed to determine the deposition rate of ErAs so that the size of NDs can be accurately controlled and hence optimized. Local current flow image and surface profile around ErAs NDs were simultaneously measured for local conductivity distribution corresponding to real space profile, where the correlations were studied. Because ErAs particles act as deep states (i.e. within the bandgap), they are used to enhance the recombination across TJ. This results in a large improvement in efficiency of the TJ, which is a critical component of high-efficiency multijunction solar cells. Bright-field STEM and TEM images are performed for the stacking layers of ErAs 0.7 and 1.5 ML. In ErAs 0.7 ML, the strain is well-controlled to achieve higher performance while 1.5 ML ErAs suffer larger strain. It also confirmed that the atom arrangement around ErAs is continues from bottom to top side with no wetting layer, indicating that ErAs grows in a mode similar to the V-W growth mode.

In chapter 4, ErAs-ND-embedded GaAs TJ was fabricated and characterized. The peak current of TJ was improved for the sample embedded with ErAs NDs, which can be explained by the reduced tunneling distance between p^+ and n^+ layers. If it is located under a light concentration of 1000 suns, a small voltage drop of 30 mV can be expected upon applying our TJ with ErAs NDs.

The other part describes the fabrication and characterization of Er doped GaAs based solar cells on GaAs (001) substrate operated at room temperature. In chapter 5, in order to study the emission from the Er-doped layer, Er-doped GaAs films of 1 μm deposition thickness were fabricated at various Er cell temperatures (T_{Er}) from 700℃ to 1000℃ by MBE. First, Secondary Ion Mass Spectrometry (SIMS) was performed to investigate the carrier concentrations in the stacking samples Er doped GaAs with various Er cell temperature from 700 to 1100℃. The carrier concentration was found to increase with the Er cell temperature. The PL measurement at 20 K for Er doped GaAs films with growth temperature of 580℃ was investigated. The sample fabricated with the Er cell temperature of 900℃ indicates an emission peak at ~ 1.54 μm which results from transitions between spin-orbit levels, the excited state to the ground state of Er^{3+} 4*f*-shell because its temperature independent property.

In chapter 6, for evaluation of photovoltaic characteristics, p-i-n GaAs solar cells with Er-doped i-layer were fabricated. Inside the intrinsic layer, Er was doped during the GaAs i-layer growth with T_{Er} 700, 800, 900 and 1000℃ under growth temperature (T_g) of 580℃. The difference of EQE values, ΔEQE, with and without IR light illumination at 9 K and room temperature was performed to exam the optical absorption.

ΔEQE signals are observed in the range 600nm to 900nm at room temperature for the samples Er doped in the i-layer at T_{Er} =900 and 1000℃ . This can be ascribed that the electrons are directly pumped from the VB to CB in GaAs by the light then rapidly captured into Er-induced intermediate states, and re-pumped from the intermediate states to CB by IR photons. At low temperature of 9 K, ΔEQE extends into the longer wavelength range beyond the bandgap of GaAs (880 nm). This could result from that the electrons are pumped from VB to IB, and a consequent increase in the population in IB in turn increases optical transitions from IB to CB. Furthermore, a peak of low temperature ΔEQE around 1540 nm was observed without peak shift as temperature increasing from 20 to 250 K, which is consistent with the intra-4f transitions screened from outer disturber. Therefore, it is attributed to energy transfer from optically excited $^4I_{13/2}\rightarrow{}^4I_{15/2}$ transition of Er^{+3} ion to the GaAs system. A two-step optical transition model with the energy transfer processes in Er-doped GaAs was proposed based one the experiment data.

Finally, in chapter 7 the conclusions and future work of this thesis are presented.