別紙第１号様式　　　　　　　　　　　　No.1

博　士　論　文　の　要　旨

専攻名　システム創成科学専攻

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博士論文題名

A study on wide bandgap oxide semiconductors

（ワイドバンドギャップ酸化物半導体に関する研究）

要旨

In recent years, wide bandgap oxide semiconductor has attracted considerable attention owing to its application in ultraviolet (UV) optoelectronic devices, especially in deep UV light emitters and detectors, due to their potential application in Ozone hole detection, chemical-biological agent sensors, missile plume sensors and space-to-space communications. Among all the wide bandgap oxide semiconductors, MgZnO alloy films are ideal materials for developing the UV optoelectronic devices because of their particular advantages, such as wide bandgap, low growth temperature, availability of lattice-matched single-crystal substrates, and high radiation hardness.

Since the ionic radius of Mg^{2+} (0. 057 nm) is similar to that of Zn^{2+} (0.060 nm), there can be some replacement in either structure without changing the original structure when alloying. However, there is large crystal structure dissimilarity between wurtzite hexagonal ZnO and rock-salt-cubic MgO, which leads to phase separation. It limited the application of MgZnO alloy in deep UV region. In comparison with ZnO semiconductor, Ga_2O_3 has a wider bandgap of about 4.9 eV. The bandgap of In-Al-Ga-O system which is obtained by alloying In or Al element into Ga_2O_3 can be tuned from 3.5-8.6 eV, thus In-Al-Ga-O system can be used as deep UV light-emitting diode, deep UV detector, and deep UV transparent electrode.

In Chapter 1, the review of studies on the wide bandgap oxide semiconductors were described. The purpose of this study was also presented.

In Chapter 2, film growth and characterization methods were introduced.

In Chapter 3, the influence of Mg content on crystal structure and properties of single phase MgZnO films were grown in all Mg content was been discussed. The structural transition from hexagonal to cubic phase has been observed at the Mg content around 0.4. We have also investigated the effect of the substrate temperature and oxygen pressure on crystal structure and properties of MgZnO films grown by using pulsed laser deposition (PLD) method.

In Chapter 4, we reported on bandgap bowing parameters for wurtzite and cubic MgZnO alloys from a study of high quality and single phase films in all Mg content range. The Mg contents in the MgZnO films were accurately determined using the Energy dispersive spectrometer and X-ray photoelectron spectroscopy (XPS). The measurement of bandgap energies by examining the onset of inelastic energy loss in core-level atomic spectra from XPS was proved to be valid for determining the bandgap of MgZnO films. The dependence of the energy bandgap on Mg content was found to deviate downwards from linearity. Fitting of the bandgap energies resulted in two bowing parameters of 2.01 and 1.48 eV corresponding to wurtzite and cubic MgZnO films, respectively.

In Chapter 5, (1) $(AlGa)_2O_3$ thin films were deposited on (0001) sapphire substrates by pulsed laser deposition at different substrate temperatures. The influence of substrate temperature on surface morphology, optical

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properties, and crystal quality has been systematically investigated by atomic force microscope, transmission spectra, X-ray diffraction, and Raman spectroscopy. The results revealed that all the $(AlGa)_2O_3$ films had smooth surface and high transmittance. The $(AlGa)_2O_3$ film with the better crystal quality can be obtain at a substrate temperature of 400 ℃. (2) We also report a detailed investigation on temperature-dependent Raman scattering of β-$(AlGa)_2O_3$ thin films with different Al content (0-0.72) under the temperature range of 77-300 K. The temperature-dependent Raman shifts and linewidths of the phonon modes were obtained by employing Lorentz fitting. The linewidths broadening of phonon modes with the temperature can be well explained by a model involving the effects of thermal expansion, lattice-mismatch-induced strain, and decay of optical phonon into two and three phonons. It is clearly demonstrated dependence of the linewidths and decay process on the Al content in β-$(AlGa)_2O_3$ thin films.

In Chapter 6, we reported measurements of Raman scattering of cubic In_2O_3 and $(In_{0.83}Ga_{0.17})_2O_3$ films grown on sapphire substrates by pulsed laser deposition as a function of temperature (77-500 K). We analyzed the temperature-dependent Raman shifts and linewidths of six Raman modes in In_2O_3 film and $A_g^{(1)}$ and $A_g^{(2)}/T_g^{(2)}$ modes in $(In_{0.83}Ga_{0.17})_2O_3$ film. The Raman shifts of phonon modes were found to vary linearly with temperature. The temperature coefficients for six Raman modes of In_2O_3 film were in the range of -0.014 and -0.006 cm^{-1}/K, while temperature coefficients of $A_g^{(1)}$ and $A_g^{(2)}/T_g^{(2)}$ modes in $(In_{0.83}Ga_{0.17})_2O_3$ film were -0.017 and -0.024 cm^{-1}/K, respectively. Through the aid of a model involving three- and four-phonon coupling, the effects of temperature on linewidths were clearly illustrated, which demonstrated that three-phonon process always dominated in the decay process for all the modes in both In_2O_3 and $(In_{0.83}Ga_{0.17})_2O_3$ films.