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A method for suppressing deep-level emission in ZnSe/Ge/Ge_xSi_{1-x}/Si structure

Jui-Tai Ku[1], Tsung-Hsi Yang[2], Guangli Luo[3], Wu Ching Chou[1], Tsung-Yeh Yang[4] and Chun-Yen Chang[2]

[1] Department of Electrophysics, 1001 Ta Hsueh Road, National Chiao Tung University, Hsin-chu 300, Taiwan, R.O.C.
[2] Microelectronics and Information Systems Research Center, 1001 Ta Hsueh Road,National Chiao Tung University, Hsinchu 300, Taiwan, R.O.C.
Phone: +886-3-5712121-52981 E-mail: kondo.mse89g@nctu.edu.tw
[3] National Nano Device Laboratories, 26, Prosperity Road I, Science-based Industrial Park, Hsin-chu 300, Taiwan, R.O.C.
[4] Institute of Physics, Academia Sinica, 128 Academia Rd, Nankang, Taipei, Taiwan, R.O.C.

1. Introduction

ZnSe have been grown on Ge/Ge_xSi_{1-x}/Si virtual substrate successfully [1,2]. However, there still exist considerable problems related to the epitaxy between polar and non-polar semiconductors resulting in the formation of antiphase domains (APDs), which also induce dislocations in the films. Deep-level emission (DLE) is associated with the dislocations [3] and cation-vacancy related complexes [4]. The DLE effect reduces the device performances, for example, shortening of lifetime and decreasing of radiative intensity. In this study, we present a method of low temperature MEE combined with a low-temperature ZnSe buffer layer (LT-MEE+LT-ZnSe buffer) and with *in-situ* annealing process to suppress the formation of DLE in the ZnSe/Ge/Ge_xSi_{1-x}/Si structure.

2. Experiments

The Ge/$Ge_{0.95}Si_{0.05}$/$Ge_{0.9}Si_{0.1}$/Si virtual substrates were grown by an ultrahigh vacuum chemical vapor deposition (UHV/CVD) system [1]. The *p*-Si substrates (100)-oriented with 0^o, 4^o, and 6^o tilts toward the in-plane [110] direction was used to suppress the APDs in the epilayer. The ZnSe epilayers were grown on the Ge/$Ge_{0.95}Si_{0.05}$/$Ge_{0.9}Si_{0.1}$/Si virtual substrates by using Veeco-Applied-EPI 620 molecular beam epitaxy (MBE). The growth parameters of the samples are listed in the Table 1, which also shows the full widths at half-maximum (FWHM) and D^oX emission of the samples.

3. Results and Discussion

Figure 1 shows the X-ray diffraction pattern of sample E. This sample was grown with LT-MEE, LT- ZnSe buffer layer and with *in-situ* annealing process. The diffraction pattern has four major peak as follows (400) Si, θ=34.6^o, (400) Ge, θ=33.2^o,(400) ZnSe, θ=33.0^o, (200) ZnSe, θ=15.8^o. The intensity and FWHM of the (400) ZnSe diffraction peak are 1.7×10^4 cps and 0.155 degree, respectively, indicating an epilayer of reasonably good crystalline quality.

TEM was used to determine of dislocation and estimate threading dislocation density (TDD). Fig. 2 shows the Cross-sectional TEM image of the sample E. The surface of the sample was smooth, and the interface between ZnSe and Ge layer without threading dislocation. This indicates that the method includes LT-MEE, LT-buffer and *in-situ* annealing process can improve the crystalline quality of ZnSe epilayers.

Figure 3 shows the plane view AFM images of the ZnSe/Ge/Ge_xSi_{1-x}/Si heterostructures with the various substrate tilt angle of (a) 0^o, (b) 4^o and (c) 6^o from (100) toward the in-plane [110] direction. Compare images (a), (b) and (c). The obvious APDs formed in the image (a), but in the images (b) and (c) without APDs. The APDs are structural defects, which are due to the wrong bond of the Zn-Zn and Se-Se in ZnSe epilayers.

Figure 4 shows the normalized LT-PL spectra of samples A, B, C, D and E respectively. The PL band near 2.8 eV is attributed to the near-band-edge emission (NBE), dominated by the emission of neutral donor-bound exciton D^oX (2.791 eV). Other small contributions are due to the emissions from the free excitons (2.800 eV) and acceptor-bound excitons (2.787 eV). A narrow line of PL (2.770 eV) is due to the extended structural defects [5] or the recombination from donor states to valence bands [6]. The weak emission band near 2.6 eV, commonly labeled as Y_0 line, is related to misfit dislocations [3]. The broad emission band, ranging from 1.9 eV to 2.5 eV, is associated with deep level emission (DLE), which originated in cation-vacancy related complexes [4]. The insert in Fig. 4 shows the magnified PL spectra, emphasizing the Y_0 and DLE structures. The relative intensity ratio of DLE to excitonic emission in PL spectra has been taken as a parameter of crystal quality [3]. Table 1 summarized the evaluated ratios of the peak intensity of D^oX to that of DLE. The peak intensity of DLE in sample E was successfully reduced by a factor of about 20. As pointed out in Ref. 1, Zn vacancies in a ZnSe epilayer can be reduced using the tilted substrate. The LT-MEE layer and the thermal-annealed LT buffer are expected further to decrease the inter-diffusion defects, stacking fault densities and misfit dislocations, resulting in improvement of the crystallinity of ZnSe thin films. The intensity of the Y_0 line, which correlates to the misfit dislocations, is also weakest in sample E. However, the ZnSe epilayer grown on the 4^o-tilted substrate exhibits the strongest Y_0 emission and its DLE lineshape differs from others, which fact may attribute to the effect of epilayer tilt.

4. Conclusions

The deep level emission of ZnSe epilayers grown on the off cut Ge/Ge_xSi_{1-x}/Si virtual substrate was investigated. The PL spectrum of ZnSe epilayers grown on a 6^o off cut Ge/Ge_xSi_{1-x}/Si virtual substrate with an LT-MEE layer and an in situ annealed LT-ZnSe buffer layer exhibits the maximum instensity ratio of bound exciton emission to the deep level emission. This technique is very promising for use in the development of integrating optical and electronic devices in the same chip in the future.

References

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Sample	Substrate tilted angle	Structure	Thickness of HT-ZnSe	Ratio of D°X to DLE	FWHM
A	0°	HT-ZnSe	1 μm	26	8.2 meV
B	4°	HT-ZnSe	1 μm	43	8.5 meV
C	6°	HT-ZnSe	1 μm	98	5.2 meV
D	6°	LT-MEE + HT-ZnSe	1 μm	238	4.9 meV
E	6°	LT-MEE + LT-ZnSe buffer+ HT-ZnSe	900 nm	417	4.9 meV

Table 1. The growth parameters of the samples

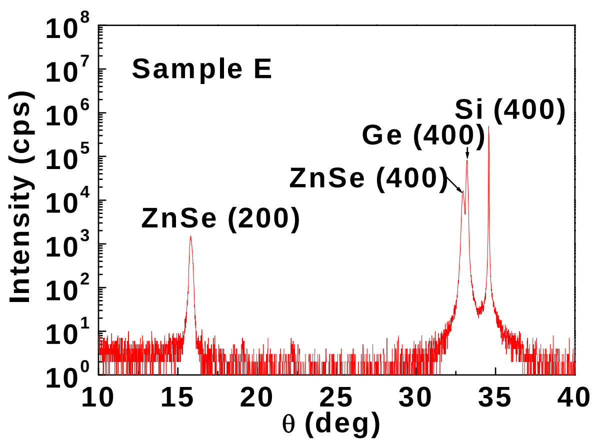

Fig. 1. XRD pattern of ZnSe/Ge/Ge_xSi_{01-x}/Si substrate.

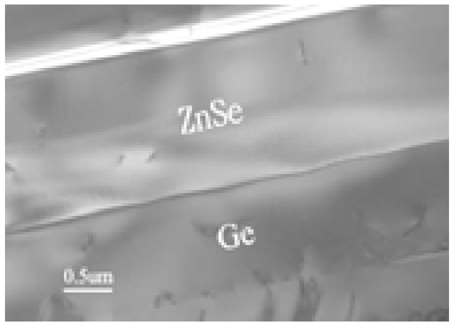

Fig. 2. Cross-sectional TEM image of sample E.

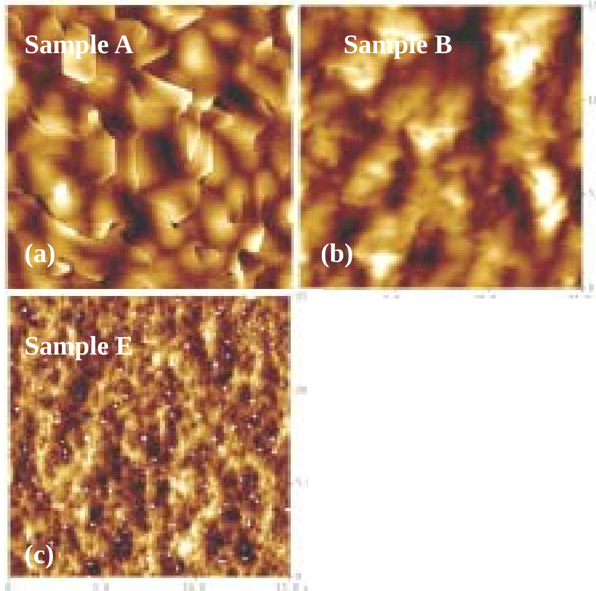

Fig. 3. AFM images of (a) sample A, (b) sample B and (c) sample E.

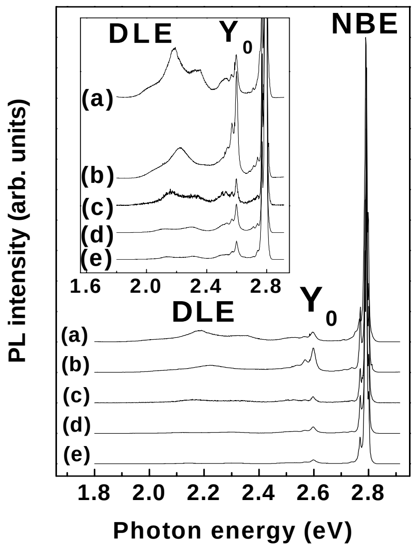

Fig. 4. PL spectra of ZnSe epilayers on $Ge/Ge_xSi_{1-x}/Si$ virtual substrates for different structures: (a) 0°, (b) 4°, (c) 6°, (d) 6°+LT-MEE, (e) and 6°+LT-MEE+buffer. The inset shows the magnified structures of DLE and Y_0 bands.