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Journal of Crystal Growth 233 (2001) 795–798
JOURNAL OF CRYSTAL GROWTH
www.elsevier.com/locate/jcrysgro

Growth and characterization of ZnCdTe-ZnTe quantum wells on ZnO coated Si substrate by metalorganic chemical vapor deposition

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Received 27 February 2001; accepted 24 July 2001
Communicated by R. James

Abstract

ZnCdTe-ZnTe quantum wells (QWs) have been grown on Si (1 0 0) substrates in a horizontal-type low-pressure metalorganic chemical vapor deposition (MOCVD) system. An oriented ZnO thin film with a smooth surface was employed to be the bufferlayer for the growth. Scanning electron microscopy (SEM) patterns showed that the ZnO bufferlayer improved the smoothness of the sample. The photoluminescence (PL) spectra of the QWs with and without ZnO layer were studied. The great enhancement of the emission efficiency of the one with ZnO layer indicated that the quality of the epilayer was improved. © 2001 Elsevier Science B.V. All rights reserved.

PACS: 68.65.+g; 81.10.−h; 81.15.Gh; 78.55.Et

Keywords: A1. Atomic force microscopy; A1. Low dimensional structures; A3. Metalorganic chemical vapor deposition; A3. Quantum wells; B2. Semiconducting II–VI materials; B2. Semiconducting silicon

1. Introduction

The growth of the group II–VI alloy quantum wells (QWs) has attracted considerable attention because they can offer direct band gaps through the whole visible spectrum at wavelengths unattainable with III–V alloys [1,2]. ZnCdTe-ZnTe QWs are particularly highlighted due to their many potential applications for optoelectronic devices in the blue-green region of the spectrum. However, for such applications to be realized, high-quality material must be grown. In recent literatures, ZnCdTe-ZnTe QWs were grown either by molecular beam epitaxy (MBE) [3] or by temperature-gradient vapor-transport deposition (TGVTD) [4]. The studies on the growth by metalorganic chemical vapor deposition (MOCVD) are beyond the scope of our investigations.

Usually, GaAs substrates are employed for the growth of II–VI semiconductors due to their similarities in some properties. However, GaAs

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substrates present several inconveniences, a case in point is that they need to grow a GaAs bufferlayer to obtain a clean and smooth GaAs surface [5], which makes the GaAs substrates very expensive. While on the other hand, Si is cheaper than GaAs, and it offers the possibilities of integrating the optoelectronics based on II–VI semiconductors with the Si-microelectronics, which motivated enormous interests and efforts to study the growth of II–VI semiconductors on Si substrates. However, the large difference in the chemical and mechanical properties between II–VI materials and silicon makes the direct growth an arduous task. In the present paper, the study of the growth of $Zn_{0.9}Cd_{0.1}Te$-ZnTe QWs on ZnO coated Si substrate was carried out, and we got samples with higher quality than those grown on bare Si substrates.

2. Experiment

Prior to the growth, the Si (1 0 0) substrate was cleaned by an ultrasonator with a sequence of trichloroethylene, acetone and ethanol for 5 min, respectively. Then, the substrate was boiled in HNO_3 to eliminate the carbon contaminants on the surface. After that, a thin surface oxide layer was formed by boiling the Si wafer in a solution of $HCl:H_2O_2:H_2O = 3:1:1$. Finally, the substrate was dipped into HF solution to remove the oxide layer. The above method has been demonstrated to be effective to clean the surface of silicon [6]. A zinc oxide (ZnO) layer was deposited on the cleaned Si (1 0 0) substrate by electron-beam evaporation employing 4N-ZnO pellets at 400°C. ZnCdTe-ZnTe QWs were then grown on the ZnO coated Si (1 0 0) substrate by LP-MOCVD at 420°C with the growth pressure of 220 Torr. The precursors are dimethylzinc (DMZn), dimethylcadmium (DMCd) and diethyltelluride (DETe), respectively. The samples investigated here consist of a 0.45 μm ZnTe buffer layer followed by ten periods of $Zn_{0.9}Cd_{0.1}Te$-ZnTe QWs and then a 30 nm ZnTe cap layer.

X-ray diffraction (XRD) and Scanning electron microscopy (SEM) were employed to characterize the structural properties of the samples discussed here. The luminescent properties were characterized by PL spectra at 77 K. The 337.1 nm line of a C067-080 pulsed N_2 laser with 10 ns duration and 10 Hz frequency was used as the excitation source for the photoluminescence (PL). The signals were measured using a 44 W grating monochromator with an RCA-C31034 cooled photomultiplier.

3. Results and discussion

As can be seen from the XRD profile of the ZnO on Si (1 0 0) prepared by electron-beam evaporation in Fig. 1, there are two peaks in the pattern at $2\theta = 34.7^\circ$ and 70°, respectively. The former is due to the diffraction of ZnO (0 0 2) plane, while the latter comes from Si (4 0 0) plane. The observation there are no other ZnO peaks indicates that the ZnO bufferlayer is highly oriented. The high-quality is verified by the SEM micrograph in Fig. 2. The morphology of the surface is mirror-like, and shows no mosaic structure. The high-quality and smooth surface of the ZnO layer on the Si substrate provide encouraging results for the growth of ZnCdTe-ZnTe QWs on it.

Typical SEM micrographs of the ZnCdTe-ZnTe QWs grown on Si (1 0 0) substrate with (sample A) and without a ZnO bufferlayer (sample B) are shown in Fig. 3a and b. In each case the surfaces of the QWs appear in a mosaic structure. However, the surface of sample B is more spotty than that of sample A. Furthermore, there are microcracks on

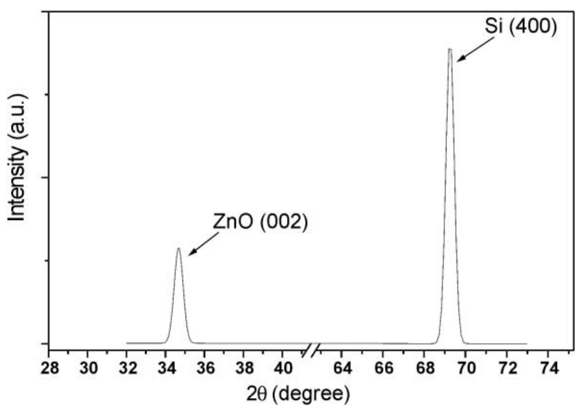

Fig. 1. X-ray diffraction pattern of a ZnO film deposited on Si (1 0 0) substrate at 400°C by electron-beam evaporation.

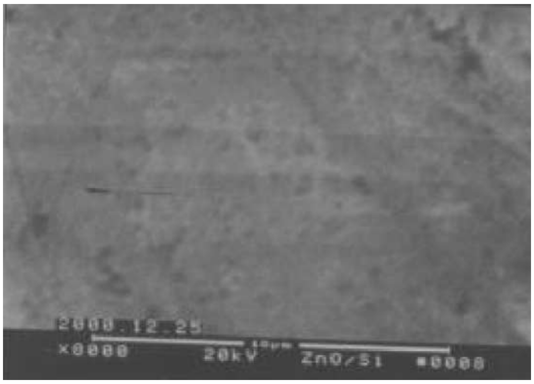

Fig. 2. SEM micrograph of a ZnO film deposited on Si (1 0 0) substrate at 400°C by electron-beam evaporation.

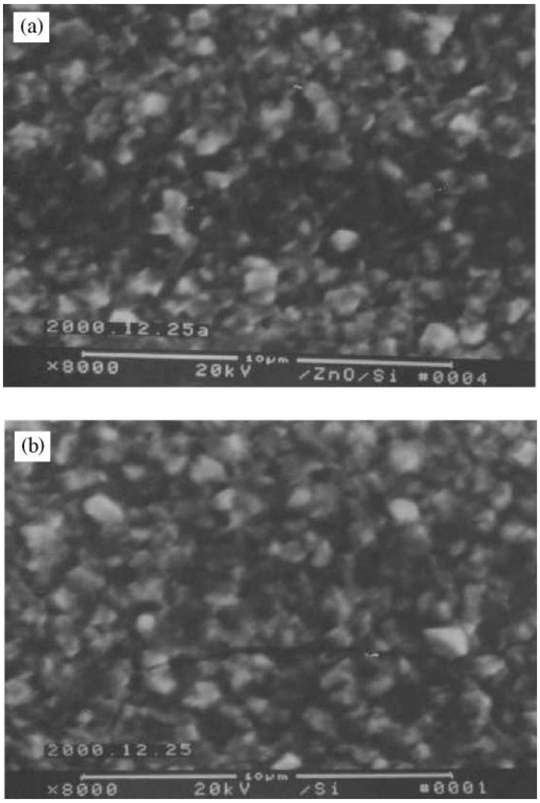

Fig. 3. Typical SEM micrograph of ZnCdTe-ZnTe QWs grown on Si (1 0 0) with (a) and without a ZnO bufferlayer (b).

the surface of B. We believe the microcracks are due to the stress that originates from the large difference in thermal expansion coefficients between the epilayer and the Si substrate. The stress is lessened by the ZnO bufferlayer, so there are no such cracks on the surface of sample A. On the other hand, the ZnO layer avoids the direct MOCVD of the polar ZnCdTe-ZnTe QWs on the nonpolar Si substrate. As is known, the direct deposition may lead to the imbalance in the interface charge, and hinder the smooth growth of the quantum well [7]. The above results demonstrate the fact that the existence of a ZnO bufferlayer enhances the quality of ZnCdTe-ZnTe QWs, which can also be seen from the following PL spectra.

Fig. 4 shows the PL spectra of $Zn_{0.9}Cd_{0.1}Te$-ZnTe QWs grown on a ZnO coated Si (1 0 0) (A) and directly grown on Si (1 0 0) (B). The well width is 3 nm. Both are excited by the same excitation intensity. The peak positions of the two samples are almost the same. However, the emission efficiency of A is much higher than that of B. Generally speaking, due to the different strain effect, the ZnCdTe-ZnTe QWs grown directly on Si substrate are under compressive stress due to the substrate. Then, the emission peak of sample B blueshifts compared to that of sample A, but the blueshift was not observed in our experiment. We speculated that this phenomenon arises from stress, and the thin ZnO film is highly strained by the Si substrate and will work in a manner similar to the substrate [8]. The lower emission efficiency in B, to us, is due to the large difference in the interfacial chemistry between the epilayer

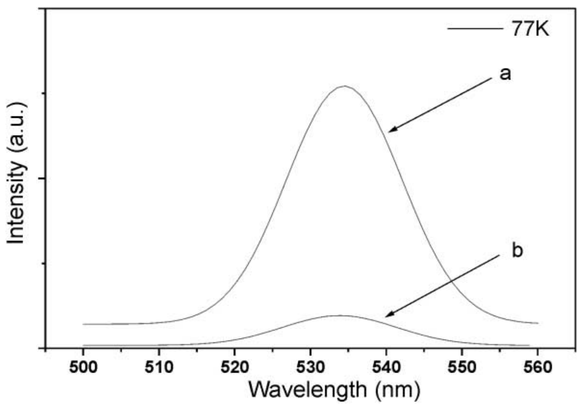

Fig. 4. Photoluminescence of $Zn_{0.9}Cd_{0.1}Te$-ZnTe QWs grown on a ZnO coated Si (1 0 0) (a) and bare Si (1 0 0) (b) under the same excitation intensity at 77 K.

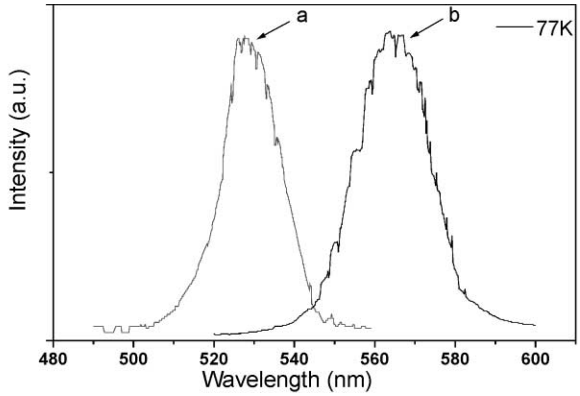

Fig. 5. Photoluminescence of $Zn_{0.9}Cd_{0.1}Te$-ZnTe QWs grown on a ZnO coated Si (1 0 0) substrate with the well width (L_w) of (a) $L_w = 3$ nm; (b) $L_w = 9$ nm at 77 K.

and the substrate, which will lead to a larger dislocation density in sample B. Carriers recombine nonradiatively at the dislocations and, as a result, the emission efficiency degrades drastically.

The PL spectra of ZnCdTe-ZnTe QWs with different well widths are shown in Fig. 5. As can be seen, the peak position of the QWs with well layer of 3 nm blueshifts by as large as 160 meV compared to the one with 9 nm well layers. Obviously, the blueshift mainly comes from a quantum confinement effect.

4. Conclusions

In summary, high-quality ZnCdTe-ZnTe QWs were grown on ZnO coated Si substrates by low pressure MOCVD. The micrographs assessed by SEM indicate that the surface of the QWs is free of microcracks. The emission efficiency of the sample grown on a ZnO bufferlayer is much higher than that grown directly on the Si substrate, which shows that the existence of a ZnO layer enhanced the quality of the epilayer. Also, the QWs grown on ZnO coated Si (1 0 0) substrates with different well widths show different quantum confinement effects.

Acknowledgements

This research is supported by the National Fundamental and Applied Research Project; The Key Project of the National Natural Science Foundation of China, No. 69896260; The Innovation Project Item, Chinese Academy of Sciences; The Program of CAS Hundred Talects and The National Natural Science Foundation of China.

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