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Optimization of VI/II pressure ratio in ZnTe growth on GaAs(0 0 1) by molecular beam epitaxy

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ABSTRACT

ZnTe epilayers were grown on GaAs(0 0 1) substrates by molecular beam epitaxy (MBE) at different VI/II beam equivalent pressure (BEP) ratios ($R_{VI/II}$) in a wide range of 0.96–11 with constant Zn flux. Based on *in situ* reflection high-energy electron diffraction (RHEED) observation, two-dimensional (2D) growth mode can be formed by increasing the $R_{VI/II}$ to 2.8. The Te/Zn pressure ratios lower than 4.0 correspond to Zn-rich growth state, while the ratios over 6.4 correspond to Te-rich one. The Zn sticking coefficient at various VI/II ratios are derived by the growth rate measurement. The ZnTe epilayer grown at a $R_{VI/II}$ of 6.4 displays the narrowest full-width at half-maximum (FWHM) of double-crystal X-ray rocking curve (DCXRC) for (0 0 4) reflection. Atomic force microscopy (AFM) characterization shows that the grain size enlarges drastically with the $R_{VI/II}$. The surface root-mean-square (RMS) roughness decreases firstly, attains a minimum of 1.14 nm at a $R_{VI/II}$ of 4.0 and then increases at higher ratios. It is suggested that the most suitable $R_{VI/II}$ be controlled between 4.0 and 6.4 in order to grow high-quality ZnTe epitaxial thin films.

1. Introduction

ZnTe is an II–VI compound semiconductor with a direct band gap of 2.26 eV at room temperature and a large electro-optic coefficient, which makes it potential applications in pure-green light emitting devices, solar cells, wave-guides, modulators, and terahertz (THz) emitter and detectors [1–5]. As of now, a lot of efforts have been made to the synthesis and characterization of ZnTe thin films. It has been proved that *p*-type ZnTe is easily obtained [6], but *n*-type doping is difficult mainly due to the self-compensation effect [7]. Although there have been several reports on *n*-type ZnTe layers [7–9], growing high-quality undoped ZnTe epilayer is still a guarantee to prepare doped materials with good conductivity and crystallinity.

Many growth techniques, including molecular beam epitaxy (MBE) [10], metal-organic vapor phase epitaxy (MOVPE) [11], pulsed laser deposition (PLD) [12], hot-wall epitaxy [13], and vacuum evaporation [14], have been employed to fabricate ZnTe layers. Among them, MBE is considered to be advantageous for getting high-quality ZnTe thin films owing to its ultrahigh vacuum (UHV) ambient and slow growth rate. In the MBE system, elemental flux ratio besides substrate temperature is another important growth parameter which has a profound impact on the composition and crystallinity of epitaxial layers [15,16]. However, there is no detailed report on the influence of VI/II flux ratio on the ZnTe growth by MBE. GaAs is desirable as a substrate from the viewpoint of device integration. In addition, perfect GaAs wafers are relatively cheap and the surface treatment is simple. In this paper, we investigated the surface structure, growth rate, Zn sticking coefficient, crystalline quality, and morphology of ZnTe epilayers grown on GaAs(0 0 1) substrates at different VI/II beam equivalent pressure (BEP) ratios ($R_{VI/II}$) to optimize this parameter.

2. Experimental procedure

ZnTe growth was performed in a solid-source MBE system using elemental Zn (6N in purity) and Te (6N in purity) as the source materials. The base pressure of the growth chamber was 6.0×10^{-10} Torr. *In situ* reflection high-energy electron diffraction (RHEED) was

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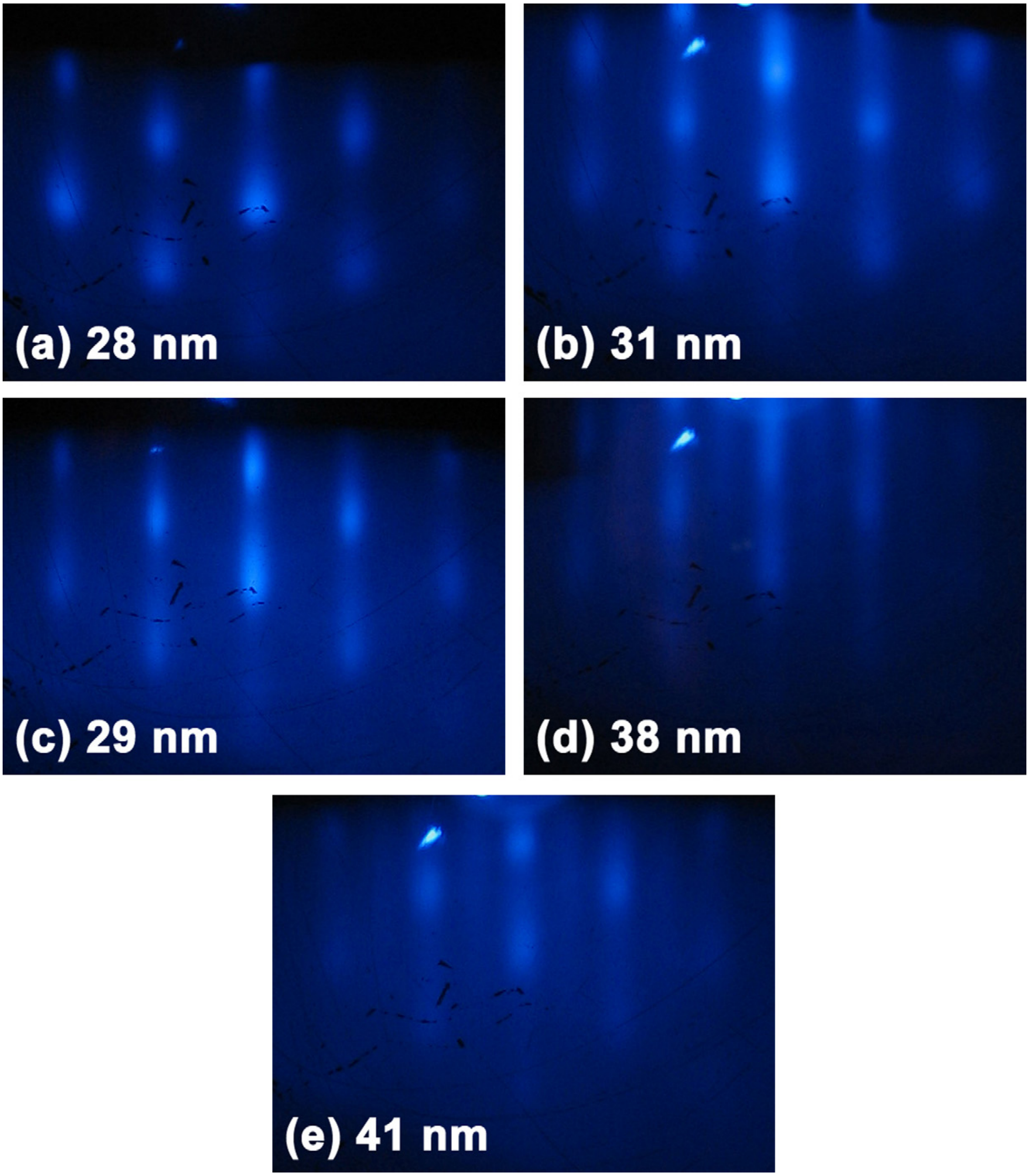

Fig. 1. *In situ* RHEED patterns of ZnTe epilayers with close thicknesses at various BEP ratios of Te to Zn and different growth time moments: 0.96, 10 min (a); 2.8, 5 min (b); 4.0, 3 min (c); 6.4, 3 min (d); and 11, 3 min (e). The azimuth is parallel to [1 1 0] direction.

employed to monitor the surface structure of ZnTe epilayer. Two-inch *n*-type GaAs(0 0 1) wafer was mounted on a Mo block using indium-free technique. The temperature was measured by a thermocouple placed between the heater and Mo block. The substrate and Mo block were thermally cleaned at 400 °C over 1 h in an UHV preparation chamber. After being loaded into the growth chamber under UHV, the substrate was deoxidized at ∼600 °C without arsenic flux protection till a streaky RHEED pattern was observed. Prior to growth, Zn shutter was firstly opened for 10 s to minimize the formation of undesired Ga–Te bonds [17]. Then the Te shutter was opened to begin the growth. After growth, the Zn and Te shutters were closed almost simultaneously. The growth duration for all the samples was 60 min, and the substrate temperature has been optimized and fixed at 360 °C [18]. The $R_{VI/II}$ was varied in the range of 0.96–11 with a constant Zn BEP about 4.0×10^{-8} Torr which was measured by an ion gauge located at the growth position via framework rotation. It should be pointed out that the Zn BEP changed gradually after opening Zn shutter due to metallization of ion gauge. But the pressure became stable after about 2 min and this stable value was used as the Zn flux magnitude. In order to maintain a high sensitivity, the ion gauge has been degassed termly. Moreover, there are two same ion gauges in our growth chamber. One is for background vacuum measurement and the other is for BEP measurement. Comparing the values from these two gauges enables us to learn whether the one for BEP read is not precise. So far, a number of experimental records of elemental BEPs at various