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Effects of dry etching processes on optical properties of ZnTe surface layers in ultraviolet region

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Abstract

We report on the ultraviolet reflection measurements of zinc telluride (ZnTe) crystals exposed to CH_4/H_2 gases under different rf plasma powers in combination with the critical points model. The effects of dry etching on optical properties such as dielectric function, refractive index and distinction coefficient in perturbed ZnTe surface layers have been investigated in the photon energy range of 3–6 eV. All of the optical coefficients decrease with the increase of plasma power, which has been explained as the effects of the etch-induced defects. The temperature-dependent ultraviolet reflection measurements on the reactive ion etching (RIE) ZnTe crystals reveal resembled effects while either increasing the rf power or increasing the experimental temperature due to the similar role of the electron–phonon and electron-defect scattering.

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Keywords: Dry etching processes; Optical properties; Ultraviolet; Zinc telluride (ZnTe)

1. Introduction

Zinc telluride (ZnTe), a semiconductor of the II–VI family, is one of the promising materials for a variety of optoelectronic devices such as green light emitting diodes, laser diodes and waveguides because of its direct transition band gap of 2.26 eV at room temperature [1–3]. Furthermore, ZnTe also attracts the attention for its relatively high electro-optic (EO) coefficient and dielectric constant, especially in the range of teraherz (THz) frequency [4–6] which can be used for EO devices. Recently, the successful growth of high quality ZnTe (both p and n types) crystals has led to the rapid development on the research of this important compound. In order to fabricate optical and electronic devices on ZnTe, technology for patterning

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and pattern transfer must be developed. Reactive ion etching (RIE), an effective technique for pattern transfer, has been introduced to study the new optical and electronic properties of ZnTe compounds [7,8].

It is well known that RIE is a dry etching process combining the selectivity of chemical processes and the directionality of physical processes to produce an anisotropic microsized structure [9]. We have demonstrated [7] that a smooth etched ZnTe surface can be obtained using methane (CH_4) and hydrogen (H_2) gases which are relatively easy to handle, less toxic and corrosive than chloride and bromide gases. We have also studied [10] the far-infrared (FIR) reflection and Raman scattering spectra of RIE ZnTe crystals, and furthermore reported the effects of dry etching process on effective refractive index of ZnTe surface layers in THz region [11], which have been applied to the generation and detection of the THz radiation [12], opening the way to extend the new applications of RIE ZnTe.

On the other hand, the energy-band structure and spectra below and above the band gap of ZnTe have been roundly reported in the previous researches. Fig. 1 is the energy-band structure of ZnTe calculated by Walter and Cohen [13]. The lowest direct absorption edges of ZnTe are 2.3 eV (E_0) and ~3.2 eV ($E_0 + \Delta_0$) at 300 K. The E_1, $E_1 + \Delta_1$, and E_2 transitions occur at ~3.8, 4.3 and 5.2 eV, respectively. Freeouf [14] has studied the far-ultraviolet reflection spectra of ZnTe, and the excitonic effects in ZnTe have been analyzed by Furumura et al. [15]. Sato and Adachi [16] have established an interband critical points (CPs) model to study the optical response of ZnTe in the photon energy range of 1.5–5.6 eV with the aid of spectroscopic ellipsometry. However, as far as we know, there are few reports on the optical properties of RIE ZnTe crystals in the visible and ultraviolet (UV) range besides the photoluminescence properties [17]. In this paper, we report on the UV reflection spectra of RIE ZnTe crystals exposed to CH_4/H_2 gases under different rf plasma powers and study the effects of RIE on optical properties of the ZnTe surface layers in the energy range of 3–6 eV.

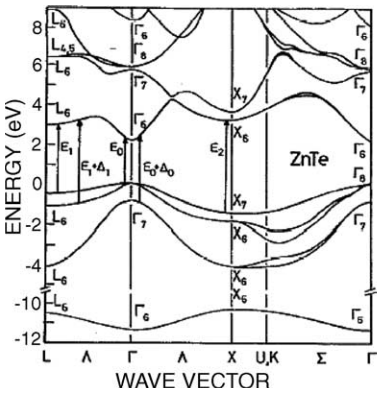

Fig. 1. Electronic energy-band structure of ZnTe [after Walter and Cohen (Ref. [13])].

2. Experimental details and theoretical model

The studied ZnTe crystals were prepared in a Bridgman furnace heated to 1200 °C. The ZnTe samples with a (1 0 0)-oriented surface were mechanically polished with 0.05 μm alundum. The samples were degreased in organic solvents and then etched in Br methanol for 40 s followed by a methanol rinse. The ZnTe samples were found to be p-type with a carrier concentration of $\sim 3 \times 10^{17}$ cm^{-3}. X-ray diffraction measurements (on a Shimadzu XD-3A system with a Cu Kα line) showed two strong (2 0 0) and (4 0 0) reflection peaks at 29.08° and 60.12° with a full width at half maximum of 0.23° and 0.22°, respectively.

The dry etching experiments were carried out in a load-locked SAMCO RIE-200L system. For plasma generation, the cathode was driven by rf power at 13.56 MHz and was water-cooled to maintain at room temperature. A rotary-backed turbomolecular pump enabled a starting pressure of less than 7×10^{-4} Pa. The RIE chamber was pre-cleaned with an O_2 discharge process to prevent contamination. The etching time was 10 min with the total CH_4 and H_2 gas flow rate of 45 sccm under different rf plasma powers (P) up to 200 W. The RIE chamber pressure during etching was maintained at 25 Pa by an automatic pressure controller system. The temperature-dependent reflection measurements on the RIE ZnTe crystals were performed on a Jobin-Yvon 460 monochromator with a resolution of 2 Å under a variable temperature closed-cycle refrigerator system.

As we know, the etching process would produce slightly porous and perturbed surface. In the calcula-