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Fluoride Resonant Tunneling Diodes Using Cd-rich $Ca_xCd_{1-x}F_2/CaF_2$ Heterostructures on Si Substrates

Motoki Maeda, Hiroshi Kambayashi, So Watanabe and Kazuo Tsutsui

Interdisciplinary Graduate School of Science & Engineering, Tokyo Institute of Technology
4259 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan
Phone: +81-45-924-5461 Fax: +81-45-924-5462 E-mail: maemoto@ae.titech.ac.jp

1. Introduction

Si-based resonant tunneling diodes (RTDs) are very attractive because compact circuit composed of small number of devices can be constructed in Si integrated circuits. Recently, Si-based RTDs with good characteristics at room temperature have been reported using heterostructure such as Si/SiGe[1], Al_2O_3/Si[2] and SiO_2/Si[3]. We have investigated RTDs using fluoride heterostructure, CaF_2(barrier) /CdF_2(well), on Si(111) substrates[4] as a candidate of Si-based RTDs. This structure has large conduction band discontinuity, and extremely large peak to valley current ratio (PVR) has been reported[5]. The co-integration of the fluoride RTDs with Si-MOSFETs was also reported[6]. However, some critical problems in durability for fabrication process of such integrated-type devices were found.

An origin of these problems is instability of CdF_2 for high temperature or wet treatment. From the viewpoint of growth temperature, the optimum growth temperature of CdF_2 is very low (around at room temperature) compared to that of CaF_2 (around at 750°C). Thus the layered structure such as $CaF_2/CdF_2/CaF_2$ should be grown at very low temperature after the first CdF_2 layer has been grown. Furthermore, thermal budget in the post growth process is very limited. These limitation leads to degradation of heterostructure quality and device characteristics.

We have investigated basic growth characteristics of $Ca_xCd_{1-x}F_2$ alloy, in which possibility of higher growth temperature than that for pure CdF_2 was indicated[7]. In this work, use of $Ca_xCd_{1-x}F_2$ alloy was studied to overcome these problems. Energy band structure of this alloy system is not clear at present, however, it is predicted that low composition alloy (x = 0.2 or less) should have low conduction band edge (Ec) level enough to use for quantum well layer under an assumption of the Vegard's law. The growth characteristics of the Cd-rich $Ca_xCd_{1-x}F_2$ alloy was investigated, and RTDs were fabricated to show the feasibility of application to quantum well layers.

2. Growth characteristics of Cd-rich $Ca_xCd_{1-x}F_2$ alloy films

The 100 nm of Cd-rich $Ca_xCd_{1-x}F_2$ alloy including pure CdF_2 layers were grown at 200°C on the 1.2 nm-thick CaF_2 buffer layers grown on Si(111) substrate at 750°C by molecular beam epitaxy (MBE). The growth temperature of 200°C was predicted to be too high for pure CdF_2 to obtain good properties from previous studies. These layers were characterized by atomic force microscopy (AFM) and double-crystal X-ray diffraction (XRD).

Figure 1 shows surface morphologies of pure CdF_2 (x = 0) layer and alloy ($0.1 \leqq x \leqq 0.3$) layers. The alloy layers exhibited fairly smooth surface, while pure CdF_2 formed rough island structure.

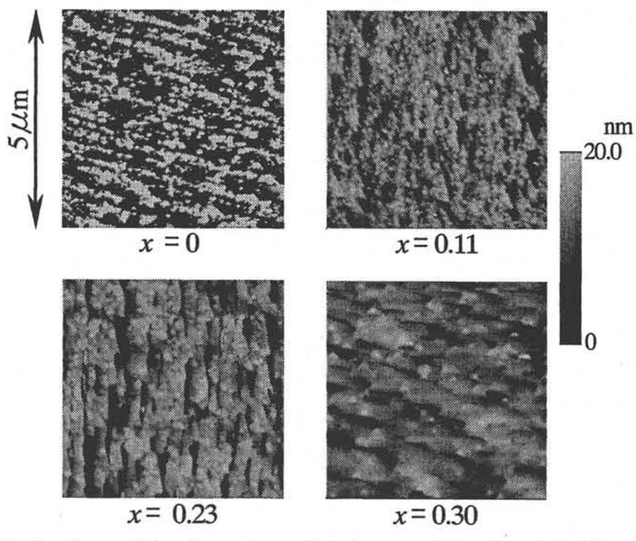

Fig.1 Composition dependence of surface morphologies of $Ca_xCd_{1-x}F_2$ alloy layer ($0 \leqq x \leqq 0.3$) grown at 200°C. 5 μm × 5 μm AFM images.

Figure 2 shows results of XRD measurements for the samples of similar structure. The single peak position shifts to lower angle with increasing composition, x, which indicates formation of uniform alloy layers.

Fig.3 shows the RMS values obtained from the AFM observations and FWHM values of rocking curves obtained from the XRD measurements depending on composition, x. Both values decreased drastically by slight addition of CaF_2

($x = 0.1$) to pure CdF_2 for the growth at 200°C.

These results show that Cd-rich $Ca_xCd_{1-x}F_2$ alloy layers can be grown with good properties at 200°C, which would be too high temperature for pure CdF_2.

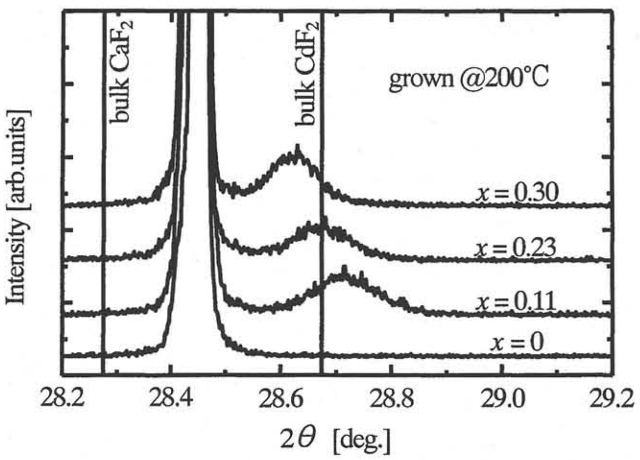

Fig.2 XRD spectra ($2\theta/\theta$ scan) depending on alloy composition, x.

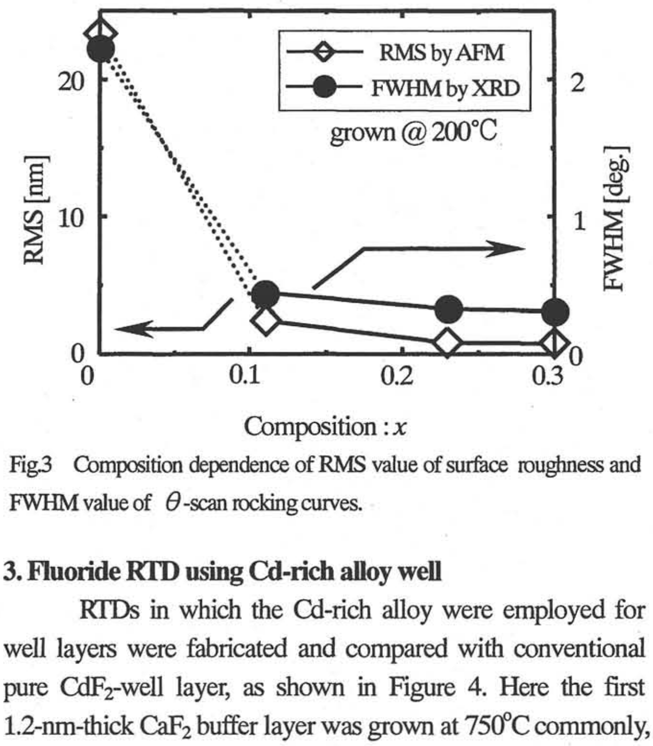

Fig.3 Composition dependence of RMS value of surface roughness and FWHM value of θ-scan rocking curves.

3. Fluoride RTD using Cd-rich alloy well

RTDs in which the Cd-rich alloy were employed for well layers were fabricated and compared with conventional pure CdF_2-well layer, as shown in Figure 4. Here the first 1.2-nm-thick CaF_2 buffer layer was grown at 750°C commonly, and the following heterostructure with pure CdF_2-well was grown at room temperature, whereas that with Cd-rich alloy-well was grown at 200°C. *I-V* characteristics of these RTDs shows that the lager PVR was obtained for the alloy-well structure. The normal operation of the alloy-well RTDs indicates that the *Ec* level of the alloy is low enough. And the better performance is considered to be due to the higher growth temperature for the fluoride heterostructure.

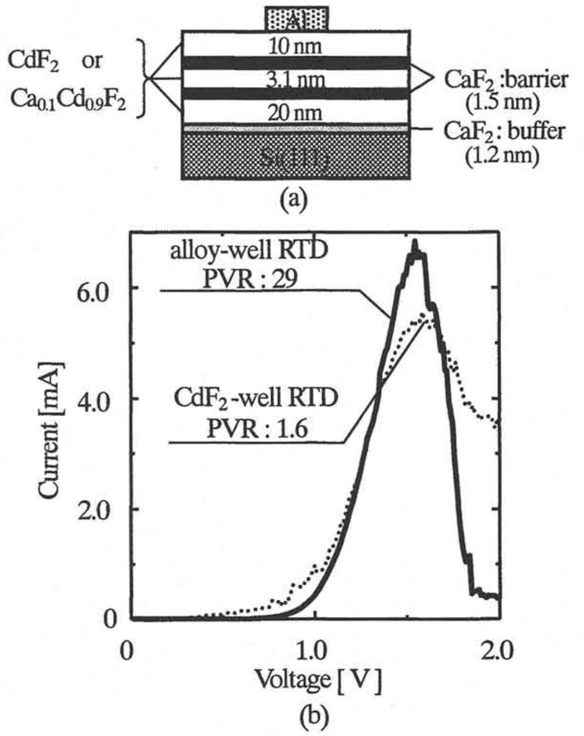

Fig.4 (a)RTD structures with CdF_2/CaF_2 grown at room temperature or $Ca_{0.1}Cd_{0.9}F_2/CaF_2$ grown at 200°C. (b) *I-V* characteristics of these RTDs.

4. Conclusion

Cd-rich $Ca_xCd_{1-x}F_2$ alloy ($x \sim 0.1$) was introduced to well layers of fluoride RTDs on Si substrates, which was substituted for conventional pure CdF_2. Higher temperature (200°C) growth of the fluoride heterostructure was achieved by this method. The alloy-well RTDs showed larger PVR than that of pure-CdF_2-well RTDs. This indicates that the Cd-rich alloy has low *Ec* level, and that heterostructure with better quality was obtained due to the higher temperature growth.

Reference

[1] S. Yamaguchi, A. Meguro and Y. Suda: Ext. Abs. SSDM 2001, p582.

[2] M. Shahjahan, Y. Koli, K. Sawada and M. Ishida: Jpn. J. Appl. Phys., **41**, 2602 (2002).

[3] Y. Ishikawa, T. Ishihara, M. Iwasaki and M. Tabe: Electron. Lett. **37**, 1200 (2001).

[4] A. Izumi, N. Matsubara, Y. Kushida, K. Tsutsui and N.S. Sokolov: Jpn. J. Appl. Phys., **36**, 1849 (1997).

[5] M. Watanabe, T. Funayama, T. Teraji and N. Sakamaki: Jpn. J. Appl. Phys., **38** L716 (2000).

[6] T. Terayama, H. Sekine and K. Tsutsui: Jpn. J. Appl. Phys., **41**, 2598 (2002).

[7] H. Kambayashi, T. Gotoh, H. Maeda and K. Tsutsui: J. of Crystal Growth, **237-239**, 2061 (2002).