Discontinuous Variation up on Annealing in Surface Fermi Level of P-Type InP

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Influence of annealing on the Fermi level pinning at (100) surface of p - type InP was investigated by photoreflectance and photoluminescence in order to make sure of the unified defect model proposed by Spicer et al. A discontinuous surface Fermi level change from 0.43 ±0.05eV to 1.23 ±0.05 eV was observed around an annealing temperature of 220 ℃.

I. Introduction

Understanding mechanism of the Fermi level pinning at compound semiconductor surface is essentially important for optimizing performance of electronic devices based on metal-semiconductor interfaces as well as near-surface quantum structures. Its previous interpretations assuming the presence of surface states are: i) discrete deep states at a surface as in the case of the unified defect model,(1) ii) an U-shape continuum of surface states with a charge neutrality level as in the case of the disorder-induced gap state(2) and the metal-induced gap state models.(3)

For the surface Fermi level pinning at (110) surface of InP the unified defect model has been considered as a dominant mechanism; it has been reported that there are two dominant pinning level at 0.9 ± 0.1 and 1.2 ± 0.1 eV above the valence band maximum.(1) In order to make sure of the presence of the two level observing an discontinuous behavior associated with the Fermi level pinning is desired, though a continuous variation in surface Fermi level ($E_{\rm FS}$) has been observed when n-type InP is exposed with oxygen up to 0.5 Langmuirs.(1) In the present study, we have investigated annealing effect on room-temperature $E_{\rm FS}$ of p-type InP, and observed a discontinuous $E_{\rm FS}$ change from 0.43 to 1.2 eV around an annealing temperature of 220 ℃.

II. Experimental

All the InP crystals studied are grown by thermal-baffle liquid-encapsulated Czochralski. Zn atoms are doped to prepare p-type samples having carrier density of about 1.0×10^{16} cm^{-3}. As-grown crystals are annealed at temperatures ranged between 150 and 450 ℃ for three minutes under argon gas flow. To measure $E_{\rm FS}$ photoreflectance(PR), i.e., a contactless method of electroreflectance is carried out at room temperature. Measurement of photoluminescence(PL) as well as surface morphology by atomic force microscope(AFM) were performed.

III. Results and Discussion

Shown in Fig. 1 are room-temperature PR spectra of p-type InP annealed at various temperatures. A significant change in the Franz-Keldysh oscillation (FKO) period is observed around an annealing temperature of 220 ℃ as shown in Fig. 2. A PR spectrum provides us a surface electric field, $F_{\rm S}$, and hence $E_{\rm FS}$ with the aids of the Shottky relation:$F_s = \sqrt{\frac{2N_{\rm S}}{\varepsilon}(E_{\rm FS} - E_{\rm FB} - k_{\rm B}T)}$. Since FKO period is proportional to $F_{\rm S}^{2/3}$ this change is found to be due to a change in $E_{\rm FS}$ from 0.43 ±0.05 to 1.23 ±0.05 eV, which is possibly assigned with a missing In donor level reported in Ref. 1.

An above interpretation is based on an assumption that ionized impurity density near surface, $N_{\rm S}$, is not increased by annealing: supposed that $N_{\rm S}$ is increased up on annealing, $F_{\rm S}$ is also increased as observed in PR. To confirm this assumption, PL measurement is performed by using a pumping energy of which the skin depth is comparable to the surface depletion length, W, of samples studied. As shown in Fig. 3, PL intensity is reduced around annealing temperature of 220 ℃ synchronized with variation in PR. This indicates an increase in W and hence an increase in $E_{\rm FS}$ because of $W = \sqrt{\frac{2\varepsilon}{N_{\rm S}e^2}(E_{\rm FS} - E_{\rm FB} - k_{\rm B}T)}$. Accordingly it may be a safe assumption that $N_{\rm S}$ is not increased by annealing.

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