Photoelectron spectroscopic study of Fe films on NEA surface

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Abstract

We investigated Fe films on a negative electron affinity (NEA) O/Cs/GaAs(1 0 0) surface by photoelectron spectroscopy and photocurrent measurements. From the results, it is shown that the Fe covered surface retains NEA character, which is comparable to that of the standard NEA, even in the thicker Fe coverage region of about 100 Å. It is also found that the change of NEA intensity is independent of the change of the work function. From the core level peak results, it is also discussed that further chemical reaction at the interface and overlayer.

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1. Introduction

Negative electron affinity (NEA) semiconductors are used as efficient photocathodes, due to their high degrees of polarization and efficiency. However, from a fundamental science point of view, the details of NEA formation are not fully understood. Several models for the mechanism of NEA formation have been suggested in the past, such as the dipole model [1,2], the cluster model [3] and so on [4,5]. Many studies have indicated that the compound of caesium and oxygen, which bonds to gallium and arsenic atoms [6], may lower the work function of the surface. Recently, Mori et al. [7] suggested that the NEA condition was distinguished with different activation processes which would make different type of oxidation at interface between the substrate and overlayer.

On the other hand, the study of magnetic thin films on semiconductor substrates has been widely carried out due to the applicability to magneto-electronics devices, such as the Spin Polarised Field Effect Transistor [8]. As a typical basis for such devices, the Fe/GaAs system has been extensively studied for decades [9–12] because of its great promise in the possible use of hybrid ferromagnetic metal–semiconductor structures for applications.

In this paper we present a study of a Fe covered NEA.

2. Experiment

Fig. 1 shows schematic diagrams of the experimental set-ups used. All experiments were carried out at RT in UHV chamber with the base pressure of about 3 × 10−8 Pa, and less than 6.5 × 10−8 Pa during Fe deposition. A Zn doped (1 × 1019 atoms/cm3) p-GaAs(1 0 0) wafer was used as a substrate, having been cleaned by Ne sputtering and annealing. This treatment led to the familiar (8 × 2) surface reconstruction. We employed the ‘Nagoya method’ [13] to activate the NEA surface, in which Cs increases the yield (NEA intensity) and O decreases it. The NEA intensity was measured as the absolute value of the photocurrent from the biased (~10 V) sample while the He–Ne laser was on and off. Fe was deposited on the NEA surface a total of five times, yielding 0368-2048/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
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estimated coverages of 9.7 (after the first Fe deposition, Fe#1), 29 (Fe#2), 68 (Fe#3), 97 (Fe#4) and 115 Å (Fe#5).

Photoelectron spectroscopy using 100 eV photons was carried out at BL-5A at UVSOR (Okazaki, Japan) with a SGM-TRAIN monochromator. The overall energy resolution was 0.2 eV.

3. Results and discussion

Fig. 2 shows a typical spectrum from Fe/O/Cs/GaAs(1 0 0) after Fe#2. The photoelectron peaks observed at around 20, 55, 71 and 85 eV originate from the Cs 4d, As 3d, Ga 3d and Cs 5p levels, respectively. The broad band at around 42 eV is due to electrons from the Fe 3p level and Cs Auger emission. The inset of Fig. 2 displays the NEA intensity.

The relative NEA intensity is shown in Fig. 3 as a function of Fe coverage and is compared with the lowering of the work function. The intensity is kept at 50, 20 and 7% of the maximum intensity obtained from the pure NEA surface after Fe depositions Fe#1, #2 and #3, respectively. According to the previous work [7], the quantum efficiency of the NEA surface activated by the ‘Nagoya method’ is about 5–10 times higher than that of other standard NEA. It means that the Fe covered NEA has still the ability of photo-amplitude which is comparable to another NEA by standard yo-yo technique. Moreover, the intensity decreases with increasing coverage, although the work function is almost constant even at thicker coverages. This is in good agreement with the literature [7] which suggests that the band bending is not a sufficient condition for the amplitude of the NEA effect.

Fig. 4. Ageing effect. Fe covered NEA retains the condition (upper), though pure NEA is easily broken after ageing.
The photoelectron spectra in Fig. 4 show the overnight ageing effect of the Fe covered NEA (upper) as compared with a pure NEA surface (lower). For the pure NEA, significant variations in peak intensities are observed: the intensities of the Cs peaks become significantly smaller, whereas the Ga 3d and As 3d peaks are seen to increase in intensity. The upper spectrum, notably, remains virtually unchanged. From this result, it is clear that the Fe covered surface is capable of preserving the NEA condition for longer than the pure, uncovered surface.

Fig. 5 shows core peaks from (a) Cs 4d, (b) As 3d and (c) Ga 3d levels. Spectra from the bottom to the top of each panel indicate different stages of Fe growth (layers Fe#1 and #2, respectively) after NEA treatment. Each spectrum is normalised to the integrated intensity of each peak area after the baseline subtraction. The valence band (VB) spectra in panel (d) are not normalised, to show the metallic feature near the Fermi edge. The Cs 4d and Ga 3d peaks shift to higher kinetic energies, and a new component is seen to grow at the lower energy side of the As 3d peak. The Ga 3d peak appears to obtain a higher energy side component whilst losing a lower side one. Moreover, the width of the Cs 4d peak was found to decrease.

In Fig. 6, the integrated intensities of the As 3d, Ga 3d and Cs 4d peaks are shown. Both of the As 3d and Ga 3d peaks are normalised to those of the clean surface, and the Cs 4d peak is normalised to the intensity after the NEA treatment. The Ga 3d peak intensity decreases rapidly as the coverage increases, while the As 3d peak decreases more slowly before reaching a steady value of around 7% of its maximum intensity. The intensity of the Cs 4d peak sits at around half of the maximum, up to an Fe coverage of about 100 Å.

These results indicate that Fe atoms bond to O that were initially a Cs–O bond, therefore some becoming free and excess Cs atoms may make new bonds to Ga in the interface region and to Fe in the upper overlayer region. As the Ga 3d intensity drops rapidly, such the Ga atoms bonding to Cs stay in the interface region between the substrate and overlayer. As atoms keeping bonds to O should make further bonds to O and stay at slightly upper region than Ga atoms, because the decay with the Fe thickness are different. The fact that the Cs peak intensity is almost constant (after Fe#2) means Cs atoms are bonding to Fe, and hence segregated, even in the thicker Fe region. From this overview, therefore, the bonding state of overlayer should have a complex structure which depends on the depth, and consists of Fe, Cs, As and O atoms.

4. Summary

We investigated Fe films on a NEA O/Cs/GaAs(1 0 0) surface by using photoelectron spectroscopy and photocurrent measurements. It was found that the Fe covered surface still has NEA characteristics which is comparable to the standard NEA, even in the thicker Fe coverage region of about 100 Å. Furthermore, the change of NEA intensity appears to be independent of the change of the work function. The core level peak results imply that the overlayer has a complicated structure, dependent on its depth from the top of the layer. These overlayer compounds should consist of Fe, Cs, As and O atoms.

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References