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METAL-SEMICONDUCTOR INTERFACE (Al-Si)

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Abstract- The microscopic structure of metal-semiconductor interface and the behavior of Al on a p-Si(110) surface have been investigated using the probe-hole field emission microscope (FEM), the field desorption (FD) and the field emission retarding potential analyser (FPA). The Fowler-Nordheim (FN) plots for the Si tip prepared by electrolytic etching are classified into two groups, the curve and the line. The work function of Si surface by an adsorption of Al decrease with the 0(Al) and the value reaches 3.2 ±0.2 eV at 0(Al)≤1. A surface resistance of giga ohms which is difficult to remove at usual FD field have been observed for the Si tip having the curved FN plot. This layer can easily be metalized by the interdiffusion of Al at room temperature.

1. Introduction

The microscopic structure of metal-semiconductor and semiconductor-semiconductor interface and the characteristics of low temperature process of semiconductor devices are becoming important as an increase in the integration of a recent large scale integrated circuit. A number of ultrahigh vacuum surface analyser have been used for the purpose of surface analysis/1/. FEM/2/ is the most sensitive tool for the detection of very small amount of the surface contamination and FD/3/ is an ideal method of cleaning the semiconductor surface without the damage of the outer-most surface layer by an ion bombardment or the high temperature heating for the cleaning.

In this paper, FEM and FD cleaning method are combined to get an ideal clean semiconductor surface and to investigate the metal-semiconductor interface. Al can be deposited on the Si surface in an atmosphere almost completely free from any contamination for the period of time while the experiments are performed.

2. Experimental procedure and results

A thin Si(110) bar (0.5x0.5x10 mm) cut from p-200-cm wafer was fixed in the hollow Ni tube spotwelded on a Mo loop. A fine Si tip(500~1000Å) can be made by electrolytic etching applied ac 60 V in a mixed solution of one part of HF (50%) and three parts of HNO3 (68%). After the dregs of etching solution on the etched Si tip had been removed by rinsing the etched tip in a deionized water immediately after etching, then the FEM tube mounted with the tip was baked at 150 °C during the evacuation. An ultimate pressure of 10^-7 Pa reached after the evacuation for 5hr. A clean Si tip with a curvature of less than 1000Å was obtained easily by FD at 10 KV in UHV and 4 ~ 5 KV in 10^-3 Pa H2 gas. The FN plots at each FD cleaning process from immediately after the evacuation are classified as follows(Fig.1): (1) line (2) curve. The characteristics of FN plots are believed as the electrolytic etched Si surface is covered with a foreign material such as SiOx, especially on the surface of the curved FN plot. The shape FN plot changed from the curve into the line with relatively low or high field desorption according to its curvature, but it was sometimes difficult to change the shape of curved FN plot at usual FD field.
When Al was deposited with varying coverage on the Si surface at room temperature, the slope of largely curved FN plot decreased with coverage of Al, θ(Al), and finally changed to the line at θ(Al) ≈ 1. The irradiation of focused laser beam on the Si also varied the shape of FN plot from the curved one to the line. Though the slope of curved FN plots were recovered partially by FD at small θ(Al), it was never back to the initial one once the curve had changed to the line at θ(Al) ≈ 1 as shown in Fig.2.

When Al was deposited on a Si surface cleaned by FD, the work function of surface decreased with the θ(Al) and the value reached 3.2 ± 0.2 eV at θ(Al) ≈ 1 as shown in Fig.3. As the field increased, deposited Al was desorbed gradually up to clean surface.

In order to investigate the origin of the curved FN plot and the metallization of the surface layer of Si by the adsorption of Al at room temperature, the variation of the threshold values of collector voltage during the FD cleaning process for both the etched and Al deposited Si surface were measured at each field emission current.

In the case of the curved FN plots, the threshold collector voltage (Vc') in the beginning of cleaning was larger than that of the collector work function (Vc) itself and then decreased as the cleaning proceeded, but it is never equal to (Vc) as shown in Fig.4. The value of (Vc') as a function of field emission current increases quadratically in the case of largely bended FN plot as shown in Fig.5. If the curvature of FN plot was small compared with the FN plot of Fig.5(a), the value of (Vc') was smaller than that of (a) at high current (correspond to higher field) as shown in Fig.5(a), (b).
In the case that FN plot is a line from the beginning of cleaning, \((Vc')\) increases linearly with field emission current as shown in Fig.5(c). The value \((Vc')-(Vc)=(V_i)\) which is related to the potential drop at the Si surface, as shown in Fig.6, depends on the cleanliness of the surface. On the bases of this results, it can be concluded that there exists a high resistive layer on the Si surface etched electrolytically. Since the value of \((Vc')\) becomes larger with the increase of the bend in FN plot, the resistance \((R)\) can therefore be evaluated by dividing \((V_i)\) with \((I)\) at each threshold. The characteristic curve of \((I)\) vs \((R)\) is a parabola type with minimum at about 5 nA when the bend in FN plot is larger.

The higher current side of the parabola decrease as the bend was small and finally become a line. When the FN plot is linear from the initial state, \((V_i)\) vs \((I)\) curve is I type having nearly flat beyond 5 nA. It become evident that the value of \((R)\) at the surface differs from the degree of electrolytic etching. It should be noted that the surface resistance has a negative characteristic at the left side of the parabola.

The negative characteristic is explained as the reduction of \((R)\) occurs due to the generation of conduction electrons by the electron impact ionization as the field increase and then the resistance \((R)\) increases due to the decrease in mobility of the electrons as the scattering effects become dominant at above a certain field. The scattering effect disappear when the high resistive layer are removed in the etching process or by FD, but there always exist the negative characteristics even in the surface of stright line FN plot as shown in Fig.7. A nother important fact is that \((V_i)\) and \((R)\) become nearly equal to zero with the decrease in the work function due to the deposition of Al on the high resistive surface at room temperature. This metallization is caused by the interdiffusion of Al into the high resistive layer or semiconductor even at room temperature/4/.

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Fig. 7 Resistance (at room temp.) as functions of field emission current, with the bend of FN plot as a parameter.

Fig. 5 Voltage drops at the Si surface as a function of field emitter current, with the bend of FN plots as parameter. (a) The bend of FN plot is larger. (b) The bend of FN plot is large. (c) The bend of FN plot is linear. (d) The FN plot from the Al covered Si surface.

Fig. 6 Electron energy band diagram of the oxide covered p-Si for the retarding potential analyzer. (S); p-semiconductor, (O); oxide layer, (A); anode, (C); collector.

References
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