

Influence of Ambients on the Reverse Current of Surface Barrier Detectors I

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In order to obtain better semiconductor surface barrier nuclear particle detectors, an investigation of surface effects on the reverse current is made. Gold is vapor-deposited on the etched silicon surface, in the shape of concentric circles; one of which is a central solid circle, and the other an outer ring surrounding the former. The currents that flow these two separated gold layers are measured respectively, as functions of ambients. It is then shown that the surface leakage current is a large component of the reverse current, and that the strong inversion layer is formed on the silicon surface, *in vacuo*, resulting in high surface current, and in room air atmosphere the depletion or accumulation layer is formed, though the formation of it is very sensitive to water vapor.

Introduction

A considerable amount of work has been reported on the electrical properties of metal-semiconductor contacts prepared by vapor deposition, chemical deposition and so forth. However the correlating experimental data to theories are complicated by uncertainties in the exact values of the work functions of deposited metals and the surface states of semiconductors. A metal work function is very sensitive to crystal structure and surface contamination.^{1,2)}

A surface barrier nuclear particle detector is usually made of n-type silicon, which is initially sliced from a single crystal ingot and polished mechanically, and then subjected to chemical treatments of etching, and finally put into vacuum for deposition of gold or other metals. During such preparation of the detector, especially after chemical treatments, thin intervening oxide and gas adsorbed layers are inevitably formed on the silicon surface of the detector. Moreover atmospheric contamination occurs easily during handling and long periods of storage. The variation of surface, described above, modifies the density of surface states, determines the conductivity type at the surface and contributes to surface leakage current in the detector.

Therefore, the reverse current of the detector comes to a troublesome problem. It, however, is an important factor in the operation of the detector because it can be the main source of noise in the measuring system and may limit resolution. The reverse current of the detector prepared in the conventional way seems to be influenced by surface states rather than the work function difference.³⁾ And the surface leakage

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current may be the most dominant component of the reverse current. Then, in this paper, an investigation to understand the problems of surface effects is made in order to obtain better surface barrier detectors, and preliminary results of a study of guard ring type surface barrier detectors will be given.

Preparation of detectors

N-type silicon wafers with (111) orientation and resistivity between 200 to 300 Ω cm were used. The wafers were polished by Fuji meta-polish No. 2 and washed by deionized water. Then the wafers were nickel-plated to make ohmic contacts. They were etched by using CP4-A except the back surfaces covered by picein, and then washed in trichloroethylene, methanol, and finally deionized water. After keeping few days in clean air thin layers of gold were vapor-deposited on the top of the detector as shown in Fig. 1. The thickness of the gold layer was approximately 400 Å. The pressure within the vacuum evaporator was about 10^{-4} mm of Hg.

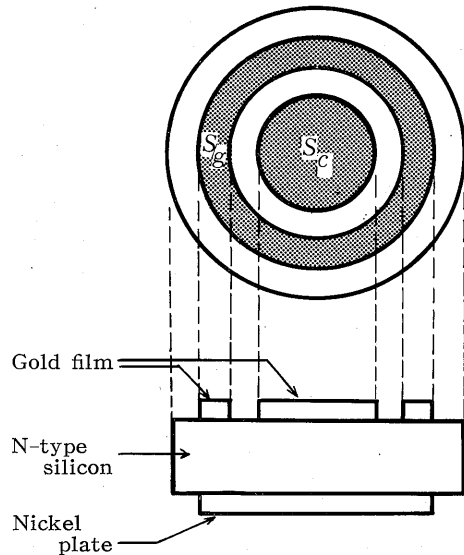


Fig. 1 Configuration of the detector tested in the experiment.

Measurements

The electrical properties of the detectors fabricated were measured by the system shown in Fig. 2. The detector was put into a vacuum chamber which could be

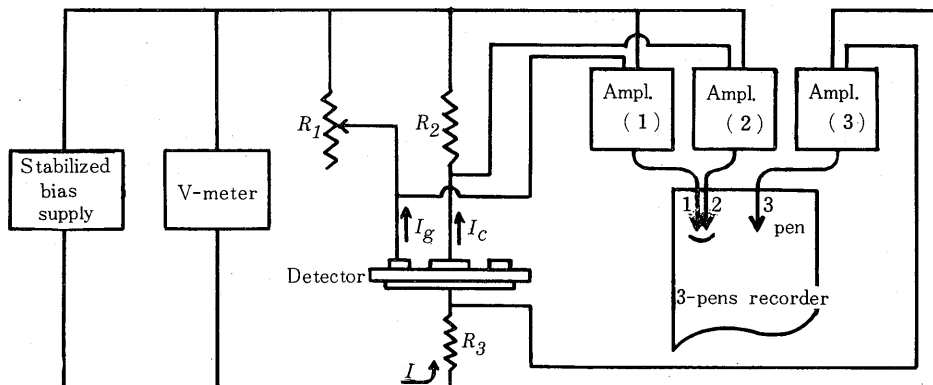


Fig. 2 Schematic diagram of the electronic apparatus used in the experiment.

pumped out by a rotary pump. Hence the lowest pressure in the chamber was about 10^{-3} mm of Hg. The reverse currents of the detector to various kind of ambients were measured indirectly by the voltage drop appearing at both ends of 1.5 K Ω resistances R_2 and R_3 . And R_1 is a variable resistance, the voltage drop of which is controlled manually so as to be the same value as that of resistance R_2 . That is, the track of

the pen 1 is adjusted to tread upon that of the pen 2 by controlling the resistance R_1 .

Results of measurements

Immediately after gold was deposited by vaporization *in vacuo*, the detector was put into the vacuum chamber, and then the reverse currents were measured. They are shown in Fig. 3, where I_c and I are currents that flow the resistances R_2 and R_3

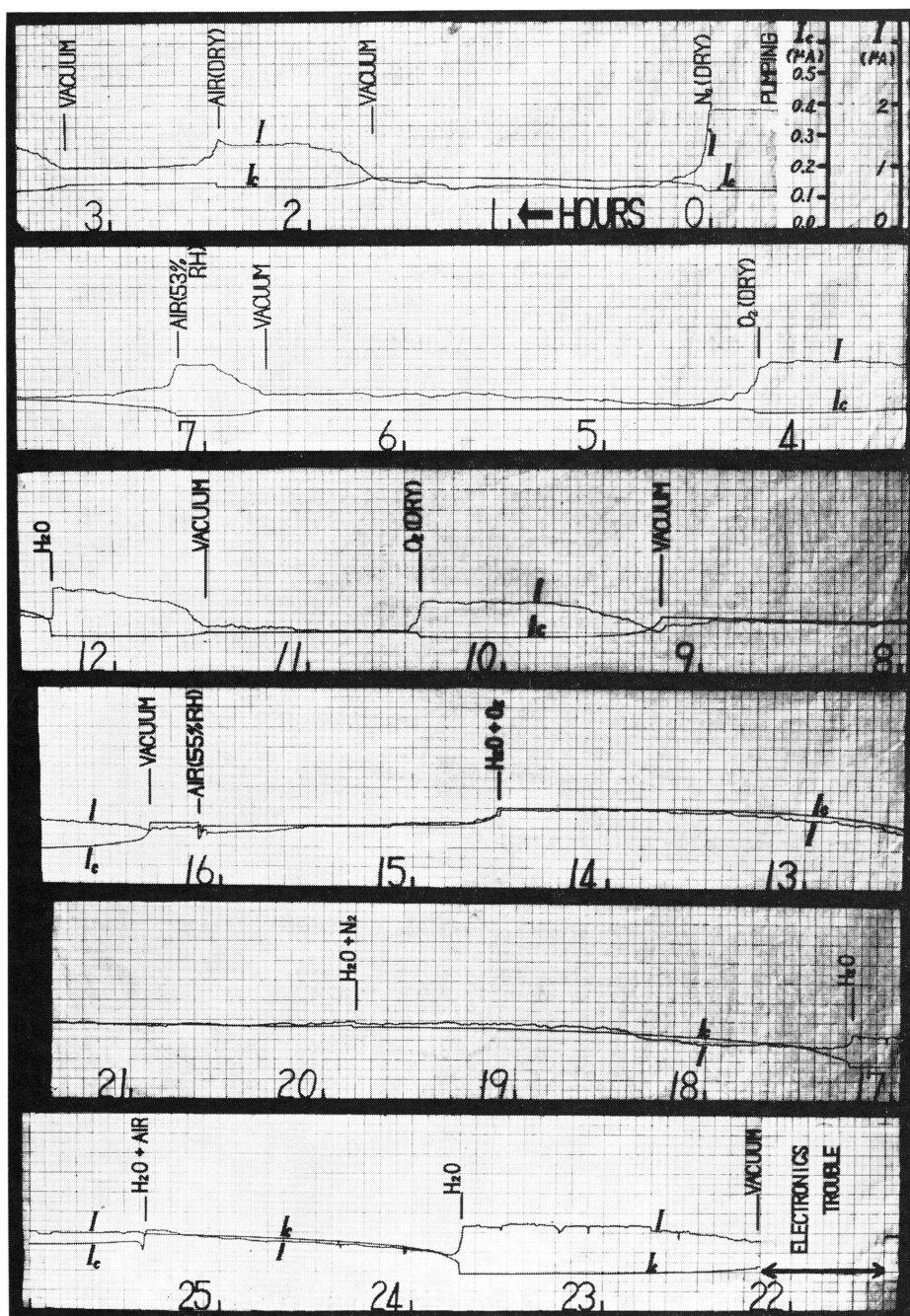


Fig. 3 Influence of ambients on the current I and I_c .

respectively. Here I is the total reverse current of the detector and $I = I_c + I_g$, where I_g is the current that flows the resistance R_1 . The constant polarizing voltages of six volts were applied to the detector throughout the measurements. The resistances R_1 , R_2 and R_3 are much less than the reverse resistance of the detector, R_{rev} . The measurements were carried out at room temperature (28°C) by changing ambient conditions. At each ambient sufficient time was taken for the current I_c to reach equilibrium. It was usually longer than about an hour as shown in Fig. 3.

Discussion

The results in Fig. 3 bring up some relevant information. The values of I_c at equilibrium would correlate to surface potential. Mean values of I_c in Fig. 3 are listed as relative values in Table 1. As a result, the series of ambients in Table 1 corresponds well to that of surface Fermi level vs. ambients obtained by R.H. Kingston.⁴⁾

ambients	I_c	
H ₂ O	3.85	n-type
N ₂ + H ₂ O	3.80	↑
air + H ₂ O	3.30	
O ₂ + H ₂ O	3.00	
N ₂ (dry)	2.53	
air (dry)	2.26	↓
O ₂ (dry)	2.00	p-type

Table 1. Relative values of I_c at equilibrium obtained from Fig. 3.

Fig.4 obtained from Fig.3 shows I vs. I_c . The reverse current of the detector has three components as follows;

- (1) the carrier generation current due to carriers produced by thermal generation in the depletion zone,
- (2) the drift current due to diffusion of minority carriers into depletion zone,
- (3) the surface leakage current.

The first two components involve a flow of current through the bulk of the silicon and are, therefore, proportional to the area of gold deposited on the silicon surface. These areas are shown in Fig. 1 as S_c ; the central area, and S_g ; the guard-ringed one, and have the relationship: $S_g = 1.9 S_c$. Therefore the surface leakage current I_s of the detector fabricated should be represented by, $I_s = I - I_c - 1.9 I_c$. The generation and diffusion current I_{gd} is then represented by, $I_{gd} = I - I_s (= 2.9 I_c)$. As shown in Fig.4, I_s is about three times as large as I_{gd}

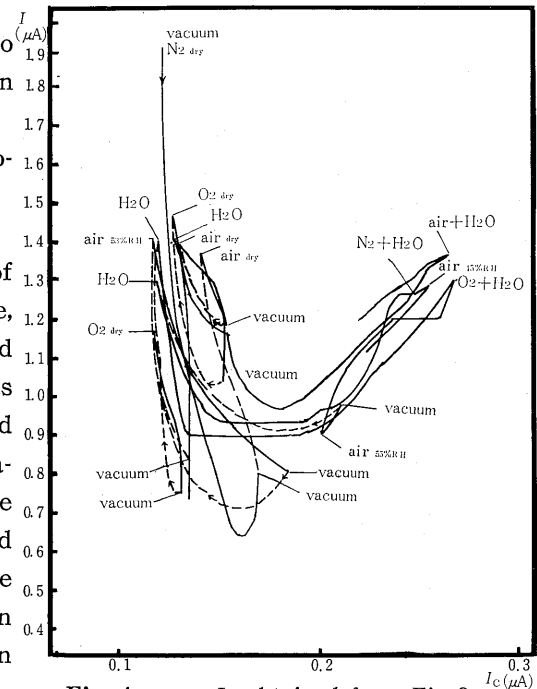


Fig. 4 I vs. I_c obtained from Fig. 3.

in vacuo. Thus the surface leakage current is a large component of the reverse current, and presumably results in breakdown at relatively low bias. Fox and Borkowsky⁵⁾ showed that breakdown in surface barrier junctions occurred first at the edge of the gold electrode owing to the space charge layer in the silicon surface. They eliminated this by changing the sign of the surface charge at the edge of the gold with a ring

of amine-free epoxy resin doped iodine. Another approach to eliminate the surface leakage is a coating of Apiezon wax on the sides of the crystal.⁶⁾ Both these approaches have drawbacks that they lead to spurious signals in some applications owing to protons being ejected from them. And there is another doubt about the reliability of epoxy resin encapsulations. Since the coefficient of expansion of epoxy resin differs from that of silicon, they do not give a really durable bond to silicon, and especially at low temperatures they are not effective. They are known to change composition with age, and they may suffer tracking and surface breakdown in some ambients.⁷⁾

One of the curves in Fig. 4, correlated to H_2O , is chosen for example and shown as the dotted curve in Fig. 5. The solid curve in Fig. 5 is obtained by subtracting $I=2.9 I_c$ from the dotted curve, and this curve shows change of surface leakage current vs. ambient, in other words, surface conductance vs. surface potential, from which it is clear that the inversion layer is formed on the surface of crystal *in vacuo*, and the surface is very P type and has a large conductance. Since the pressure within the chamber is about 10^{-3} mm of Hg, there are many residual and adsorbed gases, and gases due to rotary pump back-streaming. These gases may have resulted in such effects. It is also clear that in the room air, the accumulated layer is formed on the silicon surface. It seems, however, to vary with the change of humidity. Thus, the detector is quite sensitive to the ambient atmosphere. The surfaces must be prepared to have minimum surface leakage current and they must then be kept that condition as long as possible. Therefore providing some suitable physical or chemical barrier to prevent unwanted ambients except the selected ones is needed.

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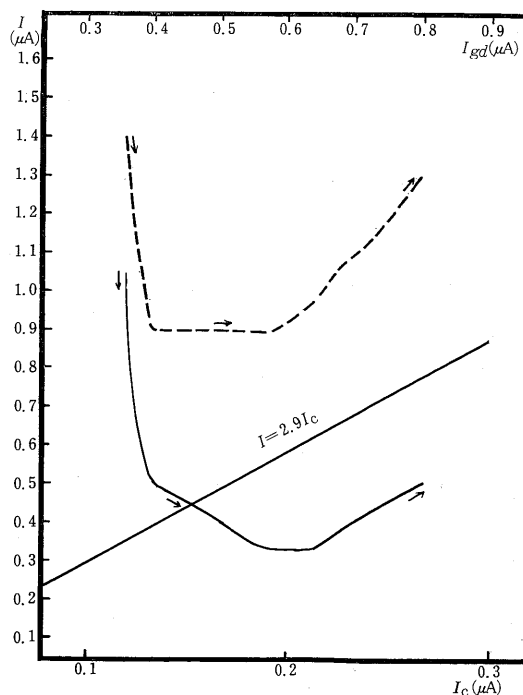


Fig. 5 Surface leakage current vs. I_c .

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