An Investigation of Surface Conduction Mechanisms in Semi-Insulating Gallium Arsenide.

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Abstract

This is a study of surface and bulk currents between contacts fabricated on semi-insulating (SI) GaAs substrates. This includes a study of bulk and surface electrical conduction behavior. An annulus shaped electrode structure was used. To separate the bulk and surface conductance effects, the samples were exposed to a variety of surface treatments. Current measurements were taken over a range of voltages and the results compared by use of current-voltage plots.

Introduction

Semi-insulating (SI) GaAs materials have a very high resistivity of $10^8-10^9 \text{ohtm-cm}$. They are produced by either addition of oxygen or chrome to the crystal growth melt. In this paper, an annulus shaped electrode structure was used which was produced by metal evaporation and subsequent annealing. A detailed explanation of the procedure involved in the design, fabrication, current measurements, etching, heat treatment, application of polyimide, SiO$_2$, Na$_2$S and spin-on oxide is presented. The results are analyzed inorder to find the effect on surface conduction of SI GaAs.

Background Discussion

Metal-Semiconductor field effect transistor (MESFET) structures fabricated on III-V semiconductors, such as GaAs, may exhibit unstable electrical characteristics which may be attributed to surface interfaces or bulk conduction effects [1].

Substrate bias (backgate or side-gate bias) in MESFET also causes a long-term drift of the electrical characteristics. This effect has been related to the presence of bulk traps and interface traps [2]. The side-gating effect is caused by the substrate current underneath the FET region, which changes the occupation function of the dominant traps such as chrome acceptors in the Cr-O doped substrate. The strong side-gating is due to increase of electron flow into the substrate by surface breakdown. If there is a large number of trapping states near the surface, which is the case for GaAs, the filling of these states by electrons gives rise to an intense local electric field which triggers avalanche breakdown which leads to surface breakdown [3].

The trapping states could either be surface states or bulk states near the surface. The sensitivity of backgating characteristics to surface processing conditions rather than to substrate properties together with the correlation between ohmic current and surface states properties[3],strongly suggests that surface states control the surface breakdown. Increase of bulk states near the surface weakens the relative importance of surface states and relaxes field concentration by more diversified distribution of ionized trapping centers. The SI GaAs MESFETs are very sensitive to surface conditions and unless the device has a surface free from movable charges or ions, it will exhibit various kinds of current instability. These instabilities depends upon the type and polarity of the trapped charge and the energy level of the traps [1]. Surface treatments of GaAs has been studied by observing the relative intensities of room temperature photoluminescence (PL). After application of an aqueous solution of Na$_2$S.9H$_2$O, the PL intensity increased by over two thousand times[4].

Experimental

The sample used in this experiment was a planar annulus shaped electrode structure. The outer diameter was 5.0mm and the inner diamters were 1.5mm, 3.0mm, and 4.4mm.
The annular pattern was designed on the computer by use of one of the graphics software available. A transparency of the pattern designed was placed on a lightbox surrounded by a black background. A 35mm camera was focused on the pattern and a Kodak high resolution photograph plate was used to record the image. Four images were exposed on the 2x2 inch plate which was then developed.

The GaAs sample was cleaned in hot trichloroethylene, acetone and methanol. It was then prebaked in a convection oven for 15 minutes at 70°C. The sample was then placed on a spinner and a few drops of hexamethydisilazane (HMDS) were applied followed by drops of positive photoresist (Shipley AZ1400 [4]) at 45000rpm for 30s. The samples were then softbaked in the oven for 15 minutes at 70°C after a 5 minutes air dry. The sample was exposed in contact with the mask plate for 40 seconds. This was soaked in chlorobenzene for 5 minutes to aid the lift-off of the excess contact metal and then baked for 5 minutes at 70°C. This was then developed in Shipley Microposit Developer [4] for 1 minute and dried in the oven for 5 minutes at 70°C.

The pattern showed in figure 1 was formed by exposing photoresist through the mask plate. A gold-germanium + nickel contact layer was deposited by electron beam evaporation. Lift-off was performed by soaking the sample in warm acetone and then ultrasonically stripping away the excess metal. An anneal at 450°C was done in a flowing hydrogen ambient. Current measurements were taken at different applied voltages. The sample was etched in hydrochloric acid for 1 minute and then in a mixture of 5H₂SO₄:1H₂O:1H₂O₂. Current measurements were again taken at different applied voltages in the dark as shown in the set-up diagram in figure 2.

Results

The graphs showed in figures 3-5 show the variation in the current-voltage plots after the sample was exposed to the above conditions. Figure 3 shows voltage-current (v-i) characteristics immediately after the sample was annealed. The measurements were taken on the image with 15nm inner diameter. Figure 4 shows the v-i characteristics after the sample was etched in hydrochloric acid (HCl). Figure 5 shows the characteristics after the sample was CaO-etched for 20s in 5H₂SO₄:1H₂O:1H₂O₂ at room temperature.

A saturation of the sample current is observed at voltages above 25V for the two etched samples. This behavior has not been explained. Etching the GaAs surface results in a considerable reduction in the sample resistance.

Conclusion

Chemical surface treatment is observed to affect the current-voltage behavior of the annular resistor structure formed on SI GaAs. Further studies of these effects will involve the application of polyimide, Na₂S.9H₂O and a spin-on oxide to the GaAs surface.

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References.

Fig. 1 Annular contact pattern

Fig. 2 Set-up for i-v measurements