Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 290-292 **PC1-1**

Surface Passivation Studies on GaAs with Octadecyl Thiol

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Passivation of a chemically etched GaAs surface with a self-assembling monolayer of octadecyl thiol was studied through the electrical characteristics of a Schottky diode. Enhanced Schottky barrier height was obtained with a Au contact without sacrificing Schottky diode characteristics. The structure of an octadecyl thiol passivation layer was also investigated by ellipsometry, infrared spectroscopy, contact angle measurement, and x-ray photoemission spectroscopy, and an attempt was made to correlate it with the Schottky diode characteristics.

I. INTRODUCTION

Effective passivation of GaAs surface could contribute to one or more of the following; 1) modification of Schottky barrier height by introducing charges or charge dipoles at the metal-semiconductor interface, 2) unpinning of surface Fermi level and reduction of surface recombination velocity by reducing density of states at surface, 3) inhibition of native oxide regrowth by forming more thermodynamically stable surface. Therefore, controlling surface passivation is a key factor in engineering GaAs-based semiconductor devices. Conventionally, $Al_{1-x}Ga_xAs$ passivation layers were used to reduce surface recombination velocity in Hetrojunction Bipolar Transistors (HBT's) [1]. However, recently introduction of sulfur chemistry to GaAs surface via. a simple chemical surface treatment was shown to exhibit effective passivation [2-4] and it has become a focus of intensive study.

Previously, thiophene (C_4H_4S) [5] and other sulfur-containing organic molecules were shown to reduce surface recombination velocity. However, its inference on a Schottky diode, a vital element in MEtal Semiconductor Field Effect Transistor (MESFET), was never been explored. In this study we have investigated the electrical characteristics of Schottky diodes fabricated on an octadecyl thiol ($CH_3(CH_2)_{17}SH$) passivated GaAs surface, and their correlation to the surface thiol layer structure studied by ellipsometry, infrared spectroscopy, contact angle measurement, and x-ray photoemission spectroscopy.

II. EXPERIMENTAL PROCEDURE

Schottky diodes were fabricated on a thiol-passivated surface in the following manner. The ohmic contact was first made on the reverse side of an n-type GaAs substrate (Si-doped, $N_D=5x10^{16}cm^{-3}$, <100>) by thermally evaporating Au/Ge alloy and sintering at 500C° for a few minutes. The substrate was then chemically etched by an

H_2O: H_2O_2: H_2SO_4 [1:1:8] solution and then by an HCl solution. It was followed by rinse in deionized (DI) water and blow dry with dry nitrogen. Subsequently, the substrate was immersed in thiol solution, after which excess thiol was rinsed off with chlorobenzene and then with ethyl alcohol. Finally, the Schottky contacts difined by a shadow mask were formed on the front surface by thermally evaporating Au. Schottky diodes were also formed on an unpassivated GaAs surface as control. For surface characterization a GaAs substrate was processed in the same fashion except for the metal contacts.

III. EXPERIMENTAL RESULTS

The electrical characteristics of a thiol-passivated Schottky diode with Au contact are shown in Fig. 1 and Fig. 2 along with those of control. Fig. 1 shows the current-voltage (I-V) characteristics and Fig. 2 shows the high frequency capacitance-voltage (C-V) characteristics of the diode plotted $1/C^2$ as a function of voltage (V). The Schottky barrier height was deduced from I-V and C-V and has been summarized in Table 1. It agrees well with the activation energy calculated from I-V as a function of temperature (I-V-T). Table 1 also shows the ideality factor and series resistance of the diode. It is evident from Table 1 that the barrier height of a thiol-passivated Schottky diode was enhanced approximately by 50meV compared to that of control without significantly degrading the ideality factor, series resistance, or linearity of $1/C^2$ Vs. V plot.

Contact angle measurement on a passivated surface suggested that the surface was covered by a uniform film of octadecyl thiol, and we calculated the surface composition of the thiol film to be 70% methyl group and 30% methylene group. The film should be free of pinholes by large as we did not observe the evidence of their significant contribution to the electrical characteristics of the thiol-passivated Schottky diode. The thickness of the octadecyl thiol film was calculated to be 9Å from ellipsometry. This is in excellent agreement with our infrared spectroscopy (IR) and x-ray photoemission spectroscopy (XPS) data. Also, this is consitent with our electrical characteristcs of the diode showing negligible influence of an insulating layer. Our analysis of transmission IR (Fig. 3) and reflection IR on the passivated surface indicates that the thiol film is a monolayer and its chains are conformationally ordered with 70 degree tilt angle. Also, XPS showed presence of sulfur atoms as well as reduced presence of oxygen atoms on the passivated surface.

IV. Conclusion

We have grown a self-assembling monolayer of conformationally ordered octadecyl thiol on a chemically etched GaAs surface. This passivation yielded enhanced barrier height for Au/n-GaAs Schottky diodes without sacrificing the ideality factor, series resistance, and linearity of $1/C^2$ Vs. V plot. Based on our electrical characterization of the Schottky diode and surface characterization of the thiol monolayer we conclude that this modification of the Schottky barrier height by an octadecyl thiol passivation is primarily due to altered electronic states at the metal-semiconductor interface.

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Table 1 Summary of Electrical Characteristics of Thiol-Treated and Control Au/n-GaAs Schottky Diode

	Control Au/n-GaAs	Thiol-Treated Au/n-GaAs
Barrier Height (I-V):	0.845eV	0.907eV
Barrier Height (C-V):	0.840eV	0.880eV
Ideality Factor:	1.028	1.023
Series Resistance:	11.0 ohms	22.9 ohms

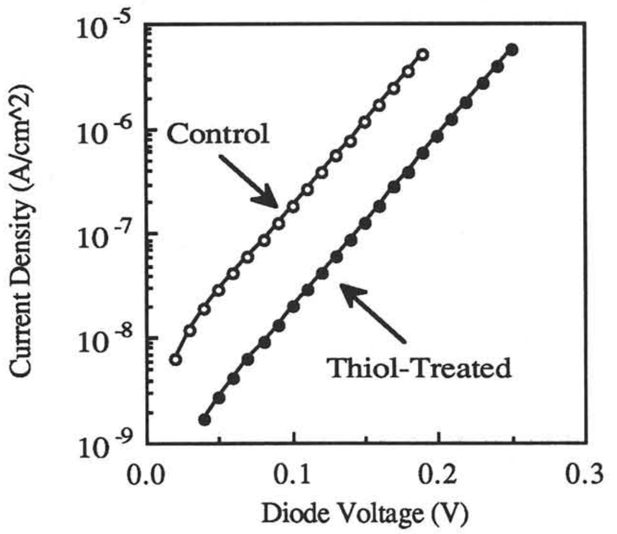

Fig.1 Current Density Vs. Voltage Characteristics of Thiol-Treated and Control Au/n-GaAs Schottky Diode

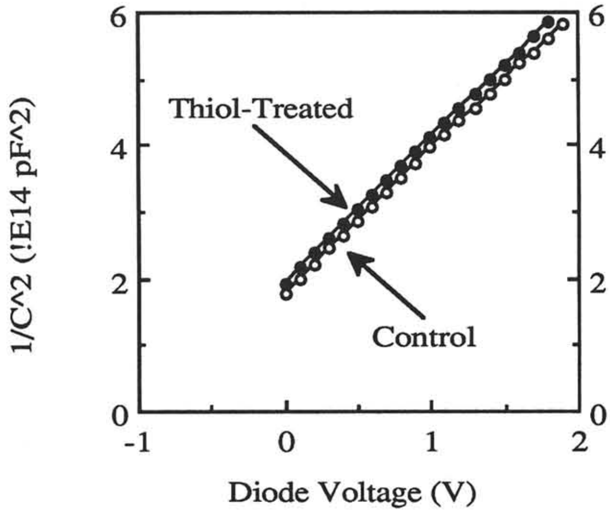

Fig. 2 Capacitance ($1/C^2$) Vs. Voltage Characteristics of Thiol-Treated and Control Au/n-GaAs Schottky Diode

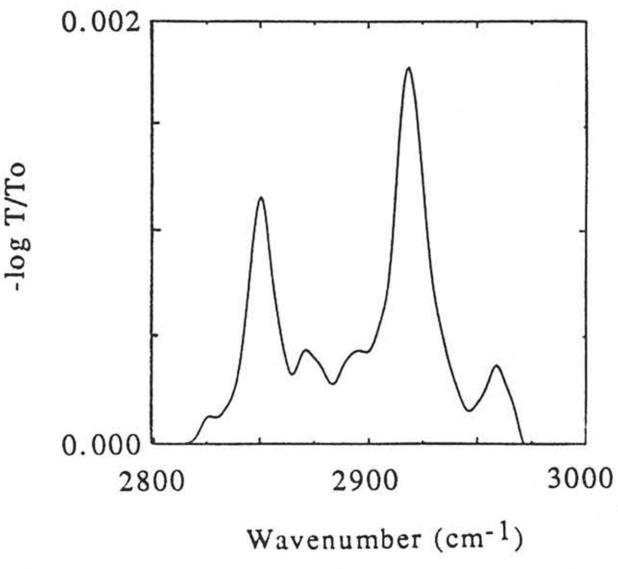

Fig. 3 Transmission IR Spectrum of CH Streching Region of Octadecyl Thiol on GaAs