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METAL-SEMICONDUCTOR FIELD-EFFECT TRANSISTORS FABRICATED USING DVT GROWN n-$MoSe_2$ CRYSTALS WITH Cu-SCHOTTKY GATES

***C.K. Sumesh*[1], *K.D. Patel*[2], *V.M. Pathak*[2], *R.Srivastava*[2]**

[1] Department of Physics, Charotar Institute of Technology,
Charusat, Changa, 388 420, Anand, India
E-mail: cksumesh.cv@ecchanga.ac.in

[2] Department of Physics, Sardar patel University,
V.V. Nagar, 388 120, Anand, India

Metal-semiconductor field-effect transistors (MESFETs) based on DVT grown $MoSe_2$ crystals and Cu Schottky gate have been fabricated and studied. When Schottky gate voltage (V_{gs}) changes from 0 to 10 V, the source-drain current (I_{ds}) increases exponentially with Vgs and the conductance shows a drastic increase with positive V_{gs}. The fabricated n-$MoSe_2$ MESFET have a saturated current level of about 100 mA and maximum transconductance of about 53 mA/V. Their results suggest a way of fabricating MESFETs from layered metal dichalcogenide semiconducting materials.

Keywords: $MoSe_2$, *MESFET, OHMIC CONTACT, SCHOTTKY CONTACT, I-V ANALYSIS.*

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1. INTRODUCTION

$MoSe_2$ - molybdenum dichalcogenide has provided extra incentive to device research due to its layered structure. The intra-layer bonding of $MoSe_2$ is predominantly covalent, while the interlayer bonding is of weak van der Waals type. Hence the crystals can be easily cleaved across the van der Waals gap. The resulting (001) basal plane contains a close-packed hexagonal array of chemically saturated chalcogenide ions. Thus, it does not contain dangling bonds with which adsorbates may react and hence can be considered to be free of surface states [1-3]. This chemical inertness of the basal plane of $MoSe_2$ makes it ideal for the fabrication of Schottky barrier devices, FETs, solar cell, etc. [4-7].

There have been many reports on the electrical and photoelectrical properties for the hexagonal $MoSe_2$ materials [1-15]. But, in contrast to other layered semiconductors, to our knowledge, no report could be found on devices like MESFETs and its analysis. In this wok, n-type $MoSe_2$ MESFETs were fabricated and the electrical characteristics were analyzed using I-V method.

2. EXPERIMENTAL

For present investigations direct vapor transport (DVT) grown crystals [8, 12-15,] of n-type $MoSe_2$ were selected as the material for fabricating the

MESFET structure. $MoSe_2$ crystals with flat shining surfaces, chosen with the help of optical microscope, were washed in acetone to remove contaminations and to make the surface clean. The cleaned crystals were mounted on the substrate holder inside the vacuum chamber for fabricating Schottky contacts. Copper has been selected as the gate material as it shows very good rectification behaviour with $MoSe_2$ [16]. Copper metal dots of area $2{,}62 \times 10^{-3}$ cm^2 were deposited using thermal evaporation technique. In order to get evaporated thin metal film deposited in confined areas on the crystal surface, crystals were masked with a thin metal sheet having appropriate circular holes. After reaching a vacuum level of ~10^{-6} torr, pure copper metal (3 kÅ) was evaporated from a W-helical boat onto the semiconductor surface. The rate of evaporation was kept very low i.e. 2 Å/sec in order to make the deposition uniform over the whole area. In addition, this gives good adhesion and other desirable properties in the fabricated Schottky diodes resulting basically from relatively slower growth mechanisms.

The front electrical contacts with evaporated copper regions were taken with low strain copper wires and Au paste (Eltec-1228C). The two ohmic contacts called source and drain (shown in figure1) were taken with indium metal ingot which was fused onto the same surface of $MoSe_2$ along with low strain thin Ag alloy wires (Lakeshore wire part No.671-260) with the help of a fine tip soldering iron [16].

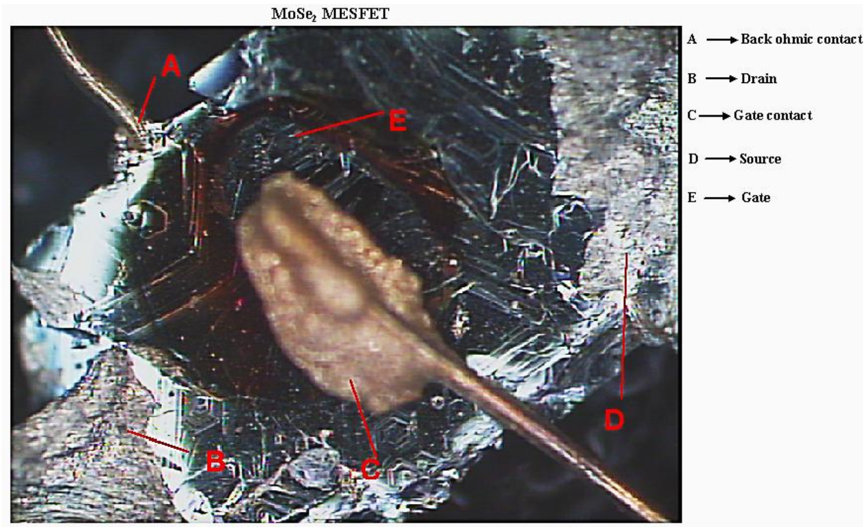

***Fig. 1** – A typical optical micrograph (20X) of $MoSe_2$ MESFET*

The whole assembly was fixed on a mica piece for support and utmost care was taken during the whole process to keep the prepared structure intact because $MoSe_2$ crystals are very much soft and brittle.

There are various methods for the determination of MESFET parameters. Amongst these current – voltage (I-V) analysis and capacitor – voltage (C-V) analysis are widely used methods. In the present investigations the current-voltage analysis method has been used and the I-V data were acquired using Keithley–Semiconductor Characterization System (SCS - 4200).

3. RESLTS AND DISCUSSION

The current-voltage characteristics of a n-type $MoSe_2$ layer in which electrons are carrying the current is important and has been shown in figure 2 as obtained between the source and drain. When a positive voltage V_{ds} is applied to the drain, electrons will flow from source to drain. Hence the source acts as the origin of carriers and the drain as a sink. As evident from figure 2, the semiconductor layer behaves like a linear resistor.

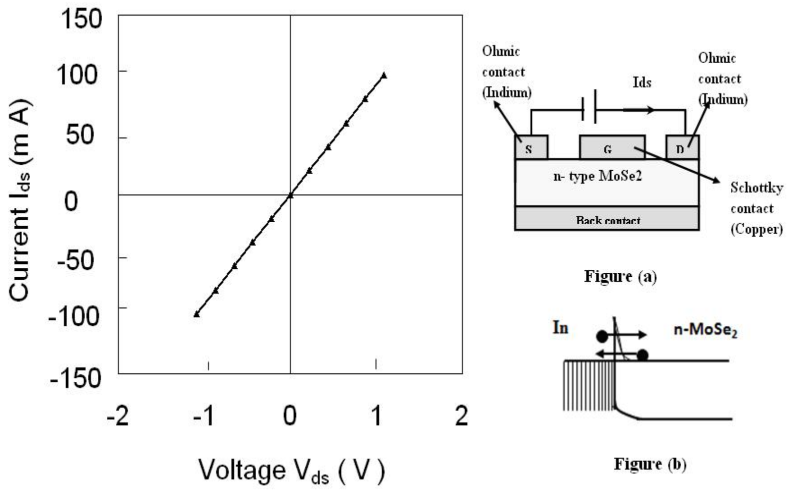

Fig. 2 *– Drain –Source I-V characteristics of n-type $MoSe_2$ MESFET. Inset figures (a) show the contacts to the n-type MoSe2 channel and (b)tunnelling of electrons across the In-n$MoSe_2$ Ohmic interface*

The gate contact in a MESFET device should be a Schottky barrier. Proper rectification of diode junctions within a MESFET structure is necessary for its electrical operation [17]. Figure 3 shows the I-V characteristics of the metal semiconductor Schottky junction formed by the Cu metal gate on the n-type $MoSe_2$ channel. It shows excellent rectification behavior, which indicates a good Schottky contact between copper and n-type $MoSe_2$ crystal. The inset figure shows the energy band diagram of n-type $MoSe_2$ and Cu. The high work function Cu metal forms a potential barrier for electrons.

The energy band bending produced by making copper Schottky barrier contact with the semiconductor creates a thin layer beneath the gate that is almost depleted of free charge carriers. As no free carriers exist in this depletion layer, no current can flow through it. The available cross-sectional area for flow of current between the source and drain is reduced by the existence of this depletion layer. As reverse bias is applied to the gate, the depletion layer penetrates deeper into the active channel. These reductions in cross-sectional area resulting in further current reduction. The gate bias, then, acts as a mechanism for limiting the maximum amount of source-drain current that can flow. When enough reverse bias is applied, the depletion region will extend across the entire active channel and allow essentially no additional current to flow.

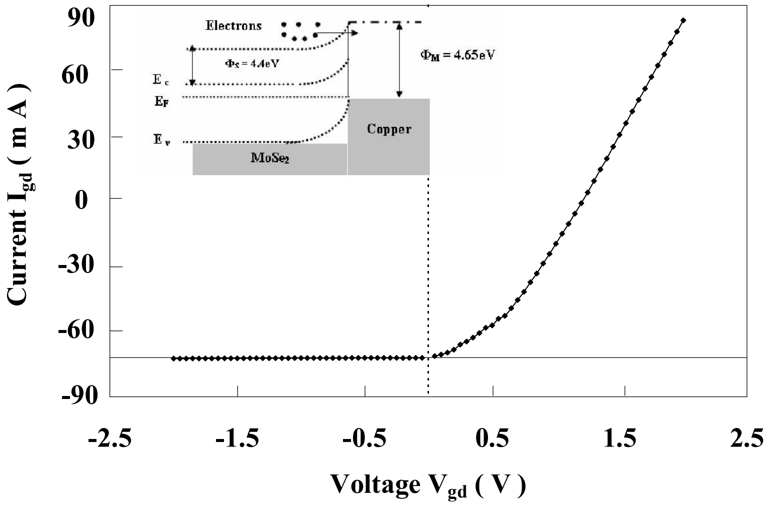

Fig. 3 *– I-V characteristics of the metal semiconductor Schottky junction formed by the copper gate on the n-type* $MoSe_2$ *channel. The inset figure is energy band diagram of n-type* $MoSe_2$ *and Cu*

In Fig. 4 the source-drain current (I_{ds}) is plotted as a function of applied drain source voltage (V_{ds}) for several different gate-source voltages (V_{gs}). The source electrode was grounded. We can see that the I_{ds} increases with V_{ds} for a given V_{gs}, and the conductance shows a drastic increase with positive V_{gs}. The device transconductance is defined as the slope of the I_{ds}-V_{gs} characteristics with the drain-source voltage held constant according to Eq. 1.

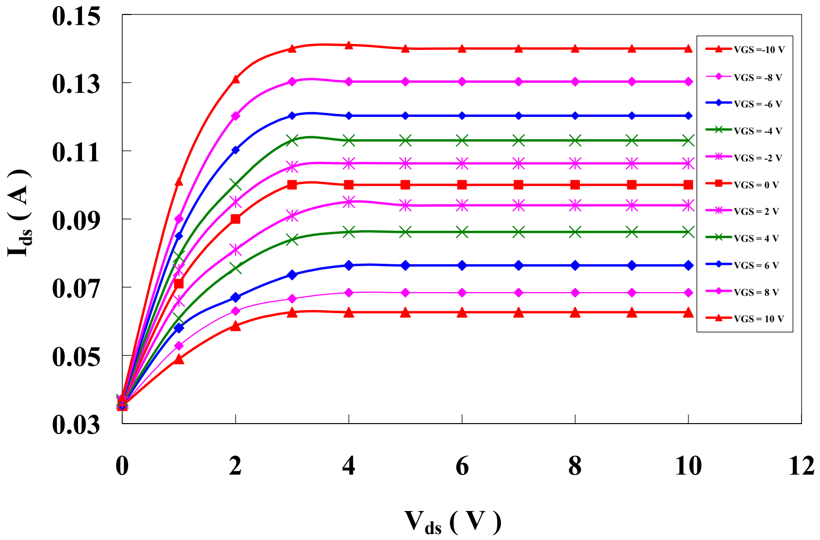

Fig. 4 *– Drain current as a function of drain-source voltage for different gate bias in the range* ± 10 *V for* n^- $MoSe_2$ *MESFET*

$$g_m = \left.\frac{dI_{ds}}{dV_{gs}}\right|_{V_{ds}=\text{constant}} \quad (1)$$

The maximum transconductance of about 53 mA/V and has been obtained at constant I_{ds} = 10 V. The saturated current level (saturated current level - I_{dss} is the drain source current at V_{gs} = 0) of the device was found to be I_{dss} = 100 mA. Thus it is seen that DVT grown n-$MoSe_2$ crystals show a good potential for flexible MESFET device development as basal plane layers of this crystals can behave as good conducting channel and copper contacts to it offers a good Schottky gate contact.

4. CONCLUSION

We have fabricated n-$MoSe_2$ MESFET based on DVT grown $MoSe_2$ crystals. A top copper Schottky contact was used as gate and indium ohmic contacts were used as source and drain. The MESFET's electrical behavior follows the established MESFET theory. The fabricated n-$MoSe_2$ MESFET have a saturated current level of about 100 mA and maximum transconductance of about 53 mA/V.

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