Passivation of InAs and GaSb with novel high κ dielectrics

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Motivation:

The research is conducted to understand the mechanism of surface Fermi level pinning/un-pinning in InAs and GaSb, and further effectively passivate them using the high κ dielectrics, well developed at National Tsing Hua University in Taiwan, to improve the device performance in mid-infrared InAs/GaSb superlattices.

Technical Milestones for 2010-2011:

1. ***High k dielectrics on InAs and GaSb***
    - ***I、 growth of high k dielectrics using molecular beam epitaxy (MBE) and atomic layer deposition (ALD)***
        - i. materials including MBE-Ga_2O_3 (Gd_2O_3) (amorphous) and Gd_2O_3 (single crystals), and ALD-Al_2O_3 and HfO_2
    - ***II、 growth of InAs and GaSb epi-layers using molecular beam epitaxy (MBE)***
        - i. un-doped epi-layers provided by Dr. Gail Brown's group in Air Force Research Laboratory (AFRL) for structural and interfacial chemical studies
        - ii. doped epi-layers grown in Taiwan mainly for electrical characterizations
2. ***Characterizations on hetero-structures of high k dielectrics on InAs and GaSb***
    - ***I、 structural studies using high-resolution x-ray reflectivity and x-ray diffraction, and high-resolution transmission electron microscopy (HR-TEM)***
        - ***i.*** to determine crystallographic structure, epitaxial relationship, strain field, structural defects, to image the microstructures and interfaces of high κ gate stacks upon subsequent thermal treatments
    - ***II、 interfacial chemical studies using in-situ/ex-situ x-ray photoelectron spectroscopy (XPS), and high-resolution XPS using synchrotron radiation***
        - ***i.*** to probe the chemistry (interfacial atomic bonding) in the hetero-structures, particular at the interfaces

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **05 JAN 2011**	2. REPORT TYPE **Final**	3. DATES COVERED **12-09-2009 to 11-09-2010**
4. TITLE AND SUBTITLE **Passivation of InAs and GaSb with Novel High κ Dielectrics**		5a. CONTRACT NUMBER **FA23860914163**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Minghwei Hong**		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **National Tsing Hua University,101, Section 2, Kuang Fu Rd,Hsinchu 30055,Taiwan,NA,NA**		8. PERFORMING ORGANIZATION REPORT NUMBER **N/A**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **AOARD, UNIT 45002, APO, AP, 96338-5002**		10. SPONSOR/MONITOR’S ACRONYM(S) **AOARD**
		11. SPONSOR/MONITOR’S REPORT NUMBER(S) **AOARD-094163**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This is the final report of a project to understand the mechanism of surface Fermi level pinning/unpinning in InAs and GaSb, and further effectively passivate them using high κ dielectrics.

15. SUBJECT TERMS

Indium Arsenide, Gallium antimonide, ALD-MBE Integration

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

III 、electrical studies using capacitance-voltage (C-V) and current density-field (J-E) measurements

3. ***correlation between electrical measurements and structural studies leading to the understanding of surface Fermi level pinning/unpinning***

The research findings derived from *state-of-the-art* characterizations will be vital to build the scientific knowledge foundation for developing future semiconductor technology. Extra efforts need to be taken to minimize and to eliminate the contamination of the high κ's during device processing.

Experimental:

The semiconductor epi-structures, shown in the following, were grown using molecular beam epitaxy (MBE), followed by the in-situ growth of Gd_2O_3 3 ML thick in ultra high vacuum (UHV) with electron beam evaporation and then by atomic layer deposited (ALD) Al_2O_3. The semiconductor epi-layers were grown on semi-insulating GaAs. Sb-based III-V materials were found to give a good smooth growth on GaAs, laying down foundation for the growth of InAs.

dielectric	**ALD-Al_2O_3**	**~14nm**
dielectric	**Gd_2O_3**	**~1nm**
Channel (2)	**InAs Be doping P-type $2e^{17}cm^{3}$**	**~1.3 nm**
Channel (1)	**InAs Be doping P-type $2e^{17}cm^{3}$**	**~5 nm**
Bottom barrier	**AlSb**	**12 nm**
Mesa stop layer	**$Al_{0.75}Ga_{0.25}Sb$**	**13 nm**
	Te-doping	
Mesa stop layer	**$Al_{0.75}Ga_{0.25}Sb$**	**1300 nm**
Buffer layer	**AlSb**	**200 nm**
SI GaAs substrate		

1.3 % lattice mismatch

Fully relaxed with 8% lattice mismatch

Note that the energy band gaps for InAs, AlSb, and $Al_{0.75}Ga_{0.25}Sb$ are 0.35, 1.7, and 1.5 eV, respectively. AlSb layers were used for the purpose of buffer (on GaAs) and barrier to confine the carriers for better device performances. The AlGaSb layers were used for the mesa etching stop. There is a 1.3% lattice mismatch between InAs and AlSb. For a strained-layer growth, InAs with a total thickness of 6.3 nm was epitaxially grown on AlSb. InAs was doped with Be, intending to be p-doping. However, it was found out later that the InAs was still an n-type, as confirmed with our XPS and MOSFET device work.

Results and Discussion

(I) XPS studies

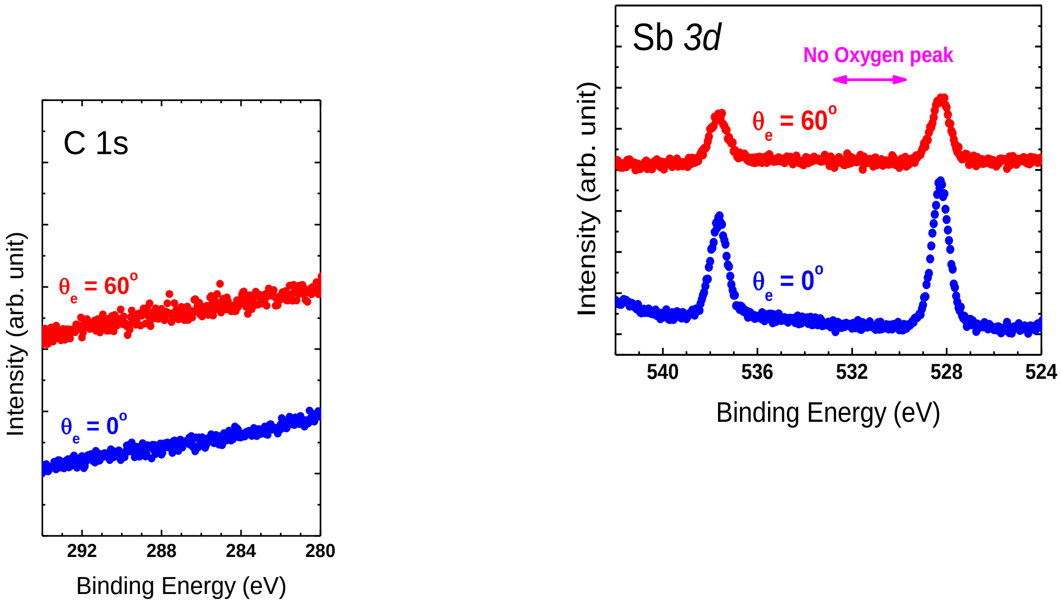
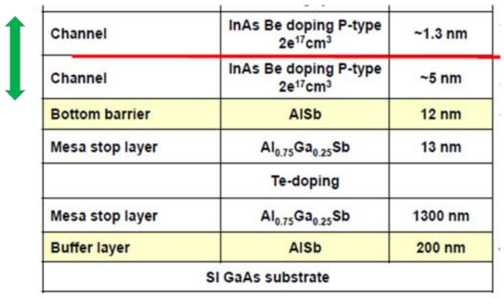


Fig. 1 C 1s and Sb 3d XPS spectra on freshly MBE grown InAs

No Carbon and Oxygen on the InAs surface



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Buffer layer	AlSb	200 nm
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Right after the MBE growth of InAs, the sample was in-situ moved to the XPS chamber for analysis. Using angle-resolved XPS (Fig. 1), no carbon and oxygen were found on the freshly MBE grown InAs surface, as expected. Moreover, we have also observed intermixing between InAs and AlSb as shown in Fig. 2.

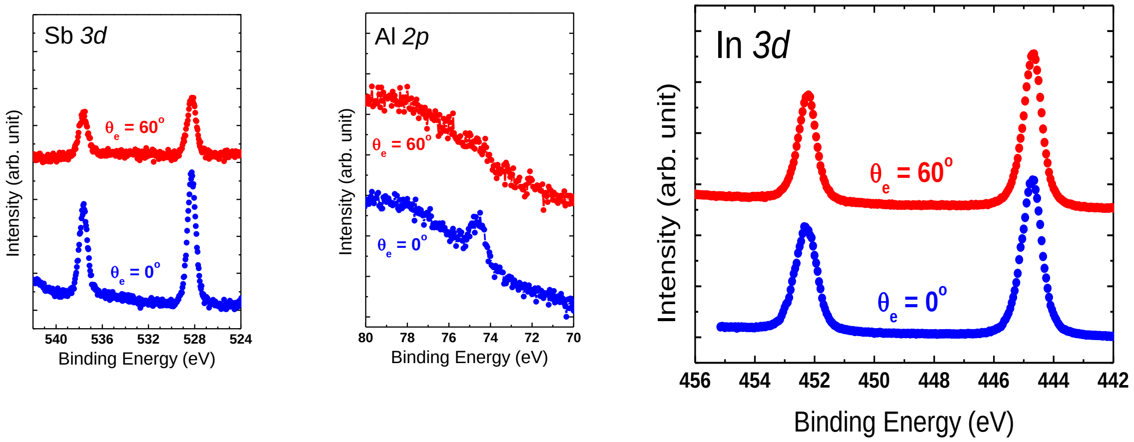
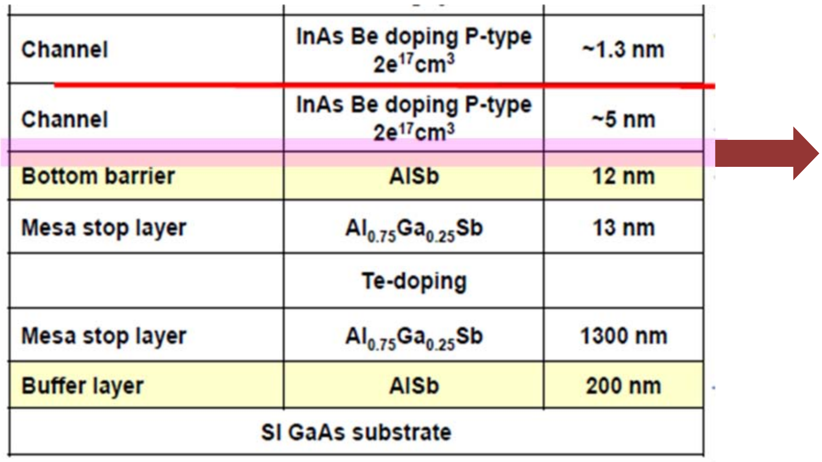


Fig. 2 Al 2p, In 3d, and Sb 3d XPS spectra on freshly MBE grown InAs



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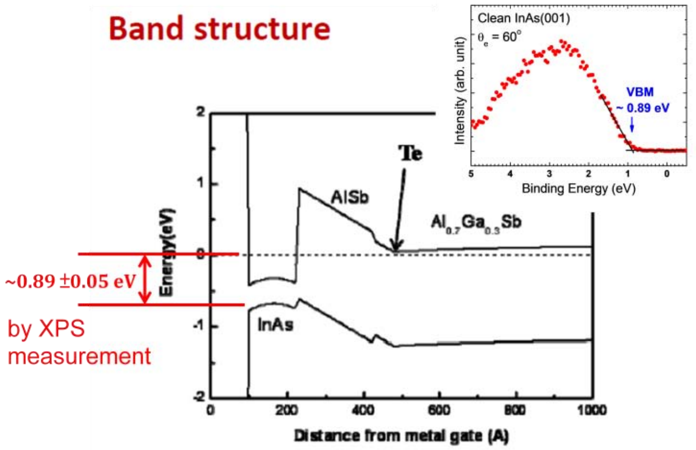
InAsSb intermixing layer



From NCU

Fig. 3 Band structure of InAs/AlSb/Te/$Al_{0.7}Ga_{0.3}Sb$ with the inset showing the measured valence band maximum (VBM) of 0.89 eV.

From the results shown in Fig. 3, InAs is an n-type doping, despite the doping with Be.

After the 3 ML growth of Gd_2O_3 on InAs, the sample was in-situ moved to the XPS for studying the interfacial chemistry.

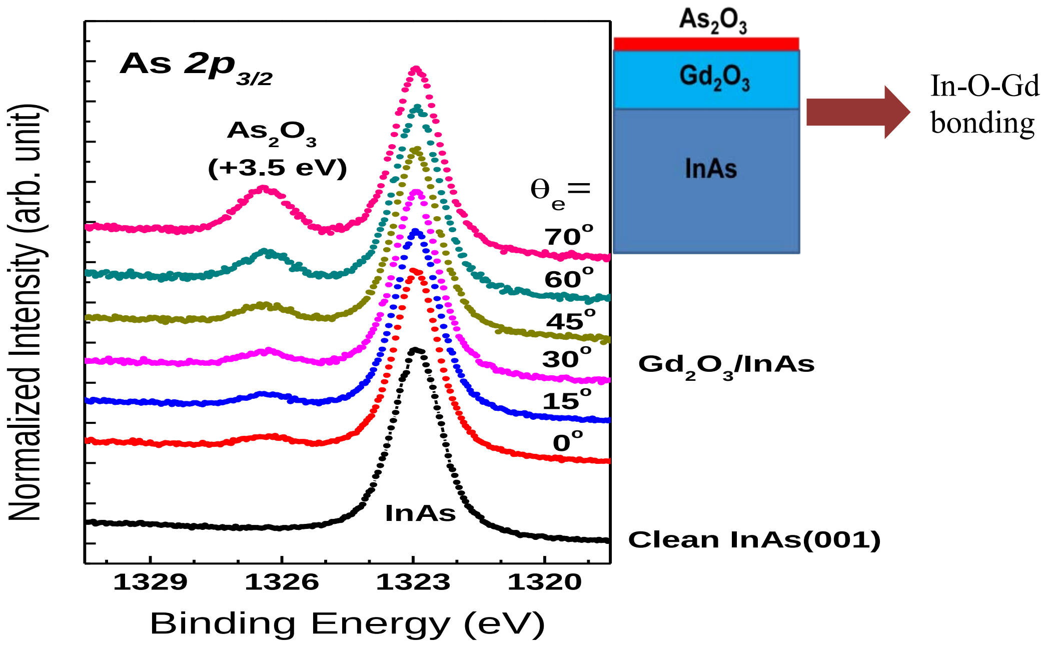


Fig. 4 As 2p spectra taken at different take-off angles.

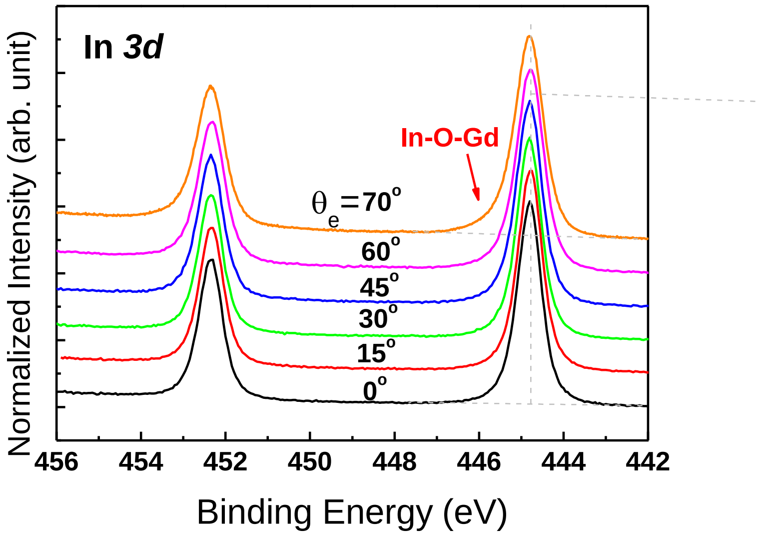


Fig. 5 In 3d spectra taken at different take-off angles.

From the results given in Figs. 4 and 5, deposition of 3 ML Gd_2O_3 on InAs gave formation of In-O-Gd bonding, with As forming As_2O_3, which diffused to the top of Gd_2O_3. $As_2O_3$was then removed with the self-cleaning ALD-Al_2O_3 deposition, as evidenced from the As 3d spectrum as shown in Fig. 6.

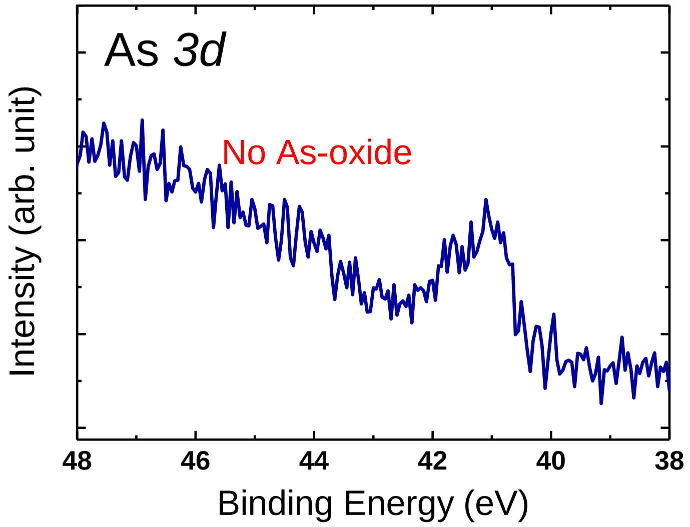
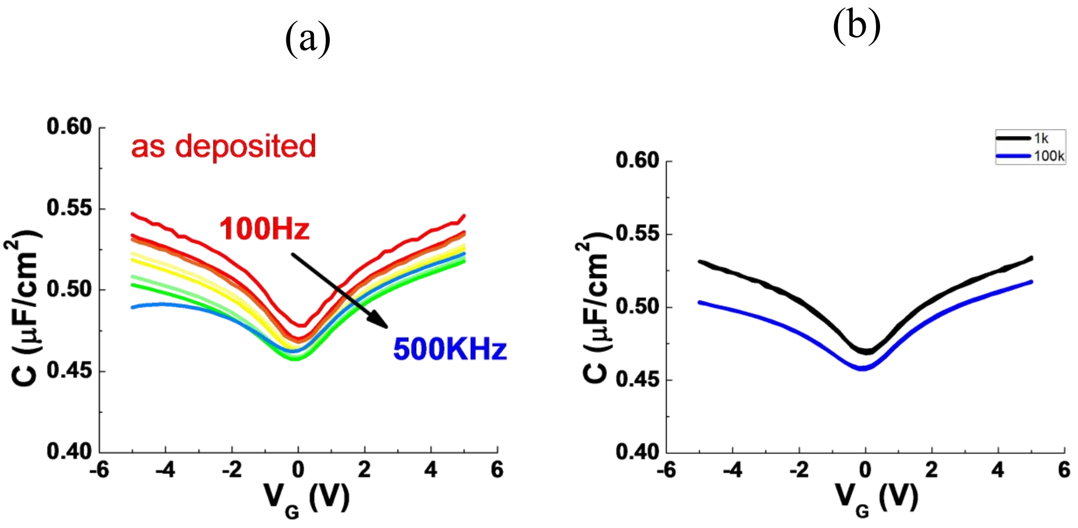


Fig. 6 As 3d spectrum on ALD-Al_2O_3 deposited on freshly MBE grown Gd_2O_3, which was grown InAs.

(II) Electrical properties of high κ Al_2O_3/Gd_2O_3/InAs MOS and MOSFET



(c)

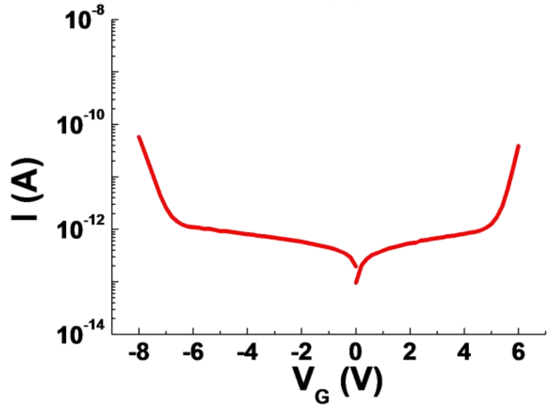


Fig 7 (a) Capacitance-voltage (C-V) characteristics, (b) C-V hysteresis at 1k Hz and 100k Hz, (c) gate leakage current for ALD-Al_2O_3/Gd_2O_3/p-InAs MOSCAP with area=7.85x10^{-5} cm^2

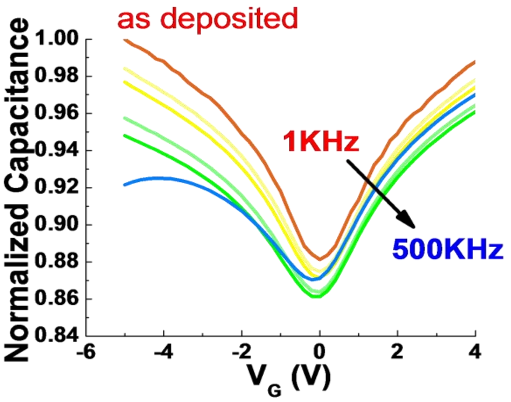
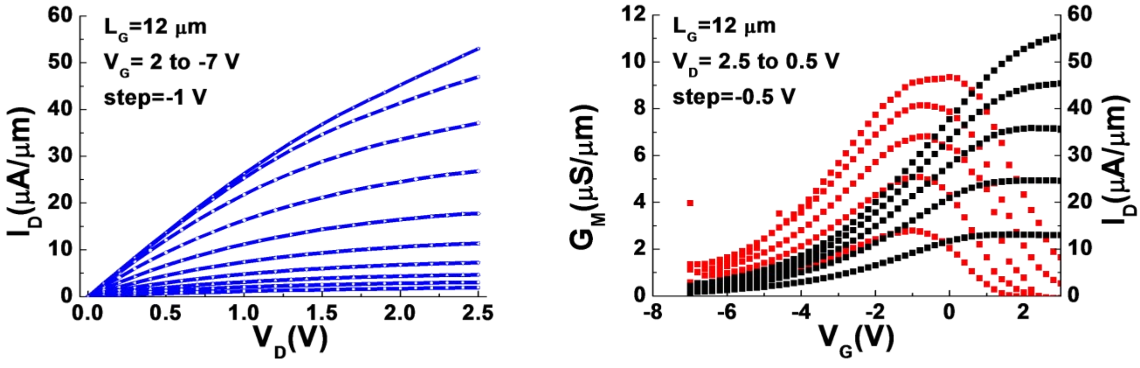


Fig. 8 Normalized Capacitance-voltage (C-V) characteristics for ALD-Al_2O_3/Gd_2O_3/p-InAs MOSCAP with area=7.85x10^{-5} cm^2



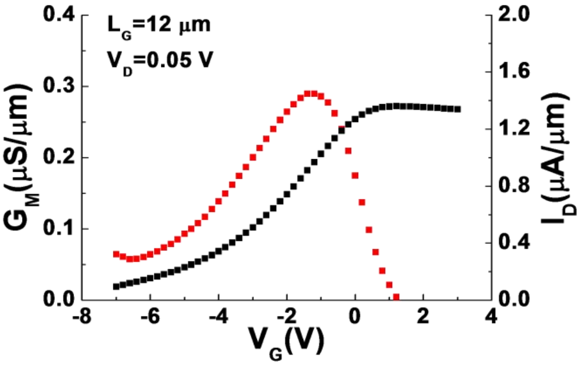


Fig. 9 (a) Output characteristics I_D *vs* V_D *and* (b) the transfer characteristics and transconductance G_M *curve of a depletion-mode* InAs MOSFET with 12μm gate length.