Nano-HEMTs Fabricated by utilizing Ne-based Atomic Layer Etching

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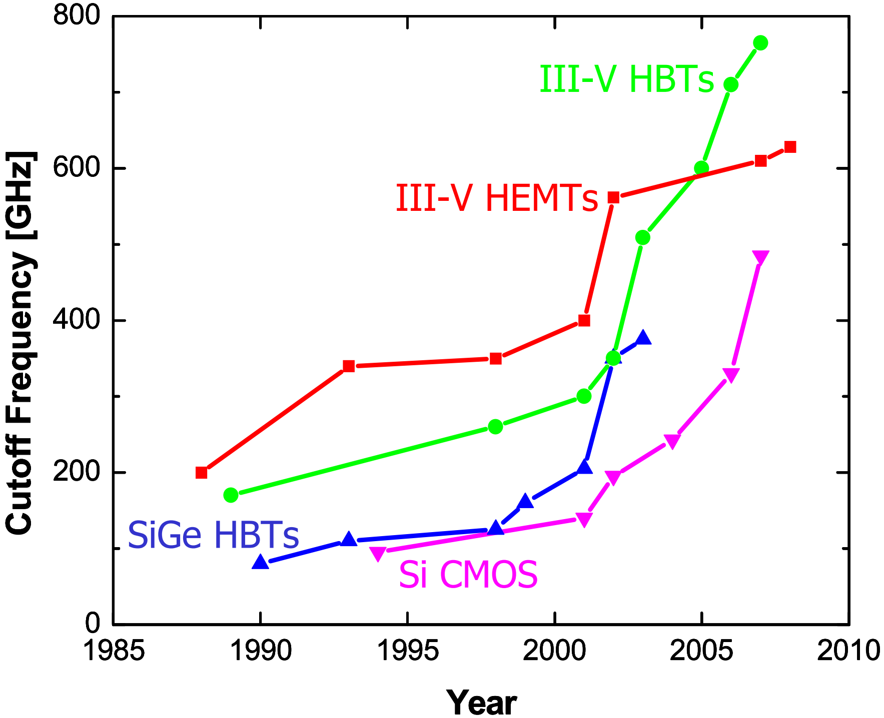
MICROWAVE-OPTOELECTRONIC INTEGRATED DEVICE AND SYSTEM MIDAS

Outline

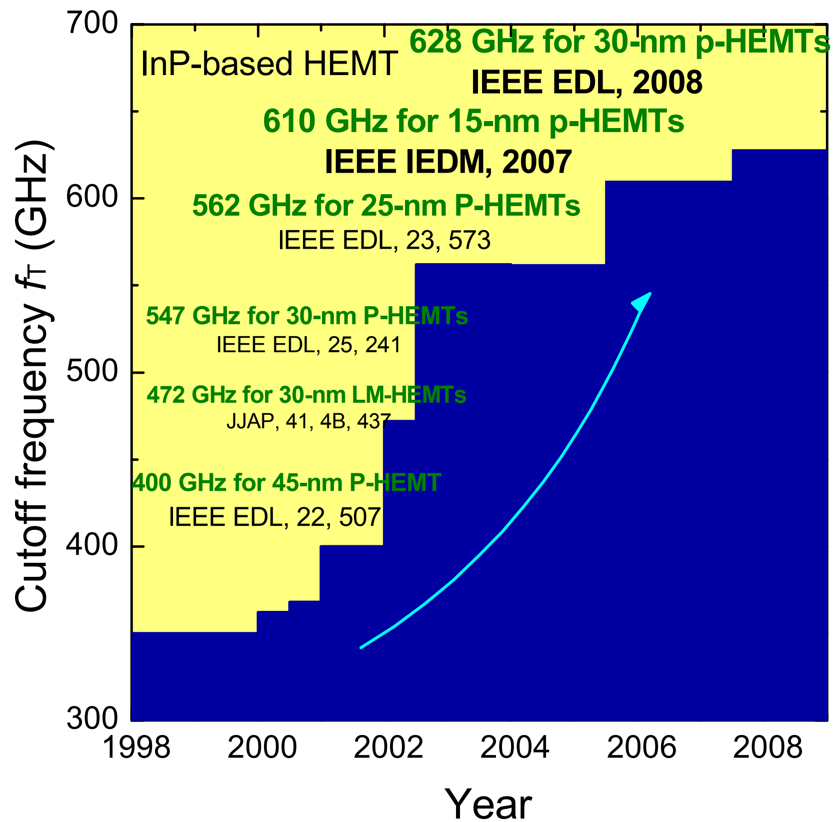
- Introduction
  1. High speed electronic devices
  2. Key fabrication processes for Nano-HEMTs
  3. Two step recess technology employing atomic layer etching
- Atomic Layer Etching
  - ✓ Properties of the etched surface (Selectivity, XPS, and AFM)
  - ✓ Characteristics of Vertical Schottky Diodes
- DC and RF Characteristics of Nano-HEMTs
  - ✓ Depletion-mode InAs Composite Channel p-HEMTs
  - ✓ Enhancement-mode InAs Composite Channel p-HEMTs
- Conclusions

Overview of Ultra-fast Electronic Devices

State of the Art
Electronic Devices



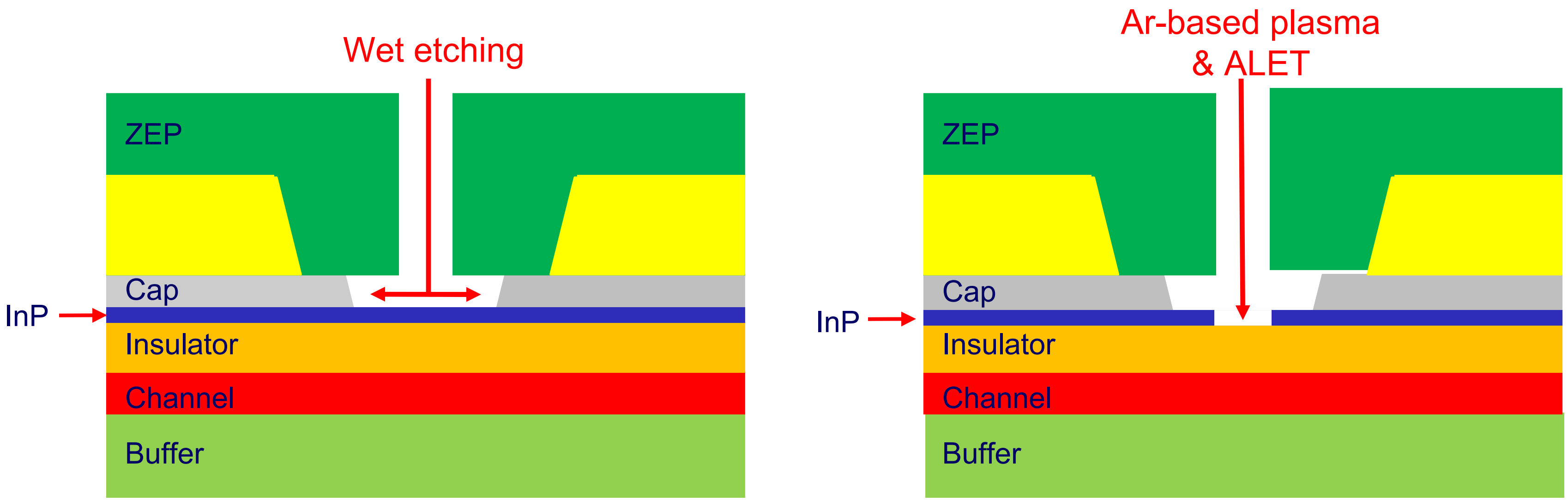
Record High f_T of III-V HEMTs



< Ref. : Shinohara *et al.* (IPRM 2004) >

Gate Recess: Critical Process for Nano-HEMT

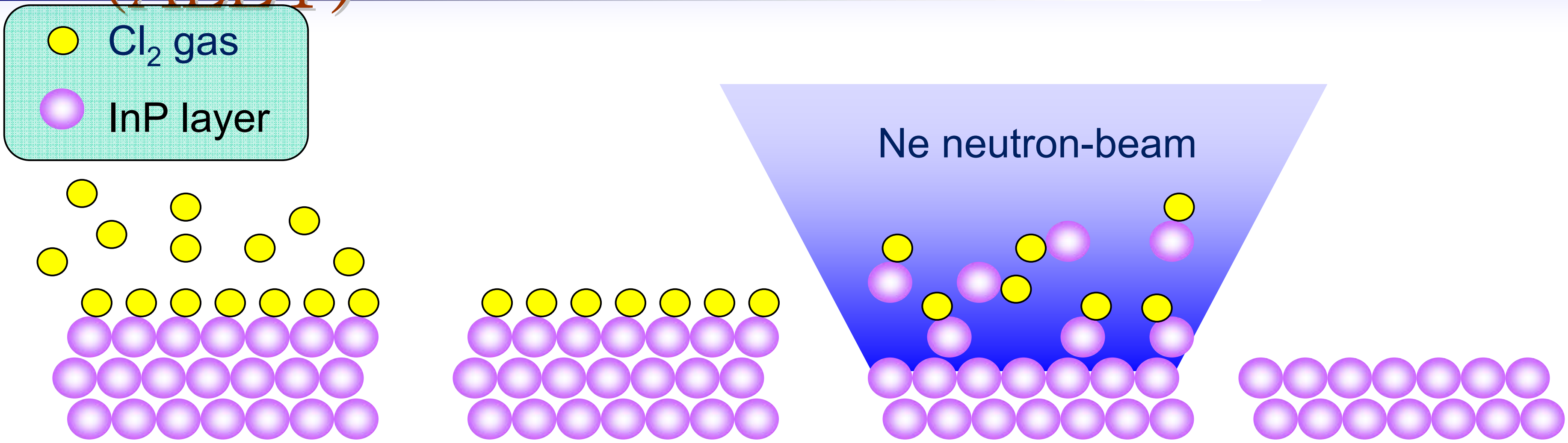
- Two-step recess for HEMT fabrication
  - 1st step: wet etch → n^+ InGaAs/InAlAs multi-layer cap removal
  - 2nd step: dry etch → InP etch stop layer removal:
    - Ar-based RIE (Conventional)
    - or Ne-based atomic layer etching (ALET)



<Ref: Suemitsu et al. (IEDM 98)>

- Problems of Conventional Ar-based RIE
  - Low etch selectivity
  - Electrical & physical damage: ← Ion bombardment

Atomic Layer Etching Technique (ALET)

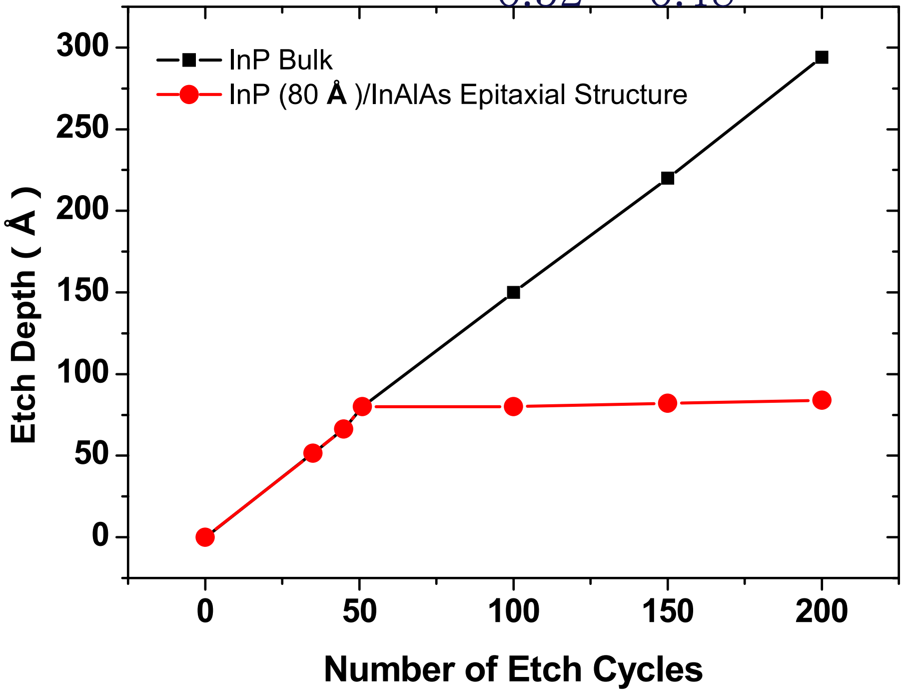


Reactant Feed	Reactant Purge	Beam Irradiation	Product Purge
Reactant molecules adsorb onto a substrate surface. The etchant does not spontaneously etch the substrate.	**Excess reactant is purged**	**An energetic beam irradiates the surface, and surface atoms bonded with reactant are etched off owing to beam-induced chemical etching.**	**Etching products are purged after which one cycle of digital etching is completed**

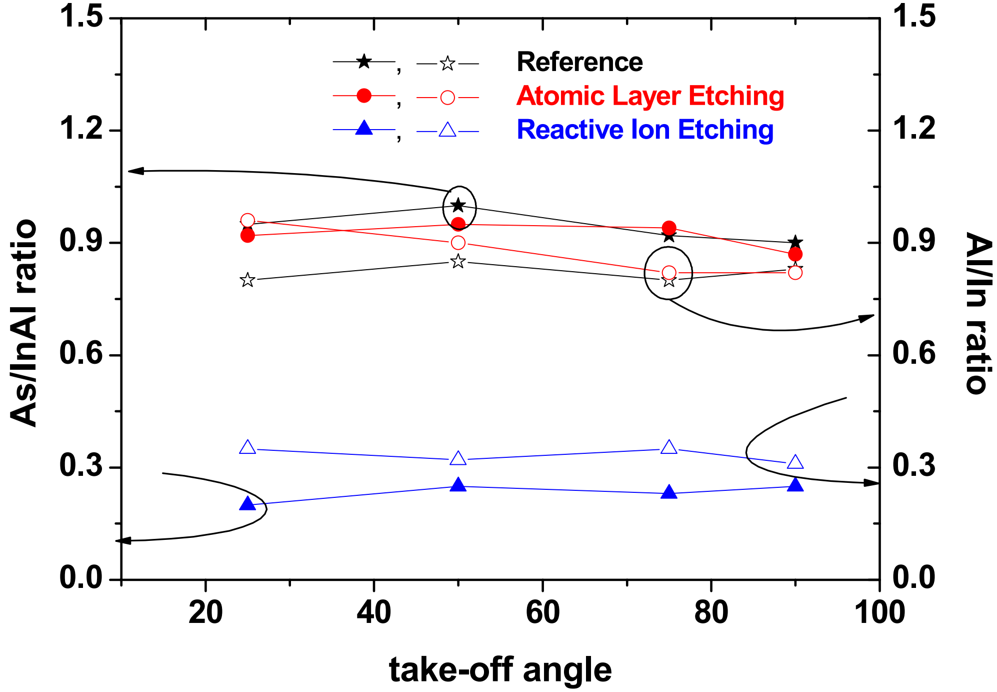
- The expected advantages of Ne-based ALET over Ar-based RIE
  - The higher etch selectivity (ALET)
  - The lower electrical & physical damage ← Low energy neutral beam

Etching Property of ALET

Selectivity of InP over $In_{0.52}Al_{0.48}As$



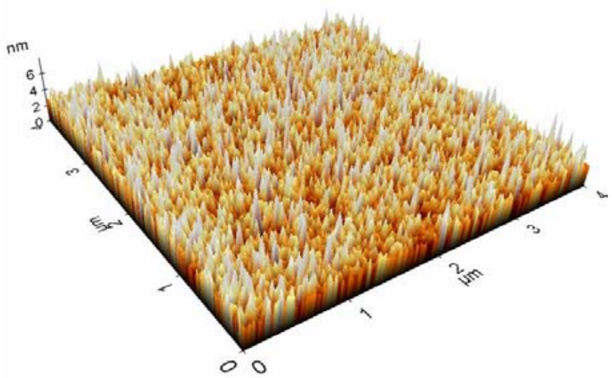
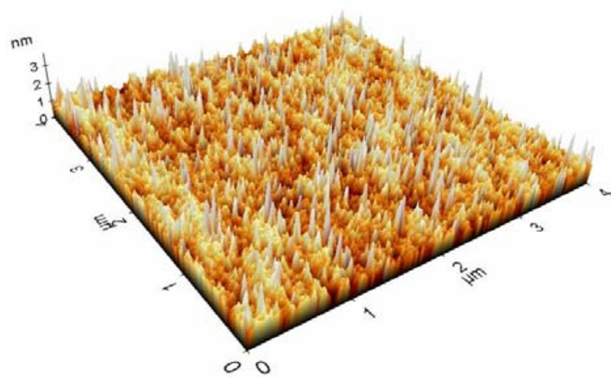
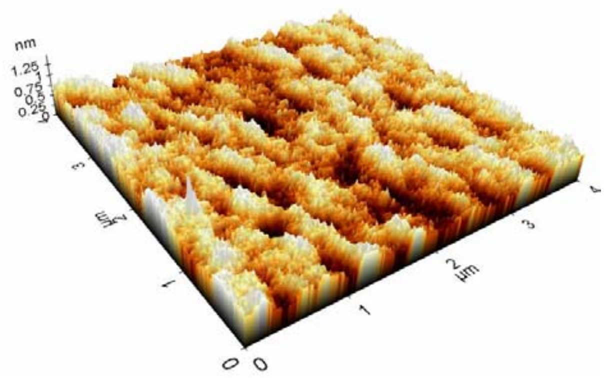
Composition of $In_{0.52}Al_{0.48}As$ surface



- Very high selectivity of InP over InAlAs (~70)
  cf) Ar-based RIE (~20)
- Minimal surface modification

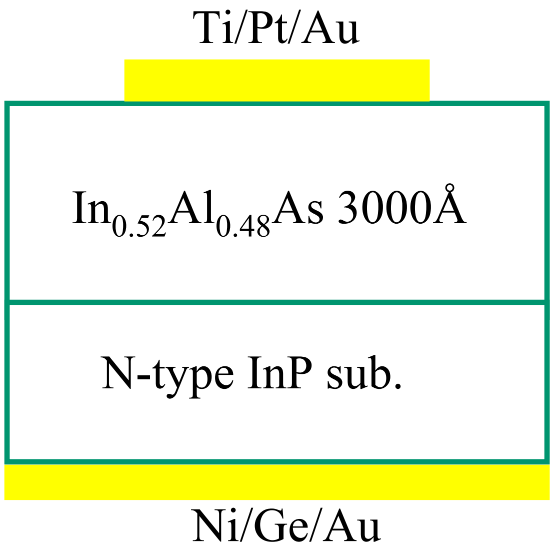
Surface Roughness

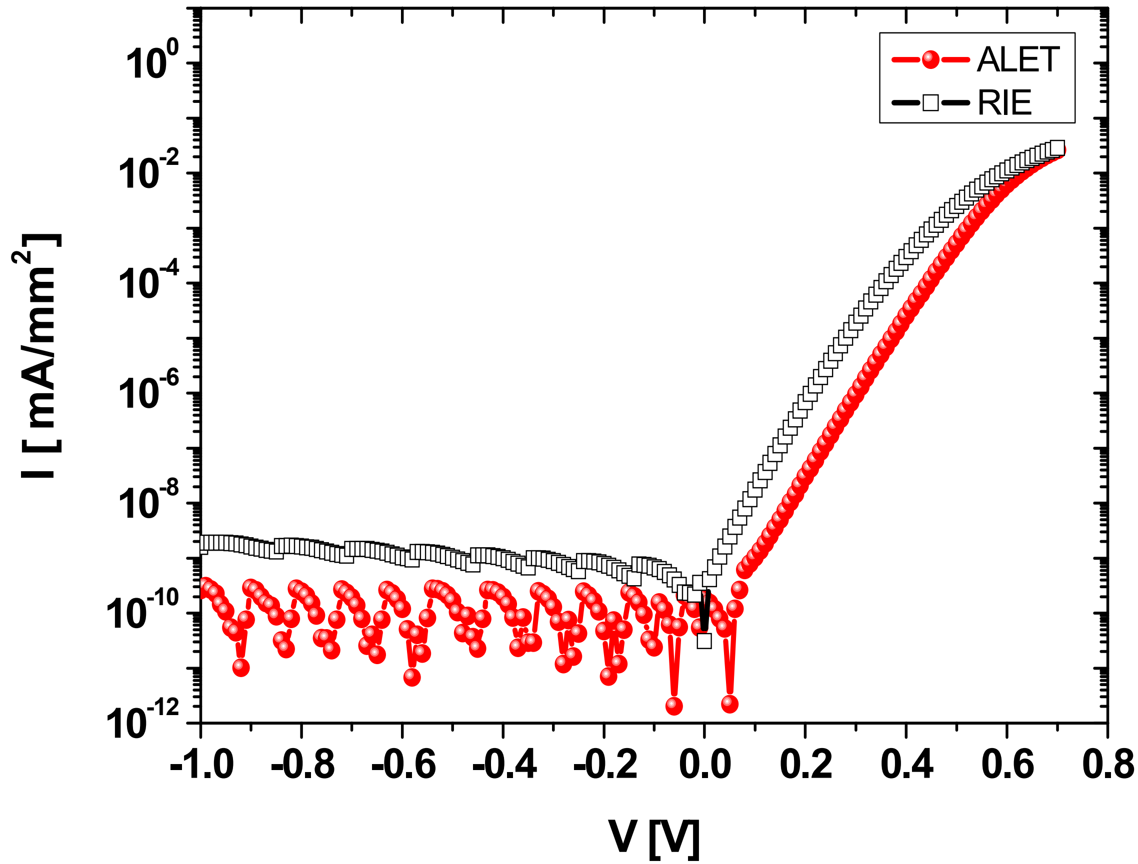
AFM image

Wet etching	RIE	ALET
		
7.77 Å	2.97 Å	1.37 Å

The smallest rms roughness achieved by ALET process

Vertical Schottky Diode

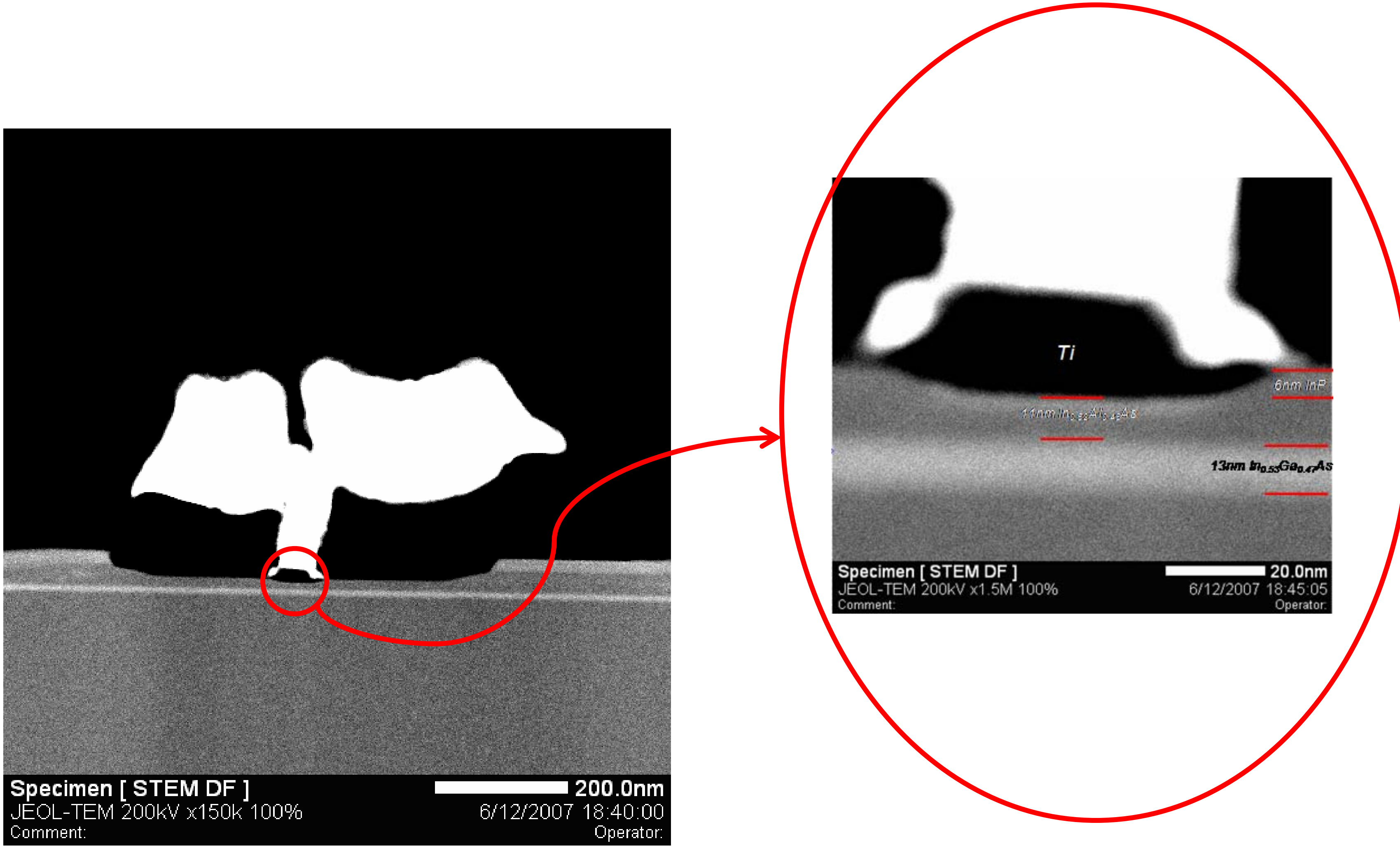




RIE: $\Phi_B = 0.56$ eV, $\eta = 1.25$

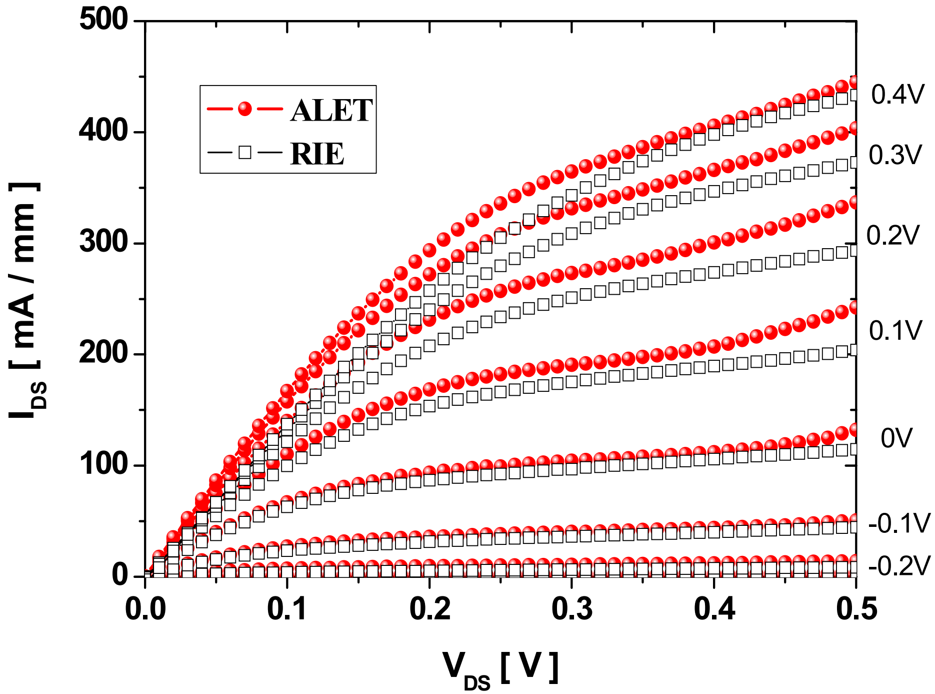
➔ ALET: $\Phi_B = 0.64$ eV, $\eta = 1.17$

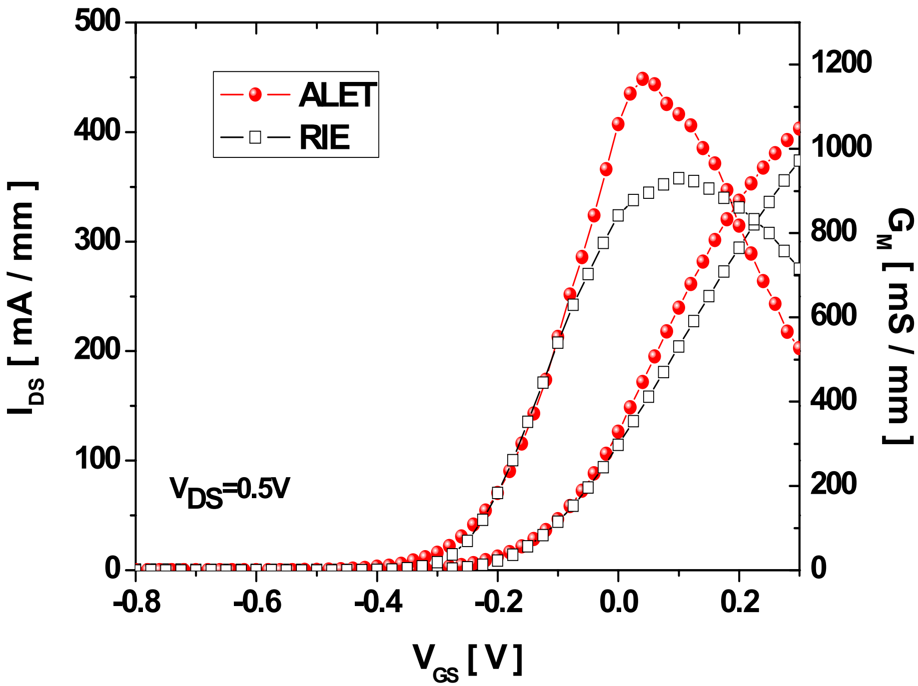
The Fabricated Devices



60-nm Depletion-Mode p-HEMTs

DC Characteristics



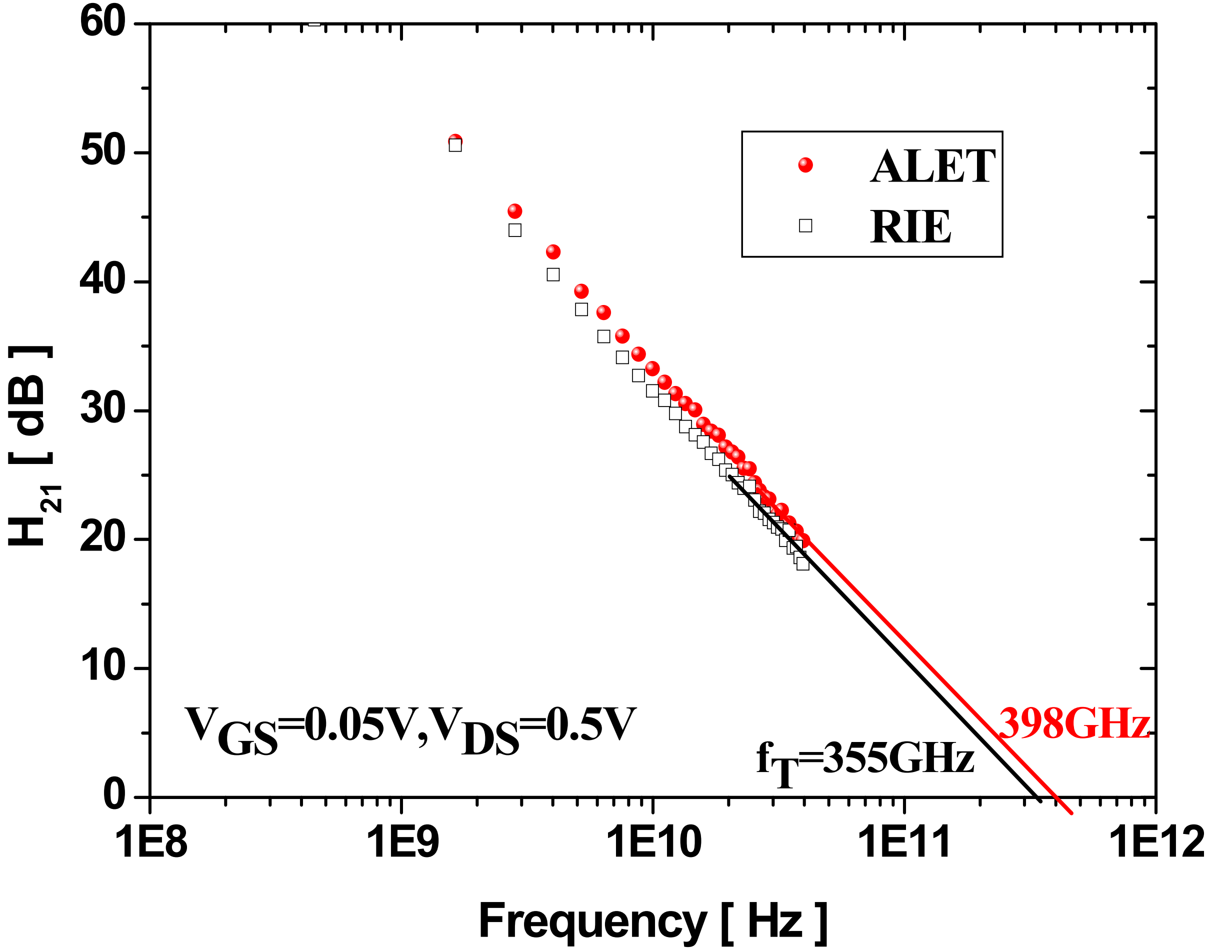


•$G_{M,Max}$ of the p-HEMTs fabricated by the ALET process was larger than that of the p-HEMT fabricated by the Ar-based RIE by 21%

→much lower plasma-induced damage characteristics of the ALET process

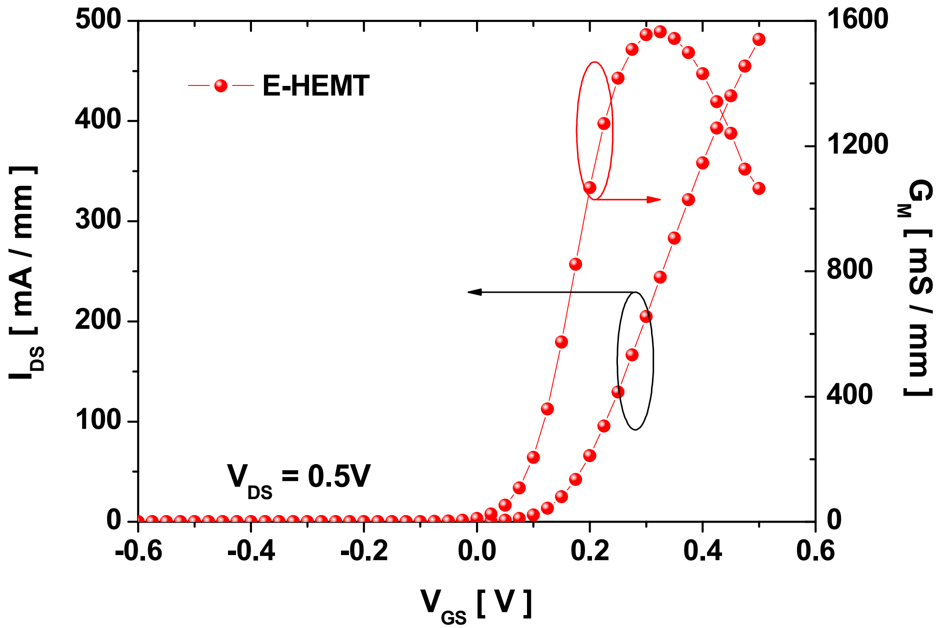
60-nm Depletion-Mode HEMTs

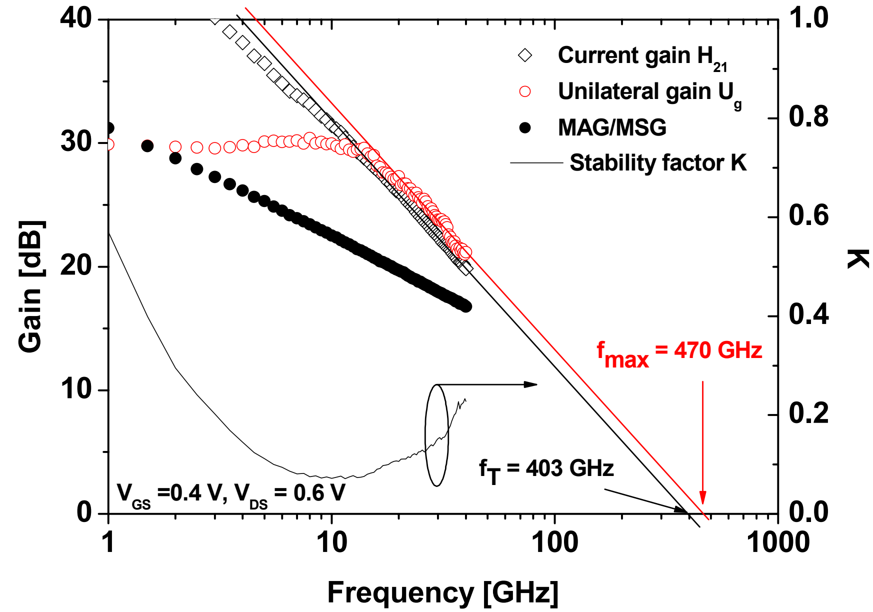
RF Characteristics



Enhancement-mode HEMT (E-HEMTs)

- E-HEMTs were fabricated by utilizing buried-Pt gate
  - Gate metal stack: Pt(6 nm)/Ti/Pt/Au
  - Post-annealing was carried out to drive Pt into InAlAs





•V_T = 0.07 V

•ALET: $g_{M,max}$ = 1.38 S/mm

•RIE: $g_{M,max}$ = 1.1 S/mm

•F_T of 403 GHz

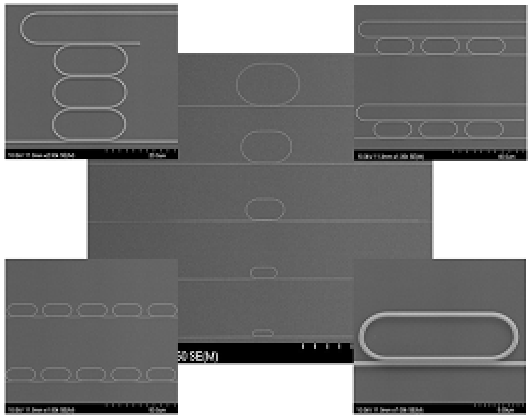
•Higher f_T than D-HEMTs

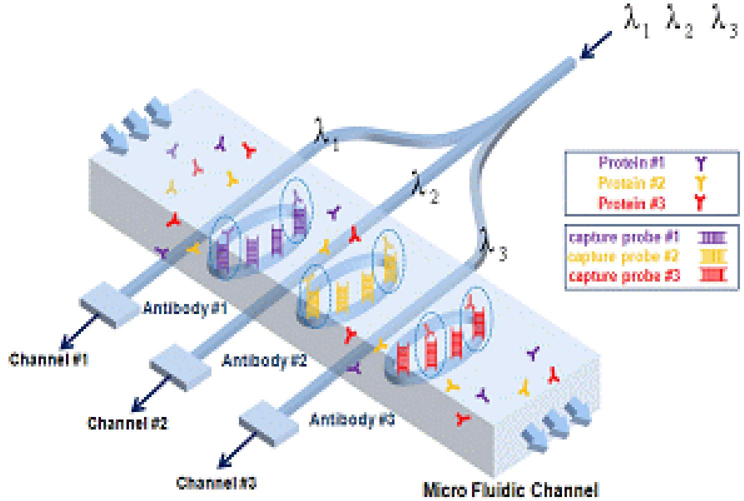
Conclusions

- The effect of ALET in the two-step gate recess process
  - Higher InP etch selectivity against the underlying $In_{0.52}Al_{0.48}As$ barrier layer
    → Better uniformity of device characteristics
  - ✓Less plasma-induced damage compared to conventional Ar-based RIE process
  - ✓The smoother etched surface
    → Better gate diode characteristics
      The higher transconductance
      The lower subthreshold slope
- Buried Pt gate
  - The thinner effective Schottky layer thickness
    → Alleviation of short channel effect
    → Better gate modulation characteristics
  - The higher Schottky barrier height due to the annealed Pt
    → Positive shift of threshold voltage
    → The smaller gate leakage current

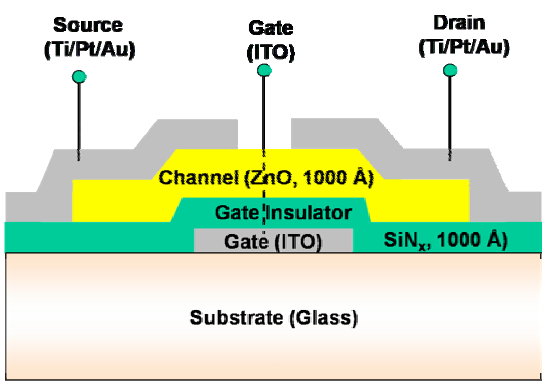
Other Interesting Stuffs !!!

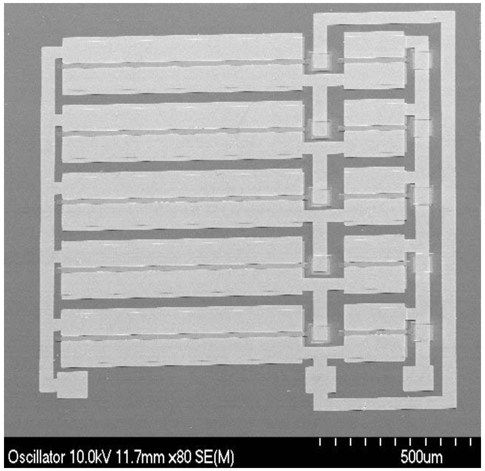
- Ring resonator based Optical Filters and Biosensors



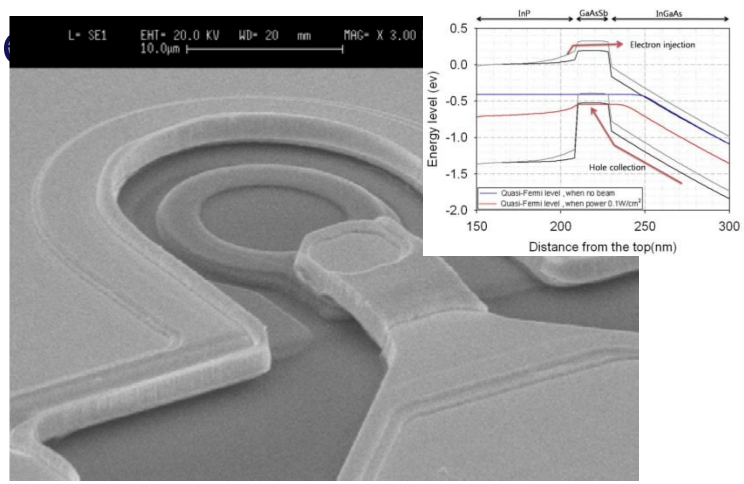


- Oxide Thin Film Transistors





- Single Photon De



Thank You!!

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