Flicker Noise Characterization and Modeling of Homo and Hetero-Junction III-V Tunnel FETs

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Introduction:$GaAs_{y}Sb_{1-y}/In_{0x}Ga_{1-x}As$ based III-V staggered hetero-junction Tunnel Field Effect Transistors were demonstrated with MOSFET-like high drive currents at low Vds [1], demonstrating feasibility of TFETs to scale supply voltage for future low power logic applications. More than 2x enhancement in Ion was demonstrated over the $In_{0.7}Ga_{0.3}As$ homo-junction counterpart due to reduction in the effective tunneling barrier (Eb_{eff}) at the hetero-interface. In this work, we characterize the flicker noise performance of $In_{0.7}Ga_{0.3}As$ homojuntion and $GaAs_{0.35}Sb_{0.65}/In_{0.7}Ga_{0.3}As$ heterojunction TFETs to quantify the impact of heterointerface on flicker noise - which is an important figure-of-merit for analog and RF applications. We show that heterojunction TFETs exhibit lower flicker noise levels along with higher drive currents. Finally, a number fluctuation based analytical model is developed to model the flicker noise characteristics of both Homo and Hetero-Junction Tunnel FETs.

Device Characterization and Modeling: Fig. 1 shows the schematic of the fabricated tunnel FET devices. The $In_{0.7}Ga_{0.3}As$ homojunction TFET with Eb_{eff} of 0.58eV and $GaAs_{0.35}Sb_{0.65}/In_{0.7}Ga_{0.3}As$ heterojunction TFET with Eb_{eff} of 0.25eV were fabricated (Fig. 2) using the process flow described in [2]. Temperature dependent transfer characteristics measurements from T=77K to T=300K at Vds=500mV confirm that both band to band tunneling (BTBT) and trap assisted tunneling and emission (TAT)[3] affect the transport in both the homojunction and heterojunction TFETs. At 300K, both BTBT and TAT dominate the transfer characteristics, while at 77K, only BTBT determines the transfer characteristics (Figs. 3,4).A dynamic non-local band to band tunneling (BTBT) model [4] was used to model the measured transfer characteristics at T=77K. Table I lists the parameters used to model the measured transfer characteristics. The non-local model uses the A and B parameters to extract the effective tunnel barrier height (Eb_{eff}) and the reduced tunneling effective mass, mr* to calculate the non-local band-to-band tunneling (BTBT) current. Flicker noise measurements were done on TFETs with pillar width =10um, channel length=150nm and pillar thickness=150nm at T=77K, 300K and at a constant drain bias of 500mV. At T=300K, where both BTBT and trap assisted tunneling (TAT) affect transfer characteristics, homojunction and heterojunction TFETs exhibit comparable drain current normalized noise levels (Fig. 7). At T=77K, where only band-to-band tunneling (BTBT) dominates, the normalized drain current, heterojunction TFET exhibits much lower flicker noise than homojunction TFET for a given drain current (Fig. 8). Since the current generation at T=77K is limited by BTBT at the junction, a number fluctuation based model is employed to explain the measured characteristics. Since BTBT is independent of channel length we define an effective channel length L' [5] based on the spread of the band-to-band generated carriers in the channel which is much smaller than the channel length. Fig. 9(a) shows the band to band generation rate of electrons and holes extracted from the dynamic non-local 2D numerical simulation of the TFETs. For a given drain current, L' is smaller in homojunction and larger for heterojunction TFET due to lower electric field (Fig. 9(b)-(c)) arising from lower Eb_{eff}. Electrons in the effective channel region with energy around the channel electron quasi-fermi level gets trapped and detrapped into the traps in the oxide (Fig. 10). Fluctuations in the trapped charge lead to fluctuation in the junction electric field which, inturn, affects the band-to-band generation rate. The frequency spectrum of the drain current fluctuation takes the form of 1/f due to the superposition of individual trapping events into states that extend into the gate dielectric occurring in the time domain.(Fig. 10).Table II lists the set of equations used to model the TFET flicker noise characteristics. The normalized drain current noise is found to depend on the electric field, L' and B parameter. For heterojunction at a given drain current, though the electric field is smaller, smaller value of B parameter and larger L' results in lower flicker noise level. Assuming $N_{it}=1x10^{13}$ cm^{-2} the measured characteristics are in excellent agreement with the analytical model (Fig. 11).

Conclusions: Temperature dependent transfer characteristics measurement confirm that the current in heterojunction TFET is limited by band-to-band tunneling at Vds=500mV. Heterojunction TFETs exhibit lower noise compared to homojunction TFET at 77K where current generation is dominated by band-to-band tunneling. However, at 300K however heterojunction TFETs have comparable noise performance due to the strong presence of trap assisted tunneling (Nit~10^{13} cm^{-2}). Number fluctuation based model was developed to explain the flicker noise advantage of heterojunction TFETs over homojunction TFETs. Heterojunction TFETs not only provide higher drive currents but also exhibit lower flicker noise levels and hence can be a suitable candidate for low Vcc RF applications.

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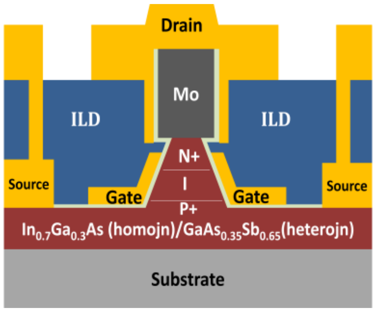

Fig 1.Schematic of the the fabricated vertical tunnel FETs [2].

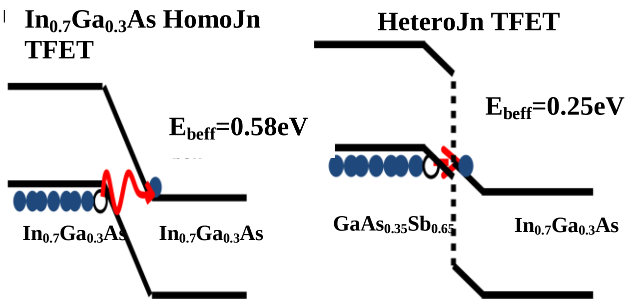

Fig 2. Eb_{eff} reduces from 0.58eV to 0.25eV as the source material is changed from $In_{0.7}Ga_{0.3}As$ to $GaAs_{0.35}Sb_{0.65}$.

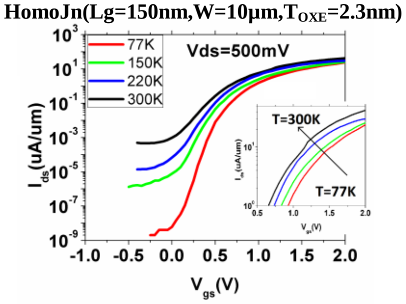

Fig 3.Temperature dependent transfer characteristics of homojunction TFET.

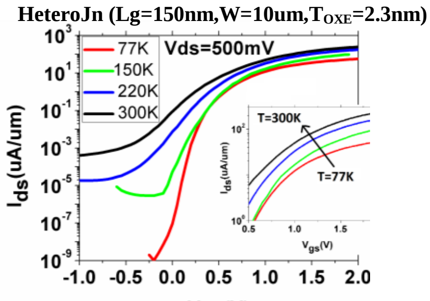

Fig 4.Temperature dependent transfer characteristics of heterojunction TFET.

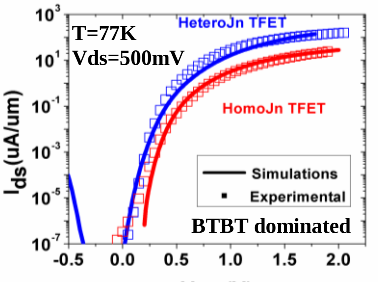

Fig 5. Transfer characteristics modeled with simulations at 77K.

Dynamic non-local band-to-band generation model [4]

Parameter	**HomoJn TFET**	**HeteroJn TFET**
T_{OXE}(nm)	2.3	2.3
Source Doping(cm^{-3})	$5x10^{19}$	$5x10^{19}$
m_r	$0.019m_0$	$0.022m_0$
E_{beff} (eV)	0.64	0.31

Table I. Simulation parameters used to model the measured transfer characteristics at 77K.

TFET FLICKER-NOISE MEASUREMENTS

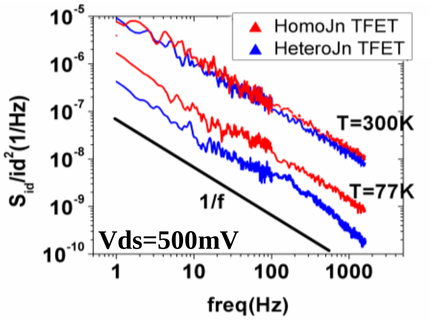

Fig 6. Normalized drain current noise spectrum at Ids= 2uA/um follows 1/f trend.

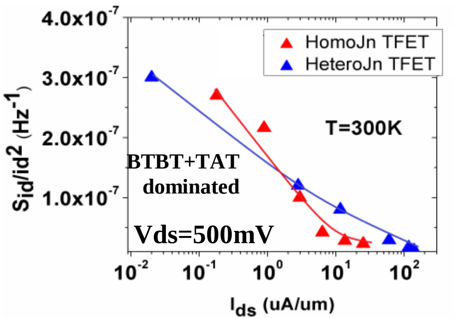

Fig 7.At T=300K, noise levels are comparable between homojn and heterojn.

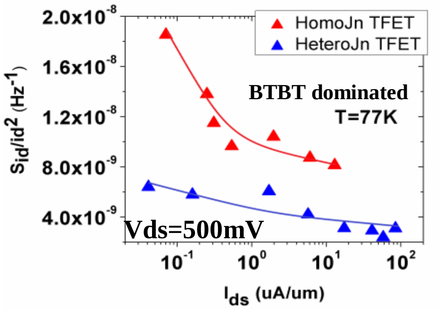

Fig 8. At T=77K, heterojn TFET exhibits lower noise at a given drain current.

TFET FLICKER NOISE - ANALYTICAL MODELING

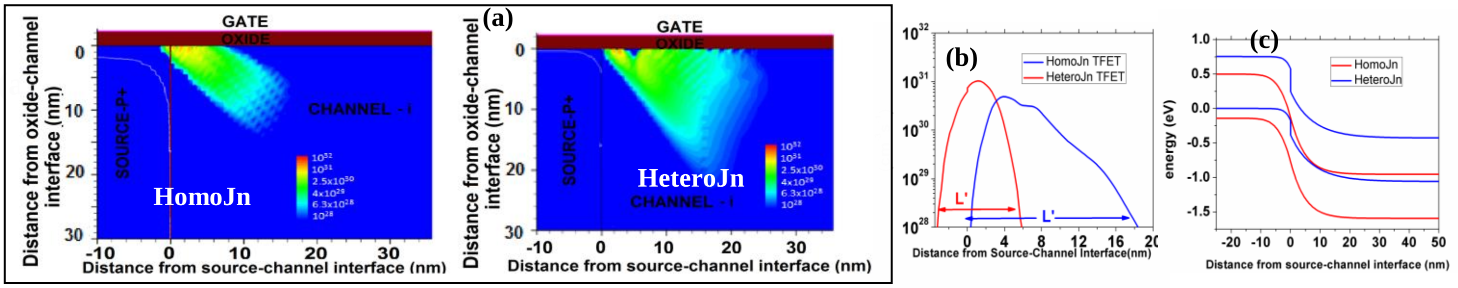

Fig 9.(a) Contour plot of electron band to band generation from 2D simulations (b) Effective channel length L' is defined based on the spread of band-to-band generated electrons (c) Corresponding band diagram shows that L' is higher in heterojunction due to smaller electric field at a given drain current level.

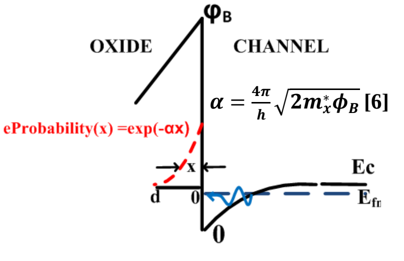

Fig 10. Trapping/detrapping of electrons around E_{fn} into the trap states in the oxide results in flicker noise.

$$I_{ds} = AF^2 exp\left(\frac{-B}{F}\right); A = \frac{\pi m_r^{0.5} q^2}{9h^2[Eb_{eff}^{0.5}]}; B = \frac{\pi^2 m_r^{0.5} Eb_{eff}^{1.5}}{qh}$$

$$\Delta F = \frac{\Delta Q}{\varepsilon_{ox}}$$

$$S_{\Delta Q} = q^2 S_{\Delta Nt} = q^2 \frac{\tau_t}{1 + w^2\tau_t^2} N_t f_t(1 - f_t)$$

$$\frac{S_{Ids}}{Ids^2} = (\frac{2}{F} + B\frac{B}{F^2})^2 \frac{q^2 N_t(Efn)}{\varepsilon_{ox}^2 W L' \alpha f}$$

Table II. Proposed analytical equations describing flicker noise characteristics in TFET assuming pure BTBT current.

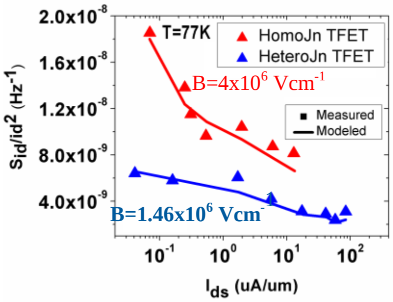

Fig 11. Proposed analytical model is in excellent agreement with the experimental data.