Noise Performance of RTD-gated plasma-wave HEMT THz Detectors

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***Abstract*— In this paper, we study the noise performance of RTD-gated plasma-wave HEMT THz detectors. It is shown that noise in these devices is dominated by gate tunneling shot noise, and that a smaller effective electron mass promises much improved noise performance by boosting the responsivity while slightly decreasing the noise spectral density (NSD). This implies that it is desirable to realize RTD-gated plasma-wave HEMT THz detectors in material systems with low effective mass.**

I. Introduction And Background

ELECTRON plasma-wave enabled high-responsivity THz detection at room temperature (RT) [1, 2] has been recently experimentally reported in high electron mobility transistor (HEMT) structures. Compared to Si MOSFET based THz detection [3], the advantage of HEMT based detection is its intrinsically high responsivity. In addition to their record high RT responsivity > 2 kV/W, these devices can allow for very low RT noise equivalent power (NEP) ~ 15 pW/Hz$^{0.5}$ at 1 THz [2], which is similar to / or better than that of Schottky diode detectors (~ 5 - 40 pW/Hz$^{0.5}$).

In this context, resonant tunnel diode (RTD) gated plasma-wave HEMTs have been shown to be capable of outperforming traditional HEMTs in terms of responsivity as THz detectors [4]. This is because the negative differential conductance of the RTD gate stack can counteract the electron-plasma wave damping in the HEMT channel [4-5].

An important parameter of detectors is the noise equivalent power (NEP). Since in the NDC region, an RTD exhibits shot noise enhancement as shown by Brown [6], it is a valid question to ask whether NEP degrades or improves in RTD-gated THz detectors. It is found that the augmented shot noise in the NDC region indeed leads to a larger noise spectral density (NSD). However a lower NEP is obtained due to a much enhanced responsivity than that in HEMT detectors without RTD gate. Furthermore, we compare the NEP of RTD-gated plasma-wave HEMTs based on GaN and InGaAs.

II. Results

Shot noise is produced due to the particle nature of electrons, manifested in a current flow carried by electrons with uncertainty in their number. Brown studied analytically the shot noise produced by a general RTD structure and showed that the shot-noise factor γ can be expressed by [6]:

$$\gamma = 1 + 2M + M^2 \quad (1)$$

Where M, the transmission modulation function; in the NDC region can be reduced to:

$$M \approx \frac{e^2 (m)^{3/2}}{16\sqrt{2}\pi^2\hbar^3\varepsilon}\left(L_B + L_w/2\right)\left(2L_B + L_W + 2/\alpha\right)\frac{\phi_B^2 E_f^c}{E_1^{3/2}\left(\phi_B - E_1\right)} e^{2\alpha L_B}, \quad (2)$$

assuming that the RTD barriers are thin and identical and the Fermi level is above conduction band edge at the anode and cathode of the RTD. Figure 1 shows the device structure as well as the band diagram for a GaN RTD-gated HEMT under zero bias. Devices with a HEMT channel and a RTD well made of GaN, $In_{0.53}Ga_{0.47}As$ and $In_{0.8}Ga_{0.2}As$ are analyzed. Each device is biased so that it exhibits its peak responsivity at 1.3 THz (Fig. 1c). The gate length of the devices is 150-nm.

The results in terms of bias, responsivity, NSD, and NEP are organized in Table 1. It is clear that the RTD-gated plasma-wave HEMTs based on lower effective mass materials (i.e. $In_{0.8}Ga_{0.2}As$) exhibit better performance in terms of NEP.

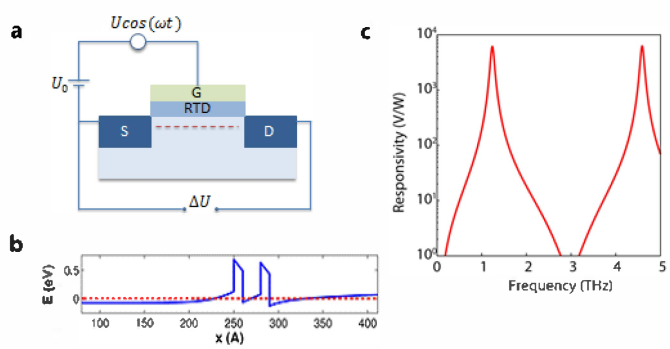

Fig. 1 GaN-based RTD-gated plasma-wave HEMT structure (a), band diagram (b), and responsivity (c).

Table 1 Comparison of various HEMT THz detectors without (GaN*) and with RTD gate

	GaN*	GaN	$In_{0.53}Ga_{0.47}As$	$In_{0.8}Ga_{0.2}As$
γ	-	18.5	2.03	1.95
m^*	$0.2m_0$	$0.2m_0$	$0.04\ m_0$	$0.03\ m_0$
Responsivity [V/W]	80	6200	22000	31800
DC Bias [V]	1	1	0.23	0.16
n_s [$\times 10^{12}$ cm^{-2}]	4.3	4	0.98	0.71
NSD [nV/Hz$^{0.5}$]	0.5	3	1	0.95
NEP [pW/Hz$^{0.5}$]	6.2	0.5	0.05	0.03

III. Conclusion

We have theoretically compared plasma-wave HEMT THz detectors with and without RTD gate. Since the device is operated under a low-field regime, its performance is dominated by the carrier mobility and effective mass. Furthermore, despite of the shot noise enhancement, the largely improved responsivity of RTD-gated HEMTs might lead to better NEP. The overall performance can be boost by employing low effective mass materials.

References

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