Temperature Dependence of Hot Carrier and Positive Bias Stress Degradation in Double-Gated Graphene Field-Effect Transistors

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Recent advances in the fabrication of graphene field-effect transistors (GFETs) [1-2] has created a demand for the characterization of their reliability. However, only a few studies have been performed so far (e.g. [3-4]). Here we examine the temperature dependence of hot-carrier degradation (HCD) in double-gated GFETs fabricated using the method of [5]. First, HC stress is applied in addition to a top gate positive bias-temperature instability (PBTI) stress V_{TG}. Then the recovery of the I_d-V_{TG} characteristics is monitored after which the next stress with larger drain voltage V_d and fixed V_{TG}-$V_{Dirac}(V_d) \approx 4V$ is applied (see [4,6]). In Fig.1a the results for PBTI-pHCD (V_d>0) are shown. We observe that PBTI, which introduces negative charge, is suppressed by the pHCD component which creates positively charged defects [6]. However, at T=120°C the suppression becomes pronounced at smaller V_d than at T=25°C which means that pHCD is strongly accelerated at higher T. Moreover, NBTI-like fast traps associated with pHCD [6] also appear earlier at T=120°C. The related results for PBTI-nHCD (V_d<0, Fig.1b) show that at T=25°C the nHCD component with small V_d creates some negative charge and accelerates PBTI, while at T=120°C it suppresses PBTI independently of V_d. In Fig.2 we depict the resulting defect density shifts. Clearly, the difference in the initial shifts (left) between PBTI-pHCD and PBTI-nHCD observed at T=25°C almost disappear at T=120°C. The only conserved trend is that at larger V_d pHCD creates much more positive charge than nHCD. The related results obtained after a significant recovery (right) show the presence of weakly recoverable positive charge introduced by the stresses with larger V_d. Since HCD is more efficient at higher T, even a rather small V_d is enough to introduce the extra positive charge. Thus, PBTI-like over-recovery is more significant at T=120°C (cf. Fig.1). The resulting mobility change versus V_d (Fig.3) correlates with a variation of the defect density and agrees with attractive/repulsive scattering asymmetry [7]. In addition, the electron mobility has a maximum associated with screening effects [8] which accompany the charge compensation. At T=120°C the maximum is considerably larger, since the compensation starts at smaller V_d but proceeds more slowly (cf. Fig.2). The former is due to acceleration of HCD at higher T while the latter is because the bias component also becomes stronger at higher T [4]. To conclude, at higher T the number of defects created by both bias and HC components is larger and the interplay between them in terms of their charges and potentials is stronger. This impacts both V_{Dirac} shift and mobility which are correlated.

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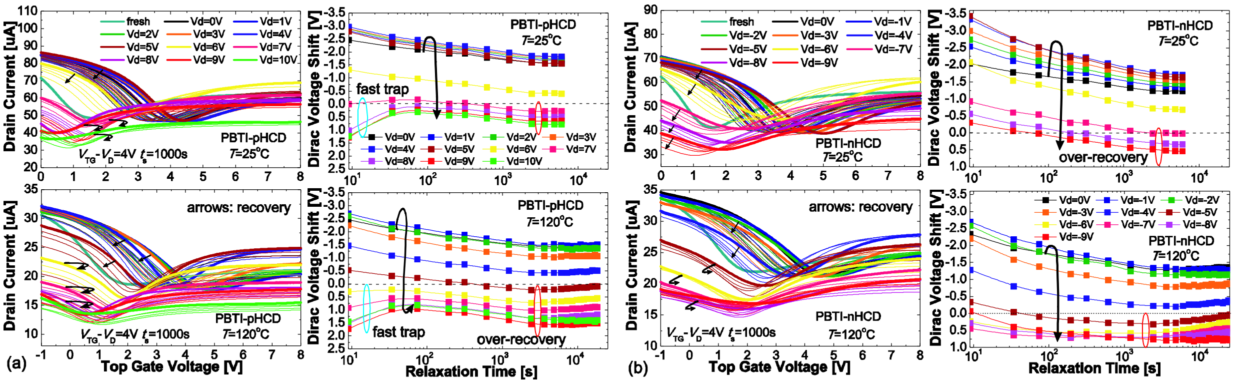

Fig.1: Top gate characteristics and recovery traces for PBTI-pHCD (a) and PBTI-nHCD (b) at T=25°C and 120°C.

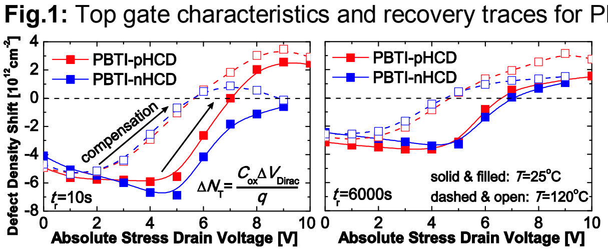

Fig.2: Defect density shift vs. V_d measured at two relaxation time points and different T.

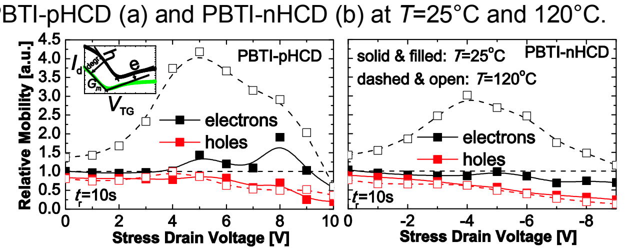

Fig.3: Relative mobility vs. V_d for PBTI-pHCD and PBTI-nHCD. The inset shows the mobility estimation scheme.