The Impact of the Graphene Work Function on the Stability of Flexible GFETs

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Graphene field effect transistors (GFETs) are promising for a wide variety of applications, such as Hall sensors [1] and photodetectors [2]. The recent demonstration of flexible GFETs expands the application space towards wearable electronics [3]. However, one of the main obstacles for the commercialization of these devices is the considerable variability and limited long-term stability of the main device parameters. For the first time, we study the stability of flexible GFETs and demonstrate how a small change in the graphene work function, which may be induced by impurities, can considerably affect stable device operation.

Our devices are flexible GFETs with two different types of CVD grown graphene, purchased from Grolltex (Type 1) and Graphenea (Type 2). Both batches use spin-coated polyimide (PI) as a flexible substrate, onto which the graphene monolayer is transferred. In a scalable process the areas of 54 devices per batch are patterned in an oxygen plasma and source and drain contacts of 50nm Ni are sputter-deposited, defining L=80µm and W=50µm. After growing 40nm of Al_2O_3 by ALD the devices are finalized by sputtering 10nm Ti/ 150nm Al as top gate contact.

We measure the hysteresis of the $I_D(V_G)$ characteristics at varying sweep times t_{SW} and sweep ranges V_{Gmin} to V_{Gmax}, and calculate the hysteresis width ΔV_H as difference between the Dirac point voltage V_{Dirac} of the forward and the reverse sweep.

From the fast $I_D(V_G)$ characteristics we estimate the field-effect mobility of the two types of graphene to be on average 4000cm²/Vs for Type 1 graphene and 1000cm²/Vs for Type 2 graphene. The Dirac point voltage V_D is on average at 0.8V for Type 1 and at 1.3V for Type 2, indicating higher p-type doping and a higher density of intrinsic defects in Type 2 graphene. The high defect density in Type 2 graphene explains the larger device-to-device variability, which becomes apparent from the ΔV_H vs. $1/t_{sw}$ dependences.

Despite the higher material quality of Type 1 graphene, the hysteresis width for slow sweeps up to +-10V maximum gate voltage is higher. In particular, the Dirac point voltage shift for forward sweeps strongly increases, resulting in a larger hysteresis width. As the voltage shift is related to a charge transfer between the channel and point defects in the insulator, this directly corresponds to more active insulator defects in Type 1 graphene devices. However, the Al_2O_3 gate insulator is the same for both batches which is why only a work function difference between the two types of graphene can explain the different numbers of active oxide traps. Indeed, the work function of graphene can be adjusted between 3.4eV and 5.1eV by chemical doping [4,5]. We estimate the work function of higher quality Type 1 graphene at 4.6eV and of Type 2 at 4.9eV, corresponding to a higher density of impurities in the latter case. This results in a more unfavourable energetic alignment for the Type 1 graphene channel to the defect band in Al_2O_3 at 2.55eV +-0.3eV below the conduction band edge [6]. During slow sweeps, at negative voltages in Type 1 more defects in Al_2O_3 can emit electrons, which shifts the forward sweep V_{Dirac} to more negative voltages and results in a larger hysteresis.

Our findings illustrate that the hysteresis width in flexible GFETs depends on the work function of graphene, which determines the energetic barrier for charge trapping by insulator defects in the Al_2O_3 defect band. Thus, in order to achieve stable operation of flexible GFETs, the

graphene work function has to be actively designed to be 5eV or higher, for instance by doping, to match the location of the defect bands in the gate insulator.

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