Supporting information for: Nanosecond spin lifetimes in single- and few-layer graphene-hBN heterostructures at room temperature

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The supporting information comprise additional spin transport measurements on the SLG and few-layer graphene devices presented in the main manuscript as well as differential $\mathrm{d}V/\mathrm{d}I \cdot A$ curves of both the spin injection and spin detection contacts of the latter devices. All data were taken at room temperature. The non-local spin signal ΔR_{nl} is measured by in-plane magnetic field loops. Clear bipolar spin signals are observed in all devices (see Figures S1(a) and S1(c)), with positive values of the non-local spin resistance for parallel alignment of the electrodes magnetization and a negative resistance for the antiparallel alignment. Hanle spin precession measurements are performed for both magnetization alignments in perpendicular magnetic fields (Figure S1(b)). The spin resistance ΔR_{nl} can also be extracted from the Hanle curves at zero perpendicular magnetic field. All gate dependent ΔR_{nl} measurements in this work were determined from respective Hanle curves. There is a strong device-to-device variation of the ΔR_{nl} values. The largest value of 17 Ω is found for a SLG (see Figure 1(c)). We emphasizes that the magnitude of ΔR_{nl} does not systematically depend on any spin or charge transport parameters. This finding is consistent with our previous study where Co/MgO electrodes were directly deposited onto graphene.[S1]

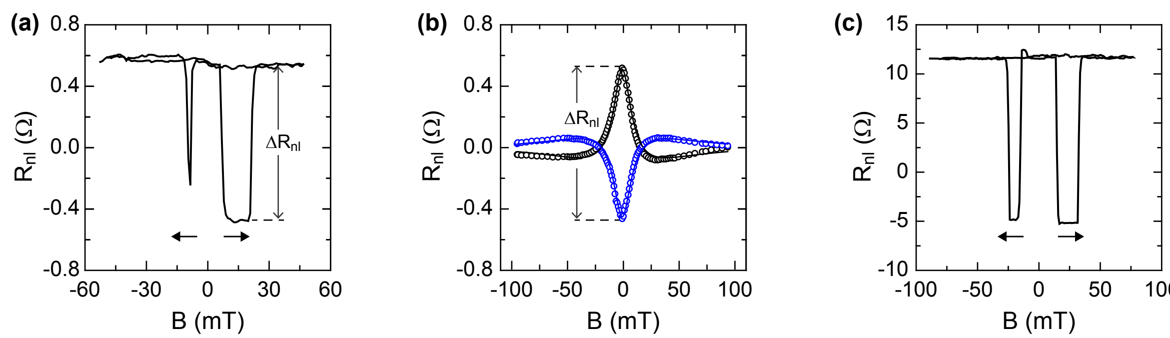

Figure S1: (a) Non-local resistance ΔR_{nl} as a function of the in-plane magnetic field of a SLG device. (b) Corresponding Hanle curve at $V_\mathrm{g} = 0\,\mathrm{V}$. (c) Non-local resistance ΔR_{nl} as a function of the in-plane magnetic field of a different SLG device.

In Figures S2 and S3 we show respective differential $\mathrm{d}V/\mathrm{d}I \cdot A$ curves (panels a) and gate dependent ΔR_{nl} (panels b) and λ_s (panels c) for a BLG and TLG device, respectively. Only for the BLG there are tunneling-like contacts as seen by the cusps in the $\mathrm{d}V/\mathrm{d}I \cdot A$ curve in

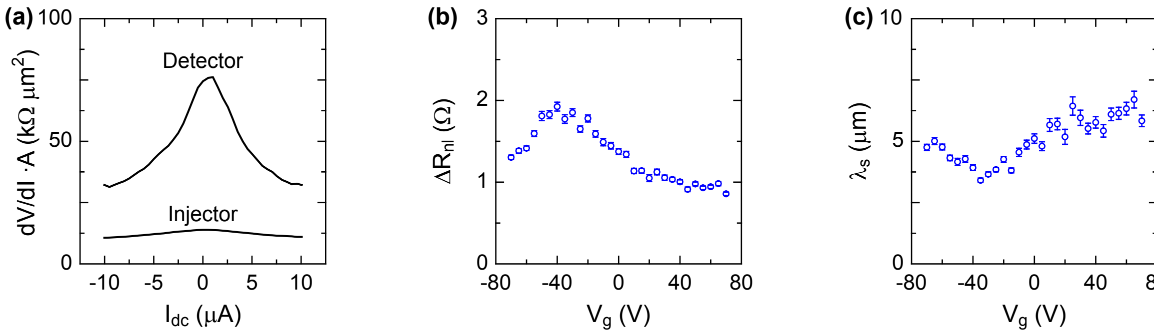

Figure S2: (a) Differential $\mathrm{d}V/\mathrm{d}I \cdot A$ curves of respective spin injection and spin detection contacts of a BLG non-local spin valve device. (b) Gate dependent spin signal $\Delta \mathrm{R}_{\mathrm{nl}}$. (c) Gate dependent spin diffusion length λ_{s}.

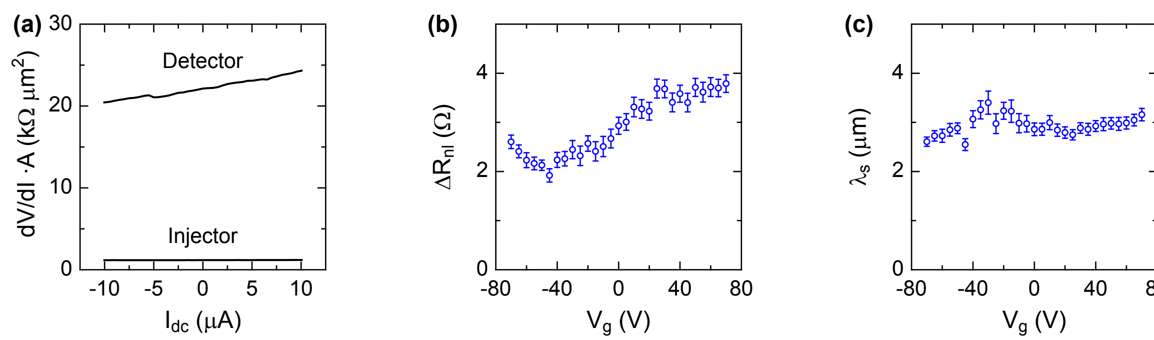

Figure S3: (a) Differential $\mathrm{d}V/\mathrm{d}I \cdot A$ curves of respective spin injection and spin detection contacts of a TLG non-local spin valve device. (b) Gate dependent spin signal $\Delta \mathrm{R}_{\mathrm{nl}}$. (c) Gate dependent spin diffusion length λ_{s}.

Fig. S2(a) while for the TLG device in Figure S3(a) the overall contact resistances are much smaller with a flat $\mathrm{d}V/\mathrm{d}I \cdot A$ curve for the injector contact. These different contact properties result in qualitatively different gate dependencies of ΔR_{nl}, i.e. it becomes maximal near the CNP for the BLG device with more tunneling-like contacts while it is minimal near the CNP for the more transparent contacts for the TLG device in Figure S2(b) (see Figure 4 of main paper for gate dependent graphene resistances).[S2] The opposite behavior is observed for the respective dependencies of λ_s as shown in Figures S2(c) and S3(c). We note that we currently cannot control these dependencies. We emphasize, however, that they do not result from the number of graphene layers as a different TLG device exhibits a similar tunneling-like behavior as in Figure S2.

References

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(S2) Han, W.; Pi, K.; McCreary, K. M.; Li, Y.; Wong, J. J. I.; Swartz, A. G.; Kawakami, R. K. *Phys. Rev. Lett.* **2010**, *105*, 167202.