

University of Groningen

Nonlinear interaction of spin and charge currents in graphene

Vera-Marun, I. J.; Ranjan, V.; van Wees, Bart

Published in:
Physical Review. B: Condensed Matter and Materials Physics

DOI:
[10.1103/PhysRevB.84.241408](https://doi.org/10.1103/PhysRevB.84.241408)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2011

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Vera-Marun, I. J., Ranjan, V., & van Wees, B. J. (2011). Nonlinear interaction of spin and charge currents in graphene. *Physical Review. B: Condensed Matter and Materials Physics*, 84(24), 241408-1-241408-4. [241408]. DOI: 10.1103/PhysRevB.84.241408

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

(Supplemental material)

Nonlinear interaction of spin and charge currents in graphene

I. J. Vera-Marun,^{*} V. Ranjan, and B. J. van Wees

*Physics of Nanodevices, Zernike Institute for Advanced Materials,
University of Groningen, The Netherlands*

(Dated: December 9, 2011)

PACS numbers: 72.25.Hg, 72.80.Vp, 75.76.+j, 85.75.-d

Here we present a derivation of Eq. (5), which is an analytical result to lowest (second) order for the nonlocal charge voltage generated by a nonlocal spin current.

The electrochemical potential for each spin channel $\mu_{\pm} = \mu_{\text{avg}} \pm \Delta\mu$ is described by the spin-diffusion relations Eqs. (1) and (2). As mentioned in the article, we use the general solutions for μ_{\pm} , J_{\pm} , and E for a homogeneous medium presented in Ref. 1. To find numerical solutions we divide the conducting system (graphene) into discrete regions and use the homogeneous solutions for each region, while keeping continuities of μ_{\pm} and J_{\pm} .

The nonlinear interaction between spin and charge is present due to the energy dependent conductivity $\sigma(\epsilon)$ of the system, which results in each region having a conductivity spin polarization β . Within this framework, the charge voltage variation ΔV across a discrete region of width Δx is

$$\begin{aligned}\Delta V &= V(x + \Delta x) - V(x) \\ &= \frac{\beta}{-e} [\Delta\mu(x + \Delta x) - \Delta\mu(x)] ,\end{aligned}$$

with β given by Eq. (4). By considering regions with infinitesimally small widths dx and describing the spin accumulation to first order via Eq. (3) we obtain

$$\begin{aligned}dV &= \frac{\alpha}{e} [\Delta\mu(x)]^2 \frac{dx}{\lambda} \\ V_{\text{nl}}(x_0) &= \int_{-\infty}^{x_0} dV = \frac{\alpha}{2e} [\Delta\mu(x_0)]^2 ,\end{aligned}$$

the latter is the result of Eq. (5) and it describes the nonlocal charge voltage shown in Fig. 1.

* Electronic address: i.j.vera.marun@rug.nl

[1] T. Valet and A. Fert, Phys. Rev. B **48**, 7099 (1993).