Charge pumping driven by a moving kink in graphene nanoribbon

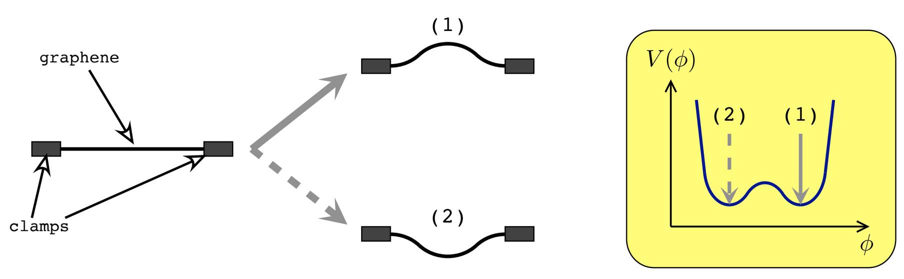
Adam Rycerz, **Dominik Suszalski**

Institute of Theoretical Physics, Jagiellonian University, Łojasiewicza 11, PL-30348 Kraków, POLAND

Abstract

A quantum pump in a buckled graphene ribbon with armchair edges is discussed numerically. By solving the Su-Schrieffer-Heeger model and performing the computer simulation of quantum transport we find that a kink adiabatically moving along the metallic ribbon results in highly efficient pumping, with a charge per kink transition close to the maximal value determined by the Fermi velocity in graphene. Remarkably, insulating nanoribbon show the quantized value of a charge per kink (2e) in a relatively wide range of the system parameters, providing a candidate for the quantum standard ampere. This finding is attributed to the presence of a localized electronic state, moving together with a kink, whose energy lies within the ribbon energy gap.

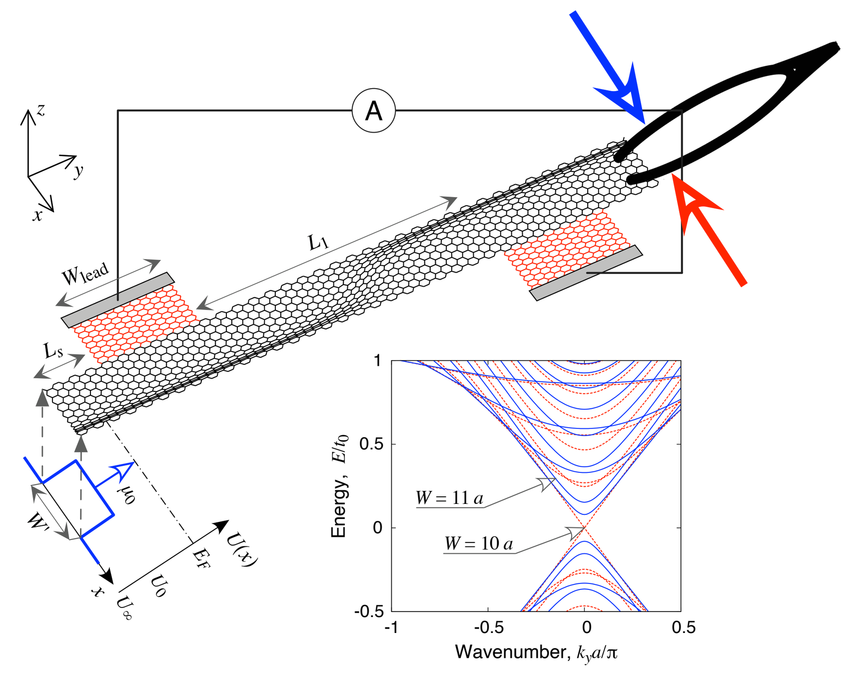
PRELIMINARIES: The ϕ^4 model in graphene



$\Longrightarrow$ Bending graphene strip (or *nanoribbon*) results in 2 different vacuum states; a domain wall (*kink*) moves along the strip

Further reading: R. D. Yamaletdinov, T. Romańczukiewicz, and Y. V. Pershin, *Manipulating graphene kinks through positive and negative radiation pressure effects*, Carbon **141**, 253 (2019). https://doi.org/10.1016/j.carbon.2018.09.032

The setup studied numerically



Model and methods (1/2)

Modified Su-Schrieffer-Heeger (SSH) model for graphene:

$$\mathscr{H}_{\rm SSH} = T + V_{\rm bonds} + V_{\rm angles},$$

where

$$T = -t_0 \sum_{\langle ij \rangle, s} e^{-\beta \delta d_{ij}/d_0} \left(c_{i,s}^{\dagger} c_{j,s} + c_{j,s}^{\dagger} c_{i,s} \right),$$

$$V_{\rm bonds} = \frac{1}{2} K_d \sum_{\langle ij \rangle} \left(d_{ij} - d_0 \right)^2,$$

$$V_{\rm angles} = \frac{1}{2} K_\theta \sum_j \sum_{\measuredangle(j)} \left(\theta_{\measuredangle(j)} - \theta_0 \right)^2 + V_\delta \sum_j \left(2\pi - \sum_{\measuredangle(j)} \theta_{\measuredangle(j)} \right),$$

with a constrain: $\sum_{\langle ij \rangle} d_{ij} = \text{const}.$

Model and methods (2/2)

Landauer-Büttiker conductance:

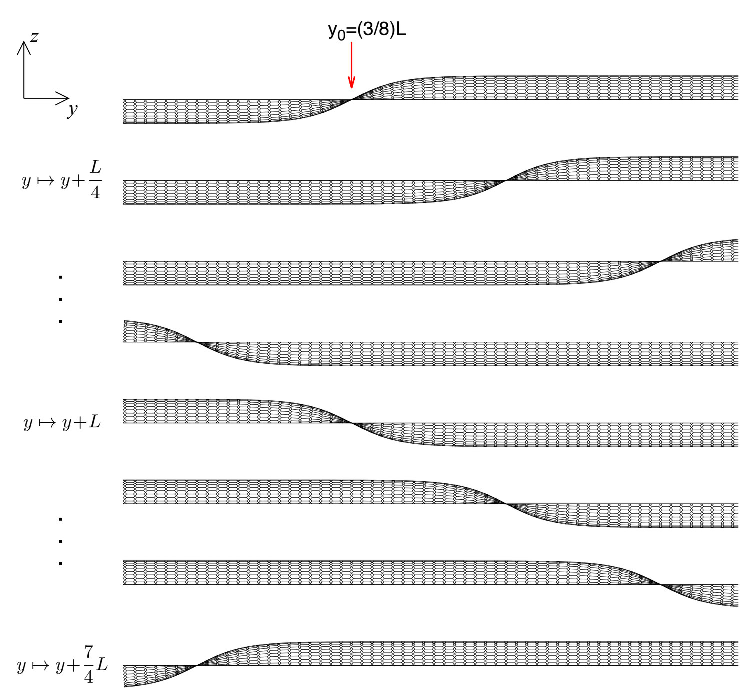
$$G = G_0 {\rm Tr}\, tt^{\dagger} = \frac{2e^2}{h} \sum_n T_n,$$

where $G_0 = 2e^2/h$ (the conductance quantum), and T_n is the transmission probability for the n-th normal mode.

Charge pumped by kink:

$$\Delta Q = -\frac{ie}{2\pi} \sum_j \int dy_0 \left(\frac{\partial S}{\partial y_0} S^{\dagger} \right)_{jj},$$

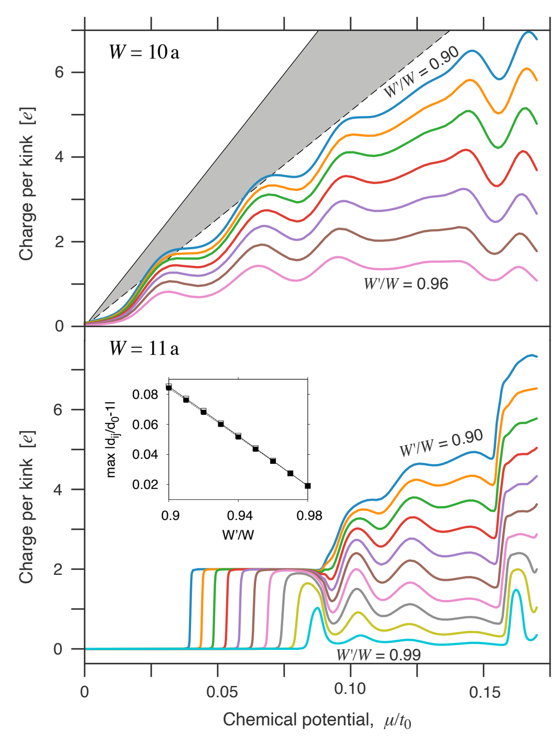
with j — the mode in *output* lead, and y_0 — the kink position.



Main results

metallic ribbon $\Longrightarrow$

semiconducting ribbon $\Longrightarrow$



Summary

Metallic ribbon: For moderate bucklings (with relative bond distortions < 10%) the kink suppresses the current flow, and shifts the electric charge when moving between the leads.

$\Longrightarrow$ *The charge per cycle is not quantized.*

Semiconducting ribbon: States localized near the kink (with energies lying within the gap) can be utilized to transport a quantized charge of 2e per kink transition.

$\Longrightarrow$ *A candidate for the quantum standard ampere occurs.*

Acknowlegments

We thank Anton Akhmerov (TU Delft), Tomasz Romańczukiewicz (UJ), and Krzysztof Rościszewski (UJ) for discussions.

The work was supported by the National Science Centre of Poland (NCN) via Grant No. 2014/14/E/ST3/00256.

Computations were partly performed using the PL-Grid Infrastructure.

Literature

1. R. D. Yamaletdinov, T. Romańczukiewicz, and Y. V. Pershin, Carbon **141**, 253 (2019).
2. D. Suszalski and A. Rycerz, Phys. Rev. B **102**, 165408 (2020).
3. G. Dresselhaus, M. S. Dresselhaus, and R. Saito, *Physical Properties of Carbon Nanotubes* (World Scientific, Singapore, 1998), Chap. 11.
4. J.-L. Tsai and J.-F. Tu, Mater. Design **31**, 194 (2010).
5. S. Plimpton, J. Comput. Phys. **117**, 1 (1995); see also http://lammps.sandia.gov.
6. C. W. Groth, M. Wimmer, A. R. Akhmerov, and X. Waintal, New J. Phys. **16**, 063065 (2014); see also https://kwant-project.org.