Fabry-Pérot oscillations in *npn* junctions in graphene

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1 Introduction

$n-p-n$ ($p-n-p$) junctions in graphene can be created by external gates, which varies the local carrier density $n(\mathbf{r})$, with the p (n) region hosting holes (electrons). The Klein tunneling in graphene allows the charge carriers to tunnel through the barrier with 100% probability at normal incidence, but the probability decreases as the angle deviates from normal. Thus, the n/p interfaces act as semi-transparent mirrors, and the charge carriers propagating across a bipolar junction can perform multiple reflections, as shown in Fig. 1(a). The transmitted and doubly reflected paths accumulate a phase difference, which gives rise to conductance oscillations [Fig. 1(c)]. **For details see** Nat. Phys. 5, 222 (2009).

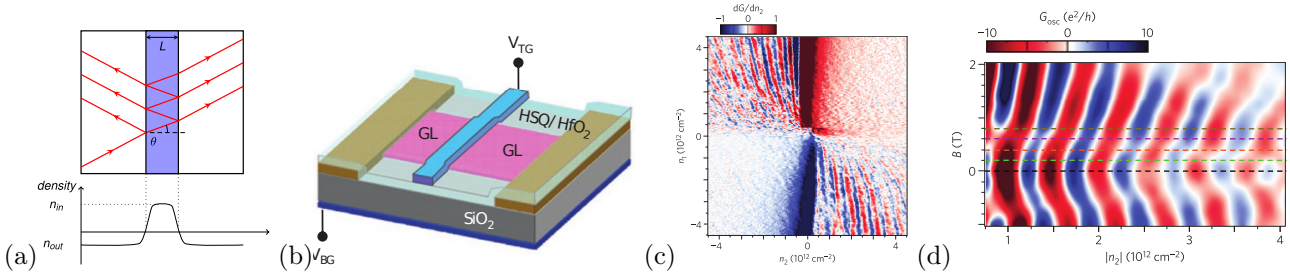

Figure 1: (a) Schematic of Fabry-Perot oscillations in a system with bipolar junctions. (b) Experimental setup. (c) Conductance derivative as a function of carrier densities under the top gate (n_2) and beyond it (n_1). (d) Conductance (with background removed) as a function of B and n_2.

In this project, consider a two-terminal rectangular system. Consider smooth, barrier-like onsite potential, for example given by the function $V(x,t) = V_{\text{np}}(\tanh((x+L/2)/d) - \tanh((x-L/2)/d))/2$, where d is the smoothness and V_{np} is the potential amplitude.

1.1 Tips on the tight-binding model in Kwant

You can use the Kwant tutorial[1]. The tutorial creates a system with a so called zigzag termination, but I suggest to use the armchair orientation along x. To do that, modify the code in the tutorial by using

```
a = nm2au(0.25)
a0 = a*s
sin_30 = np.sin(30*np.pi/180)
cos_30 = np.cos(30*np.pi/180)
graphene = kwant.lattice.general([(0, a0), (cos_30*a0, sin_30*a0)],
                                 [(0, 0), (a0 / np.sqrt(3), 0)], norbs=1)
a, b = graphene.sublattices
```

`a` is the lattice constant of graphene, and `s` will be explained further. This creates lattice depicted in Fig. 2.

To learn more about graphene properties, see e.g. Rev. Mod. Phys. 81, 109 (2009) [Chapter II. A. (excluding II. A. 1.-2.), II. B. 1., and II. H.]

Use the scalable tight binding model for graphene Phys. Rev. Lett. 114, 036601 (2015), in which the lattice constant is increased s times, $a_0 = sa$, and the hopping parameter t is divided by the same s: $t_0 = t/s$. Finally,

[1] Useful tutorial about the implementation for graphene in Kwant: link.

the Hamiltonian can be describes as

$$H_{i,j} = \begin{cases} V(\mathbf{r}_i), & i = j, \\ t/s, & |\mathbf{r}_i - \mathbf{r}_j| = a_0/\sqrt{3}, \\ 0, & \text{otherwise}, \end{cases} \tag{1}$$

and $t = -3$ eV.

Calculate the conductance as a function of energy and V_{np} to obtain a picture similar to Fig. 1(c) [Fig. 2(a) in Nat. Phys. 5, 222 (2009)]. Fix the selected variable (energy or V_{np}) and scan the other variable as well as B to recover the result in Fig. 1(d) [Fig. 3(a) in the same reference]. Explain the results and the phase shift at finite B based on the literature.

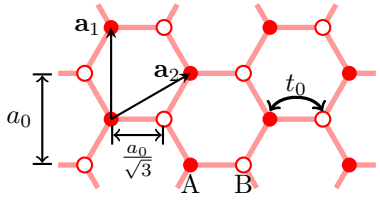

Figure 2: Graphene with lattice vectors and base.