GRAPHENE AND 2DM VIRTUAL CONFERENCE & EXPO

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Gradient-index electron optics in graphene pn junctions

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Motivation

- Study the ballistic transport on graphene pn junctions.
- Generate the pn junctions on graphene with backgate-voltages.
- Describe the current flow by analogies of the gradient-index geometrical optics.
- Propose several nanodevices in graphene.

NEGF method

Tight-binding model — External electrostatic potential

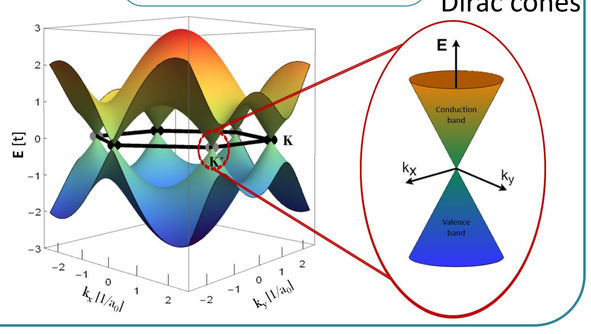
$$G = (E - H - V - \Sigma)^{-1}$$

$$G^{<} = G\Sigma^{in}G^{\dagger}$$

Electrons' Inscattering function

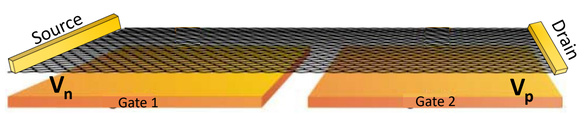
Local current on the system → $$I_{ij}^{OP} = \frac{2e}{h} Im\left(t_{ij}^{*} G_{ij}^{<}\right)$$

Graphene band structure



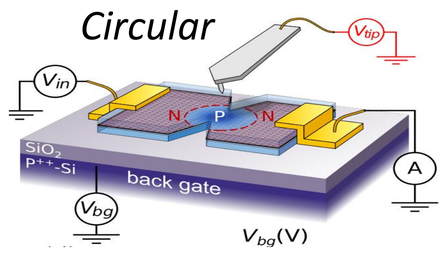
Graphene pn junctions

Straight

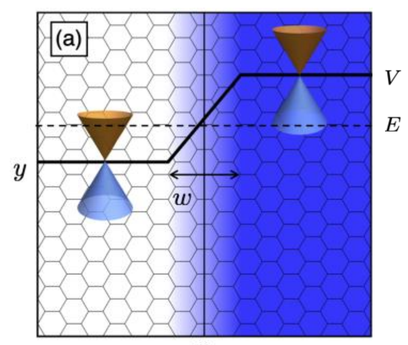


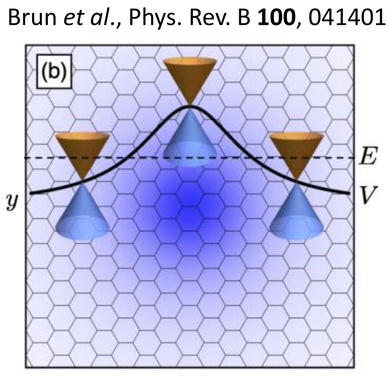
Ref: Cheianov *et al.*, Science **315**, 1252 (2007)

Circular



Ref: Brun *et al.*, Phys. Rev. B **100**, 041401 (2019)





Gradient-index optics

Effective refractive index: $$n(r) \equiv \frac{E - V(r)}{v_F}$$

The index dependence of the position of the medium/region of system.

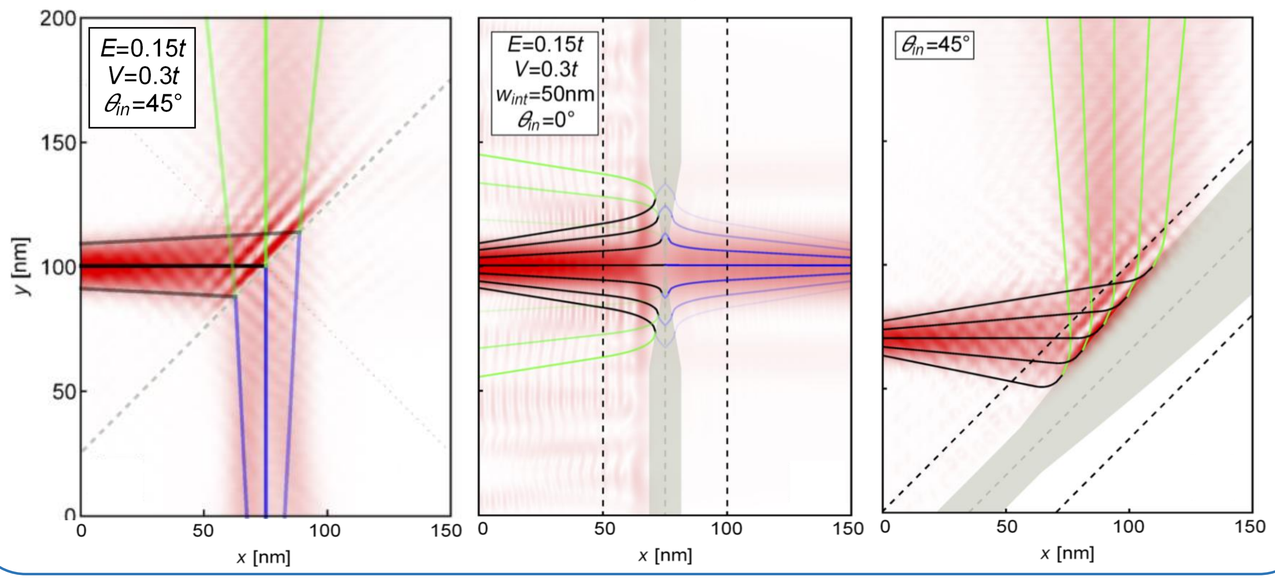
Straight pn junctions

Semiclassical trajectories: $$y(x) = y_0 + p_y \int_{x_0}^{x} \frac{s(x')\,dx'}{\sqrt{n^2(x') - p_y^2}}$$

Gradient-index optics!

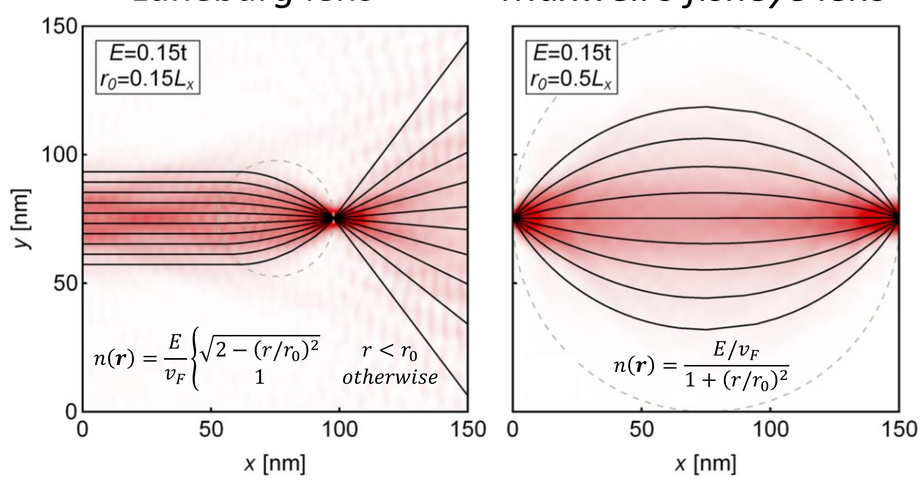
Step junction: negative refraction and Snell's law for electrons.

Smooth junction: classical forbidden zone



Optical lenses in graphene

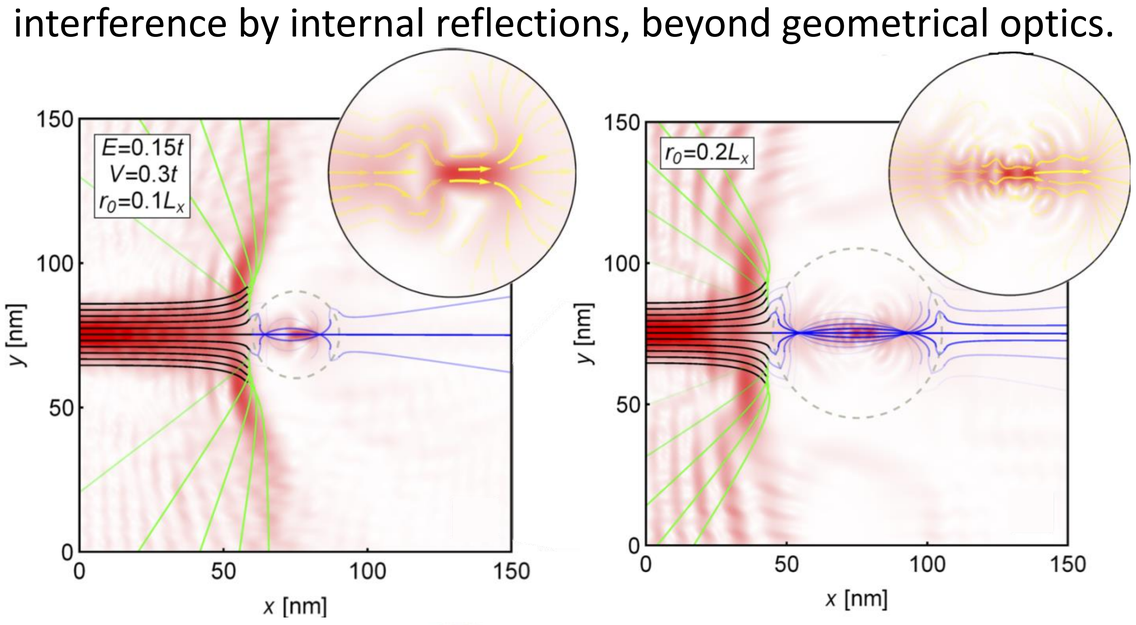
Luneburg lens — *Maxwell's fisheye lens*



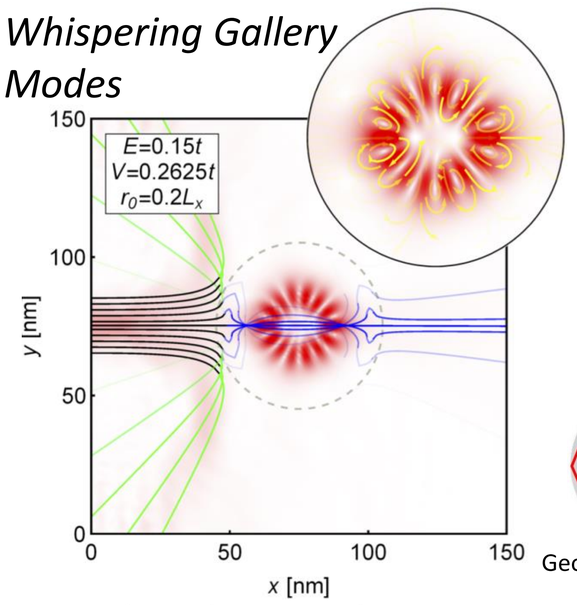
Smooth circular pn junctions

Semiclassical trajectories: $$\theta = \theta_0 + l \int_{r_0}^{r} \frac{s(r')\,dr'}{r'\sqrt{r'^2 n^2(r') - l^2}}$$

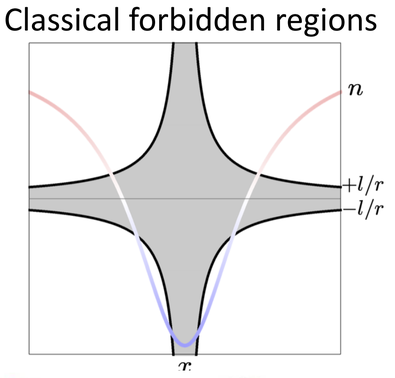
Look on the inside of the dashed circle (p region): significant interference by internal reflections, beyond geometrical optics.

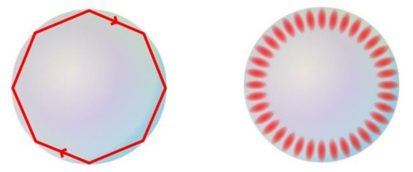


Whispering Gallery Modes



Classical forbidden regions



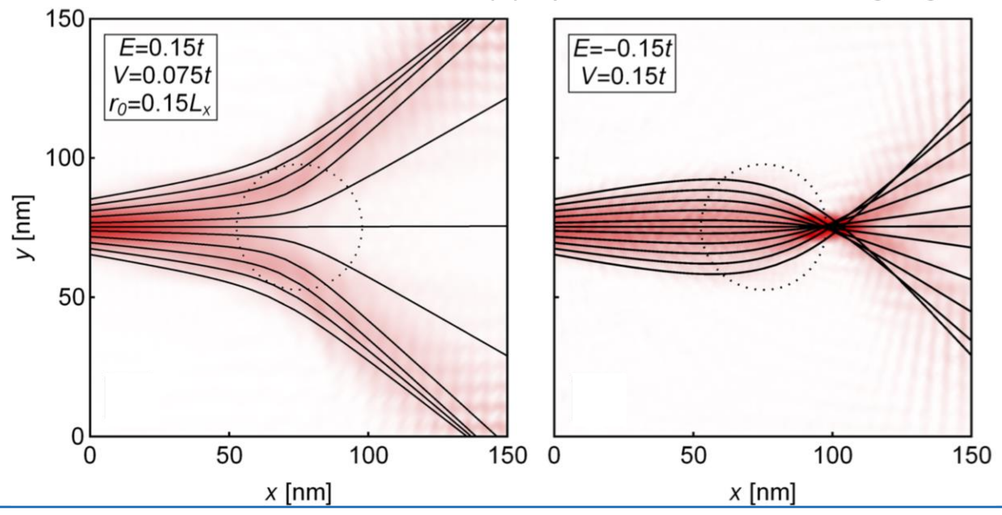


Geometrical optics — Wave optics representation

Ref: softmatter.si

nn' jct: beam splitter

pp' jct: act like converging lens



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REFERENCES

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