Enhanced dichroism in graphene nanoribbons

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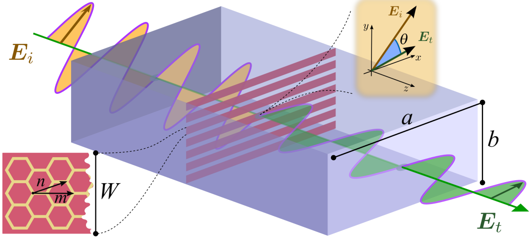
Graphene Nanophotonics, Benasque 2013

Graphene nanoribbons

- Lateral confinement effects
- Conductivity
- Dichroic absorption



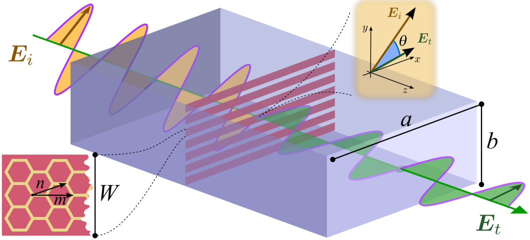
Overview

Graphene nanoribbons

- Lateral confinement effects
- Conductivity
- Dichroic absorption

Relevant issues

- Disorder
- Drude conductivity
- State of the art



Nanoribbons

- $k_\ell = \frac{\pi \ell}{N+1}$ Saito et al. 1992; Wakabayashi et al. 2010; Ruseckas et al. 2011
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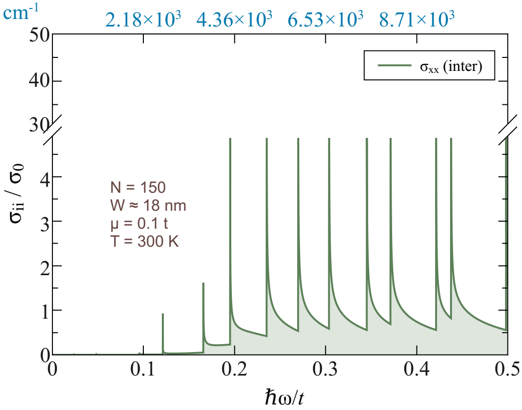
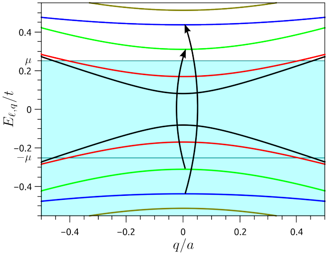
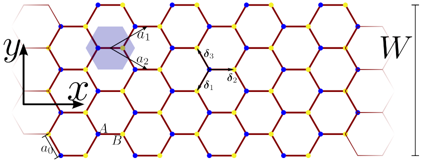
- Selection rules for transitions







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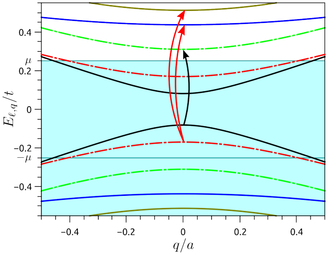

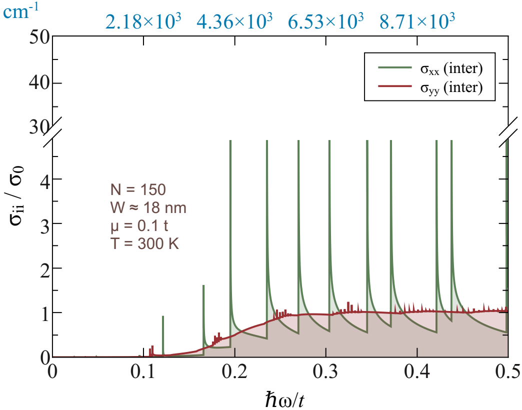

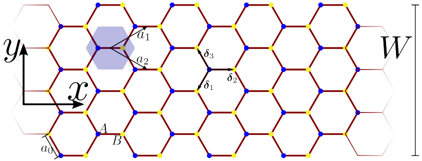

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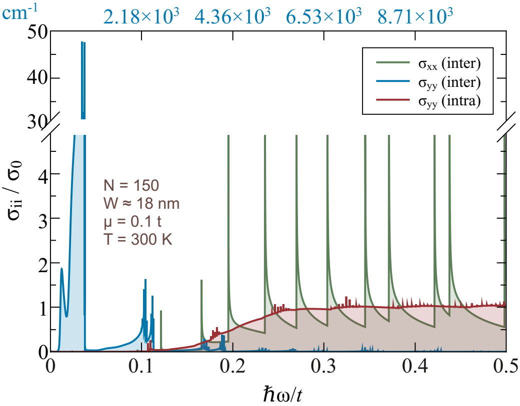

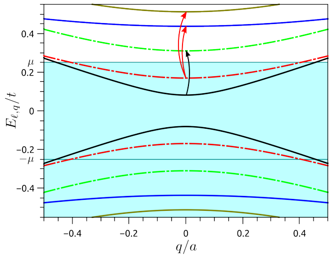

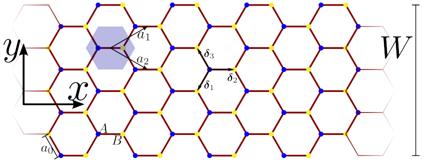

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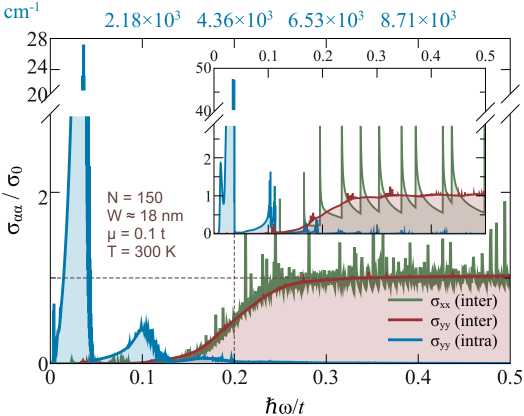

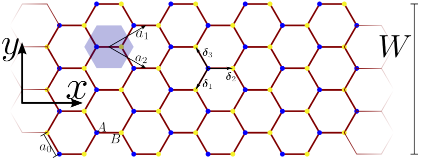

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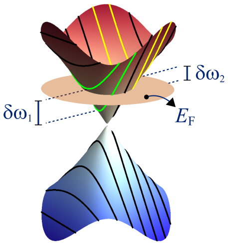

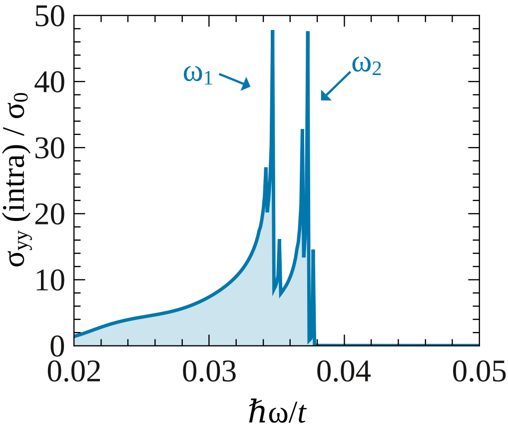

Close-up of the *intra*-band conductivity

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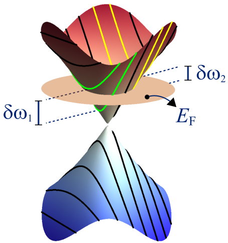

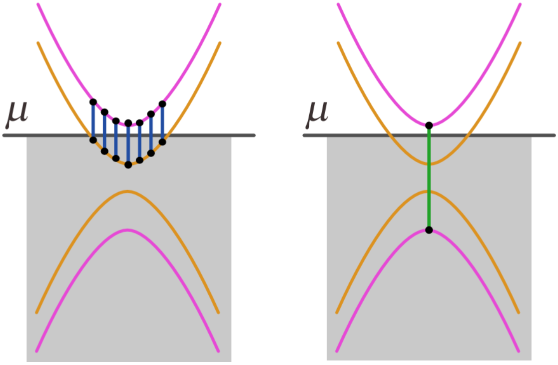

Independent of chirality

Dichroic absorption

Absorption

- $t_\alpha(\omega) = \frac{2}{2+Z\langle\sigma_{\alpha\alpha}(\omega)\rangle}$
- $\mathcal{P}(\omega) = \frac{|t_x|^2-|t_y|^2}{|t_x|^2+|t_y|^2}$

Born et al. 1997; Jackson 1999

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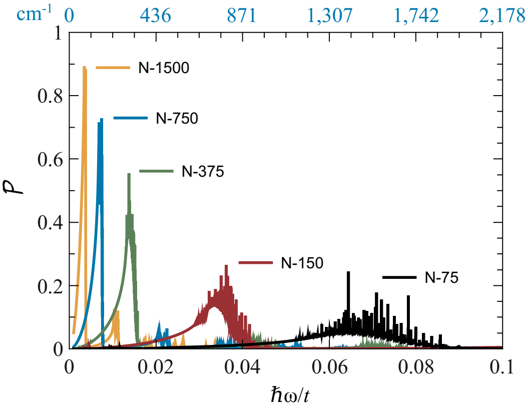
Dichroism

- $\mathcal{P}$ in excess of 50% with 45 nm ribbons
- Predictability
- Narrower ribbons $\rightarrow$ larger ω_{max} $\rightarrow$ smaller $\mathcal{P}(\omega_{max})$



Enhanced dichroism

Nanoribbons

- $Z_{mm}(\omega) = Z \frac{\omega}{\sqrt{\omega^2 - \omega_{mn}^2}}$

  $\omega_{mm}^2 = 2 \frac{c^2 \pi^2}{\mu \epsilon} \left(\frac{m}{a}\right)^2$ Jackson 1999

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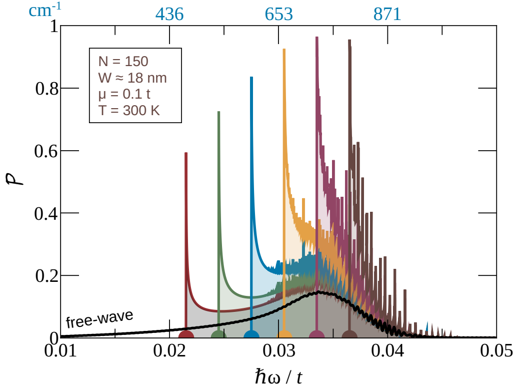

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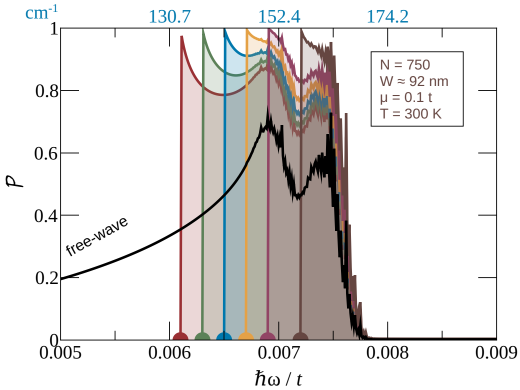
- Large increase of DP
- Tunable threshold
- Well defined band filter



Competing effects

- Plasmon absorption ressonance ($\gtrsim 1\,\mu\mathrm{m}$ range) Ju et al. 2011
- Disorder
- Drude peak at $\omega = 0$, $\gamma \sim 100\,\mathrm{cm}^{-1}$
  $\Re\frac{\sigma_D(\omega=0)}{\sigma_0} \approx 800\,|\mu|/t$

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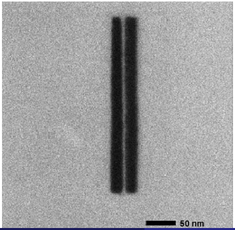
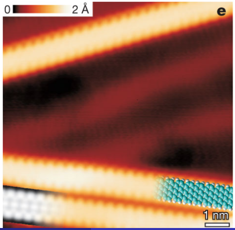
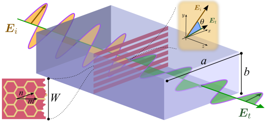
Production

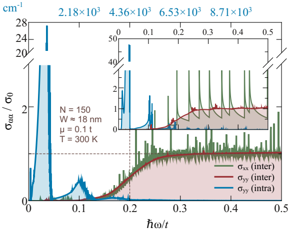
- He ion lithography – features $\sim 10\,\mathrm{nm}$ Lemme et al. 2009; Bai et al. 2009; Pickard et al. 2009
- Carbon nanotube unzipping Kosynkin et al. 2009; Jiao et al. 2010; Tao et al. 2011
- Strain engineering Pereira et al. 2009
- Self assembley – ribbons and "chevron" like ribbons $W \sim 20\,\mathrm{nm}$ Cai et al. 2010

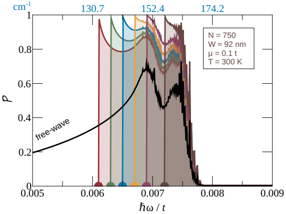




Conclusion



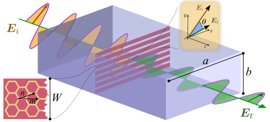


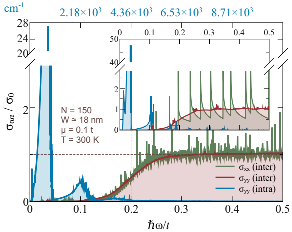


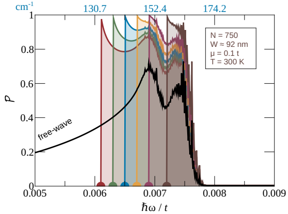
What have we done

- Exact optical conductivity tensor of GNRs
- Optical absorption can be made highly anisotropic
- Tunable via the ribbon width, and/or via the impedance of the medium.
- Strong anisotropy lies in a resonant feature that is simultaneously very strong and resilient to level broadening
- Very high degree of polarization $\sim 85\%$, enhanceable to near $\sim 100\%$

Conclusion







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Future work

- Study the influence of more specific disorder models
- Combining the intrinsic absorption response of GNRs with the geometric effects
- Interplay of the anisotropy induced here by space quantization and plasmons

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Wave function

$$\left|\Psi_{\ell,q,\lambda}\right\rangle = \mathcal{N} \sum_{n,m} e^{-iq(m+n/2)} \sin\left(k_\ell n\right) \times \Big(\left|A,n,m\right\rangle + \lambda e^{-i\theta_{\ell,q}} \left|B,n,m\right\rangle \Big)$$

Phase difference between sublattices

$$\theta_{\ell,q} = \arctan \frac{2\cos k_\ell \sin\left(q/2\right)}{1 + 2\cos k_\ell \cos\left(q/2\right)}$$

Conductivity tensor derived from the Kubo formula

$$\sigma_{\alpha\beta} = \frac{2ie^2}{\omega S} \sum_{\ell_1,\ell_2,q} \sum_{\lambda_1,\lambda_2} \frac{f\left(E_{\ell_1,q,\lambda_1}\right) - f\left(E_{\ell_2,q,\lambda_2}\right)}{\hbar\omega - \left(E_{k_2,q,\lambda_2} + E_{k_1,q,\lambda_1}\right) + i0^+} \times \left\langle \Psi_{\ell_1,q,\lambda_1} \right| v_\alpha \left| \Psi_{\ell_2,q,\lambda_2} \right\rangle \left\langle \Psi_{\ell_2,q,\lambda_2} \right| v_\beta \left| \Psi_{\ell_1,q,\lambda_1} \right\rangle$$

Longitudinal conductivity along $x-$direction

$$\Re \frac{\sigma_{xx}}{\sigma_0} = \mathcal{N}_x \sum_{\ell_0} \delta f_{q_0,\ell_0} M_x^2(q_0,\ell_0)$$

$$M_x^2(q_0,\ell_0) = \frac{\left[\cos\theta_{\ell_0,q_0} - \cos(\theta_{\ell_0,q_0} - q_0/2)\cos k_{\ell_0}\right]^2}{\sin(q_0/2)\cos k_{\ell_0}}$$

$$q_0 = 2\arccos \frac{(\Omega/2)^2 - 1 - 4\cos^2 k_{\ell_0}}{4\cos k_{\ell_0}}$$