Simulation of Graphene-based Nano-antennas

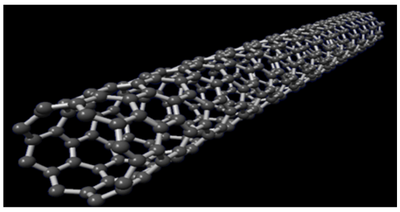
N3Cat Nanonetworking Center in Catalunya
UPC
Anastasia Pantazopoulou
ap@ac.upc.edu

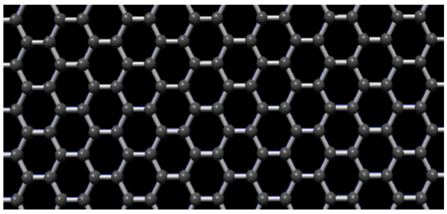
Introduction

- Nanotechnology is enabling the development of devices in a scale ranging from one to a few hundred nanometers:
  - At this scale, novel nanomaterials and nanoparticles show new properties not observed at the microscopic level.

Graphene (1)

- Graphene is a one-atom-thick planar sheet of bonded carbon atoms in a honeycomb crystal lattice. It is the building material of:
  - **Carbon Nanotubes (CNTs):** A folded strip of graphene (1991).
  - **Graphene Nanoribbons (GNRs):** A thin strip of graphene (2004).





Graphene (2)

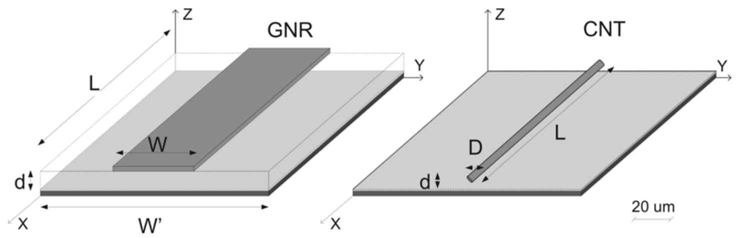
- **Graphene** is a firm candidate to become *“the silicon of the 21st century”* due to its unique electronic properties:
  - Very high electron mobility
    -> Very high speed switching devices.
  - Very high sensitivity (all atoms exposed)
    -> New types of nanosensors.
  - Thermoelectric current effect
    -> Self-cooling nano-electronics.

- New opportunities for device-technology: nano-batteries, nano-memories, nano-processors, nanosensors and **nano-antennas.**

Graphene-based Nano-antennas

J. M. Jornet and I. F. Akyildiz, "Graphene-based Nano-antennas for Electromagnetic Nanocommunications in the Terahertz Band", in Proc. of 4^{th} European Conference on Antennas and Propagation, Barcelona, Spain, April 2010.

- Graphene can be used to manufacture atomically precise nanoscale antennas, e.g., nano-dipole, nano-patch, etc.
- There are several quantum effects that alter the propagation of EM waves in graphene.
- For this, we need a new antenna theory.



Why Graphene-based Nano-antennas?

- The main property of graphene-based nano-antennas is that the EM wave propagation speed can be up to 100 times lower than in the free space or in conventional materials.
  - As a result, the radiation frequency of these antennas can be also two orders of magnitude lower.
  - E.g., for a 1um long antenna this frequency is in the Terahertz Band (0.1-10 THz).

Simulation

- There are no EM simulation tools which are able to simultaneously:
  - Simulate nanoscale antennas.
  - Include graphene in their material libraries.

Simulation tools

- Graphene simulator
  - **Atomistix toolkit (ATK)**
- Antenna simulators
  - **CST**
  - HFSS
  - IE3D
  - Sonnet
  - EMPro
  - AXIEM

Atomistix toolkit (ATK)

- Computes electronic structure and transport properties of nanoscale structures:
  - E.g. nanotubes, graphene nanoribbons, molecular electronics devices, magnetic tunnel junctions and other magnetic system, interface structures, nanowires, etc.
- The calculations are based on:
  - Density–functional theory (DFT)
  - Extended Huckel theory
  - Classical potentials
  - Non–equilibrium Green's function

Why not ATK?

- ATK is an electronic simulation tool…
- …but ultimately we need an **EM field solver**.

It is easier to adapt an EM field solver to use graphene, rather than implementing a field solver in an electronic simulation tool.

CST Microwave studio

- CST is a EM simulation tool for classical EM analysis:
  - Enables the fast and accurate analysis of high frequency (HF) devices such as antennas
  - Offers a number of different solver for different types of application

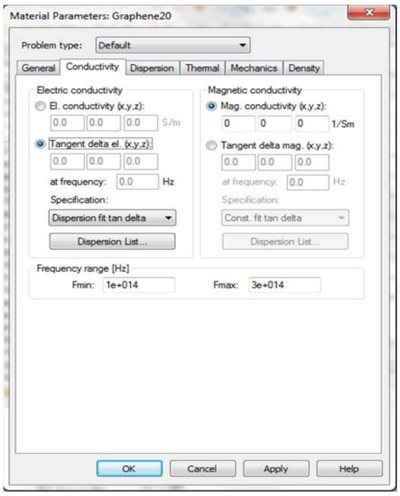
...but it does not have a model for graphene.

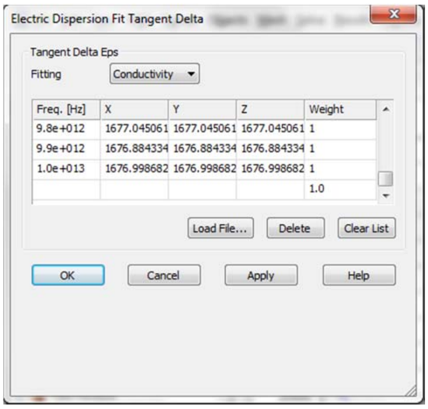
Defining graphene in CST

- There are some approximate conductivity models for graphene which we can use:
  - **Complex permittivity model**
    (accounts for intraband and interband transistions of electrons)
    Gusynin, V. P., Sharapov, S. G., and Carbotte, J. P., "AC conductivity of graphene: from tight-binding model to 2+1-dimensional quantum electrodynamics," International Journal of Modern Physics B, vol. 21, pp. 4611, 2007.
  - **Drude approximation**
    (only accounts for intraband transitions of electrons)
    Hanson, G., "Dyadic Green's Functions for an Anisotropic, Non-Local Model of Biased Graphene," IEEE Transactions on Antennas and Propagation, vol. 56, pp. 747-757, 2008.

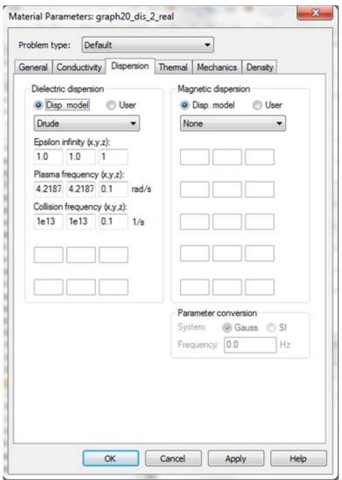
New Material (1)

- In order to define the conductivity of graphene:
  - First, we consider the complex conductivity model by using the numerical values obtained with Matlab from the previous papers.





New Material (2)



- Second, as an alternative, we use the Drude approximation and define the graphene conductivity just with:
  - The Plasma Frequency
  - The Collision Frequency

New Material (3)

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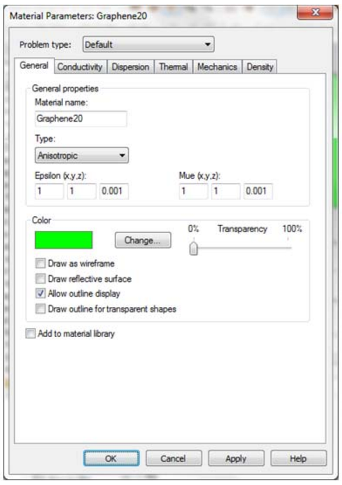

- Graphene is a 2D material (it is just one atom thick!)...
- ... but CST can only simulate 3D structures.
- For this, we define graphene as an anisotropic material with very low (~0) permittivity in the Z axis (the thickness of the material)

Patch Antenna

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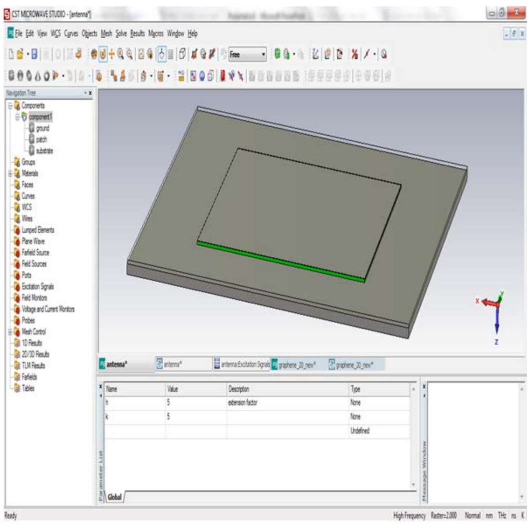
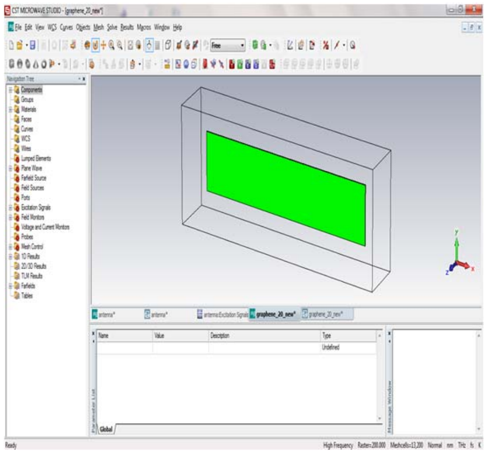
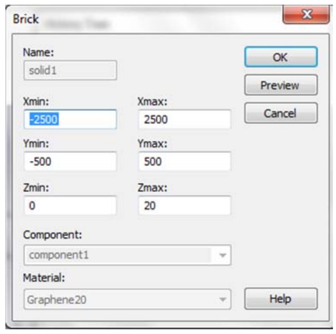
- Consists of three parts:
  - Ground plane (PEC material)
  - Dielectric
  - Patch (Graphene)

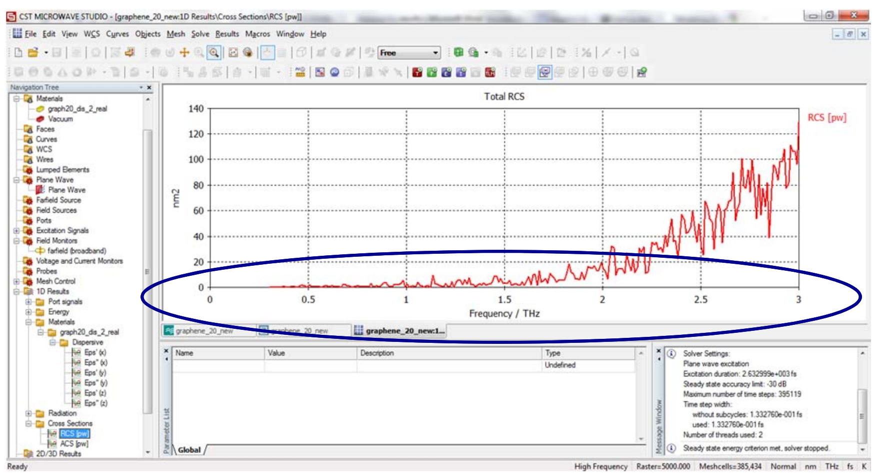


Graphene Sheet



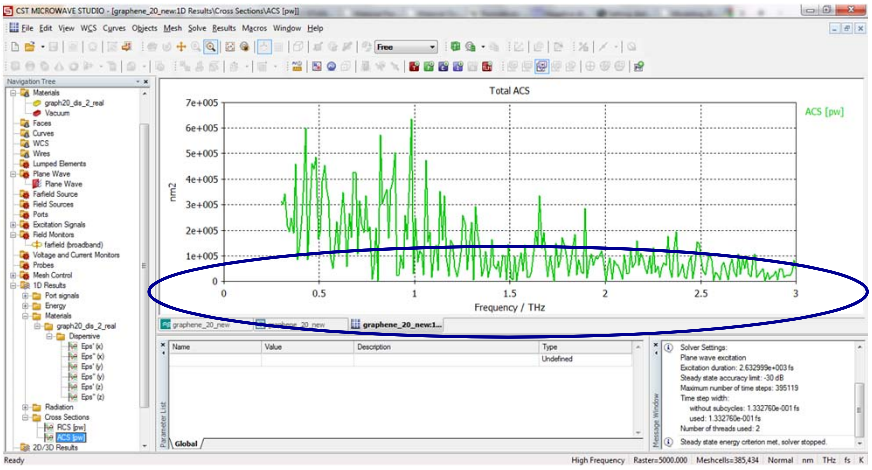


Results 1 : Radar Cross Section



- Work in progress…

Results 2 : Absorption Cross Section



- Work in progress…

Conclusions

- We can use CST to simulate graphene based nano-antennas.
  - We need a good model for graphene.
    - So far we have used some approximate models but we need a more accurate model for graphene nano-ribbons.
- We will need to validate these results with experimental measurements.
    - Maybe when ELCONA comes?

Thank you for you attention!

Anastasia Pantazopoulou
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