GreEnergy
Power from optical antennas

Characterization of two- and three-terminal graphene diodes by fully-ballistic or semi-classical methods

Davide Mencarelli

Università Politecnica delle Marche, Via Brecce Bianche 12, 60131, Ancona, Italy

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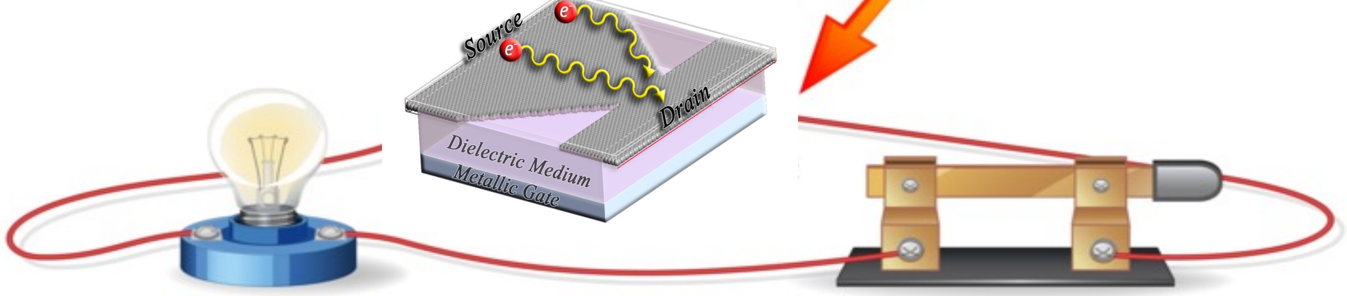
Research objectives of GREENERGY

H2020-LC-SC3-2018-2019-2020

graphene geometric diode



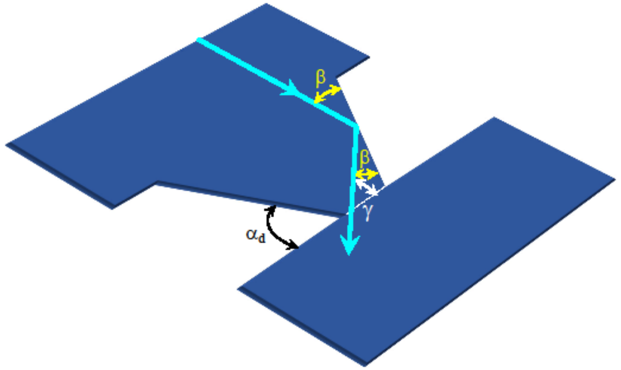
1. Optical nanoantennas:
wide bandwidth, dual polarization, angle independent

2. Nano-rectifiers based on **graphene geometric diodes** to optical frequencies

3. On-chip integration of antenna rectifier with **energy storage** components

Modelling charge transport in geometric diodes

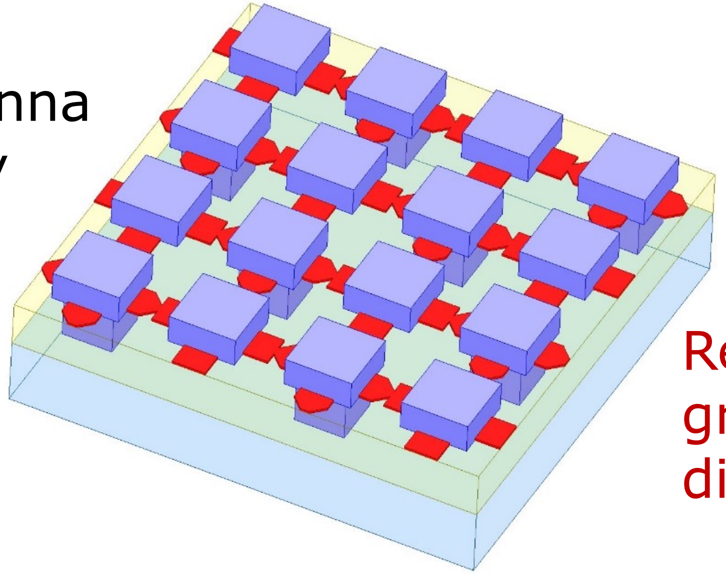
1. DFT based approach
2. MonteCarlo
3. Scattering Matrix (Landauer)
4. Drift-diffusion



Very different approaches with completely different assumptions

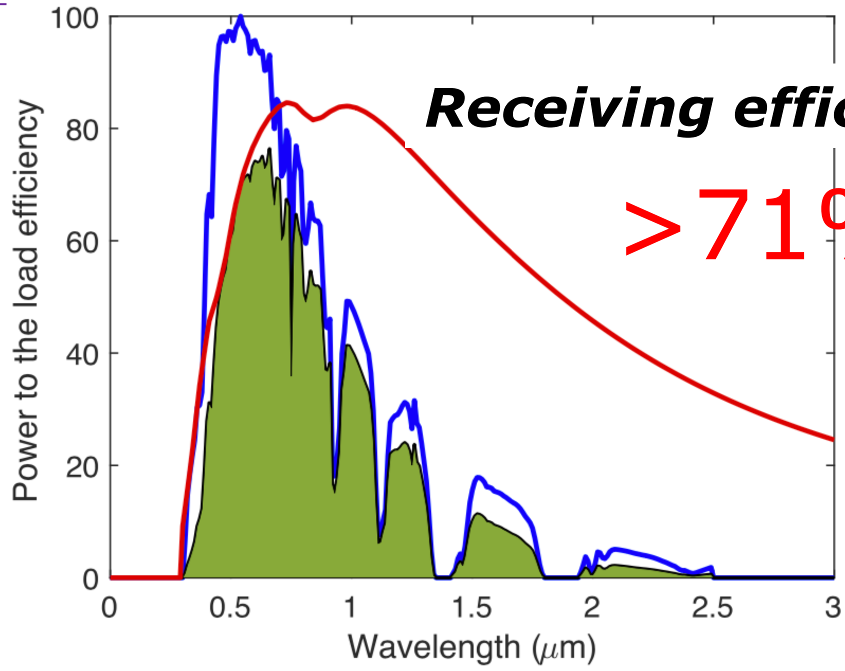
Optical simulation of the proposed architecture

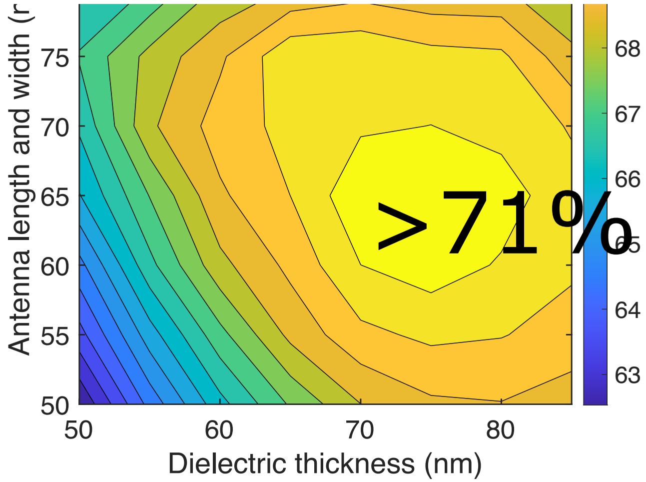
Antenna array



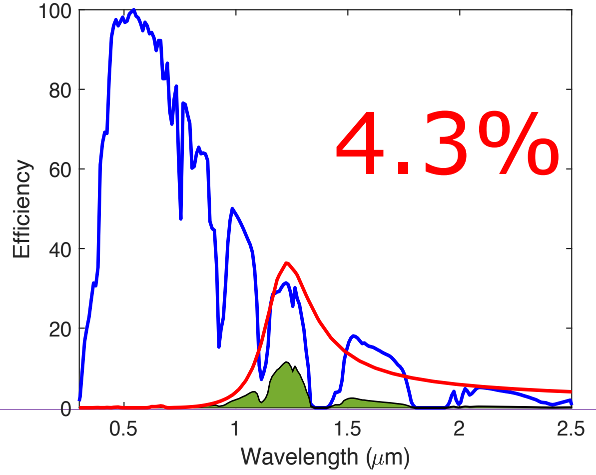
Blue squares: metal patches

Red squares: graphene ballistic diodes





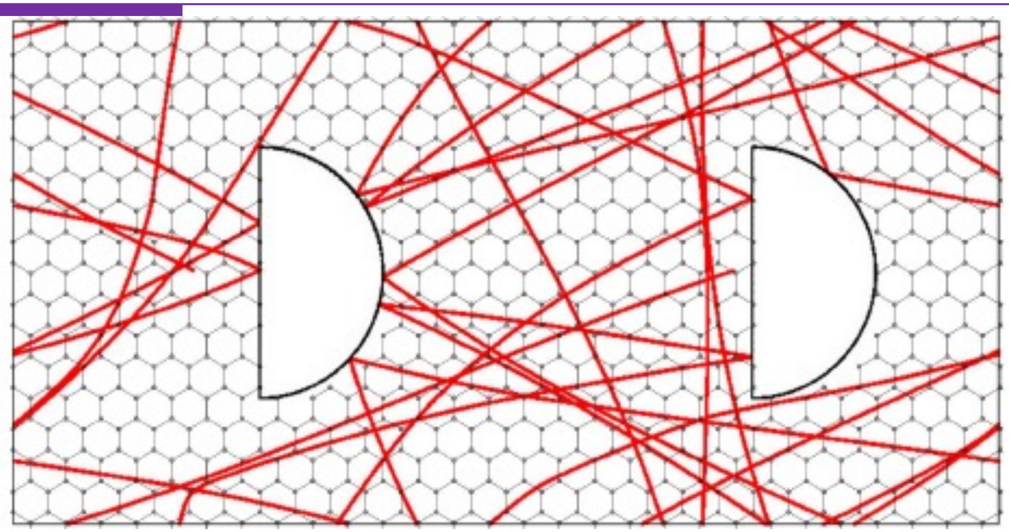
< 30% is dissipated or reflected



State of the art before GreEnergy

Modelling charge transport in geometric diodes

The ratchet effect is **a collective motion** of particles in a preferential direction, **due to spatially-asymmetric perturbations**



L. Ermann and D. L. Shepelyansky: Relativistic graphene ratchet

Semi-disk holes

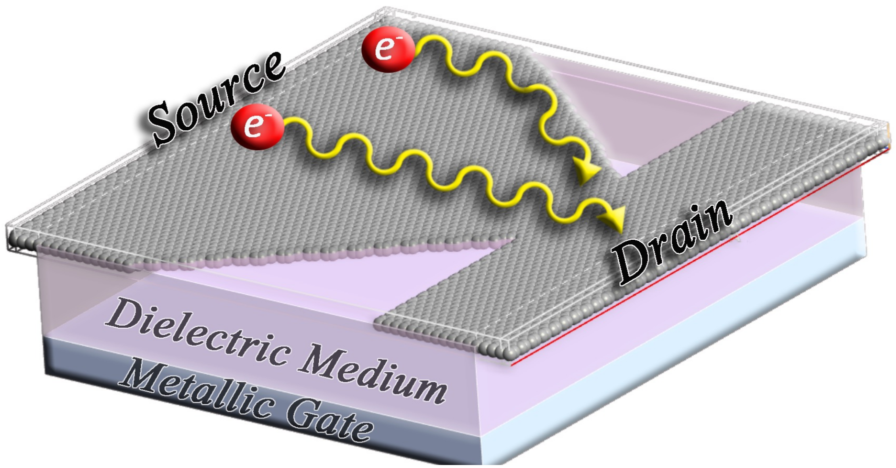
An external action is needed, to have the 2nd Law of thermodynamics preserved

In our case, EM fieds at optical frequencies

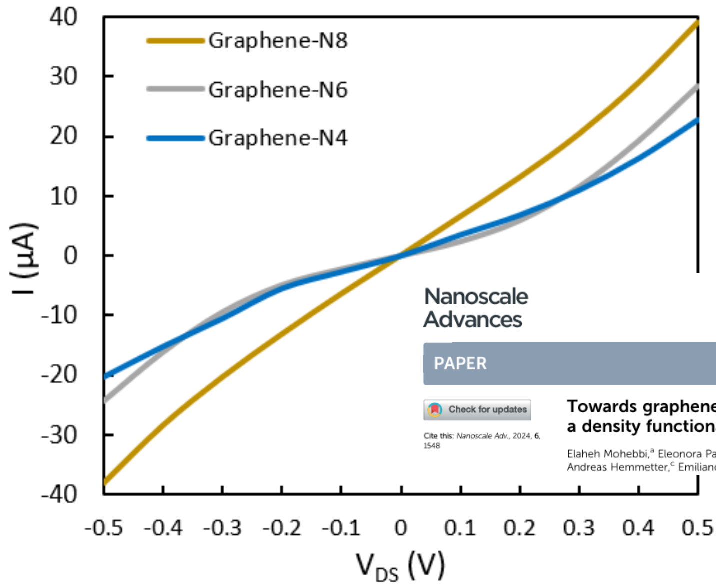
Summarizing, **two conditions** required:

1) breaking of spatial or temporal inversion symmetry
2) breaking of equilibrium (thermal, electrical mechanical)

#1 Modelling of geometric diodes: DFT based approach



Very large asymmetric graphene diodes by Density Functional TB approach



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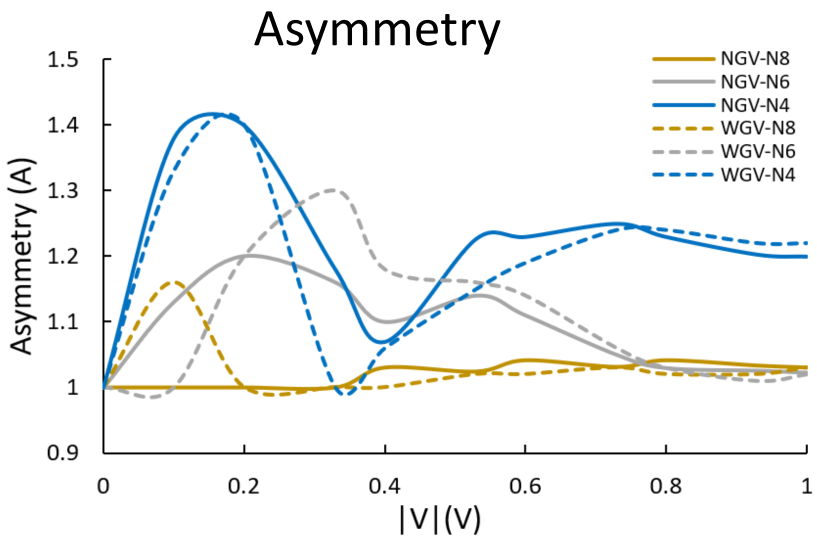
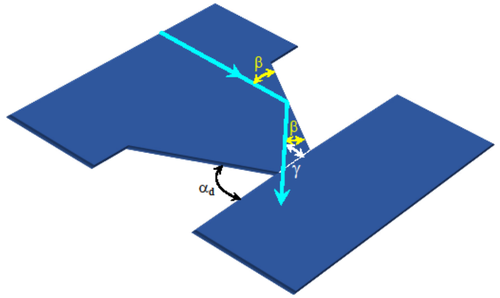
Towards graphene-based asymmetric diodes: a density functional tight-binding study

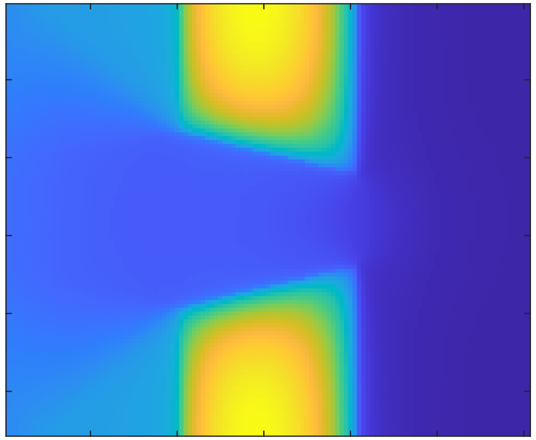
Elaheh Mohebbi,[a] Eleonora Pavoni,[a] Luca Pierantoni,[b] Pierluigi Stipa,[a] Andreas Hemmetter,[c] Emiliano Laudadio*[a] and Davide Mencarelli[b]

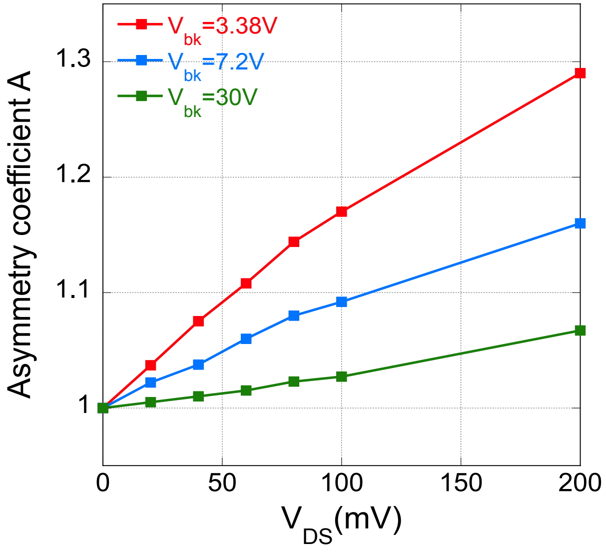


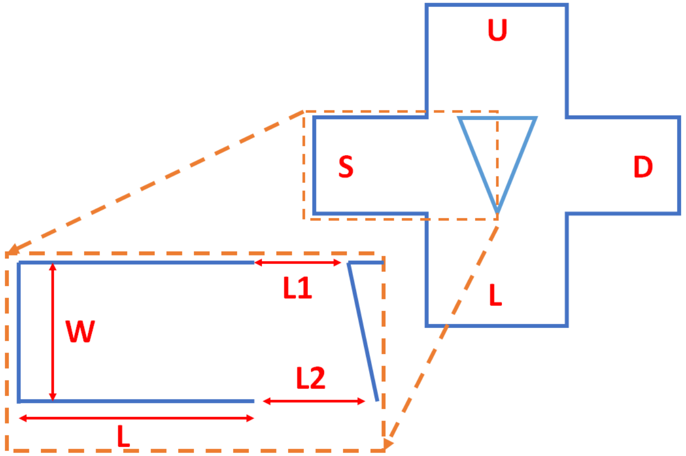
#2 Modelling of geometric diodes: MonteCarlo

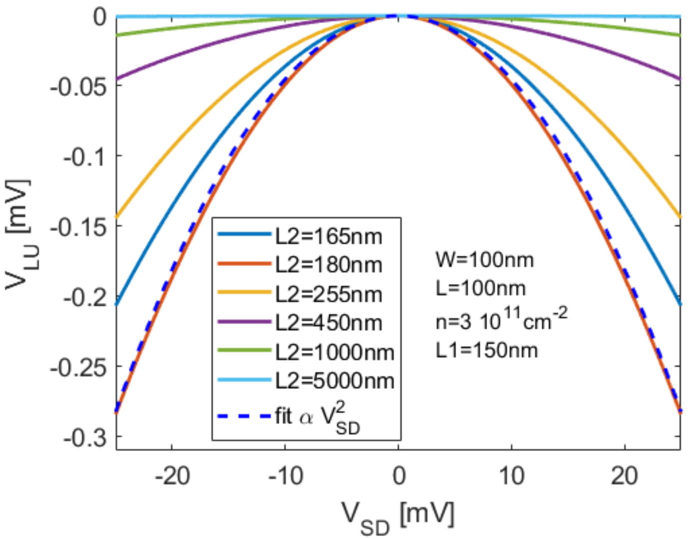
[data from D. Truccolo, M. Midrio et al., UNIUD]











Parabolic relation between input and ouput voltages

#3 Modelling of geometric diodes: Scatt. Matrix

Current from scattering parameters

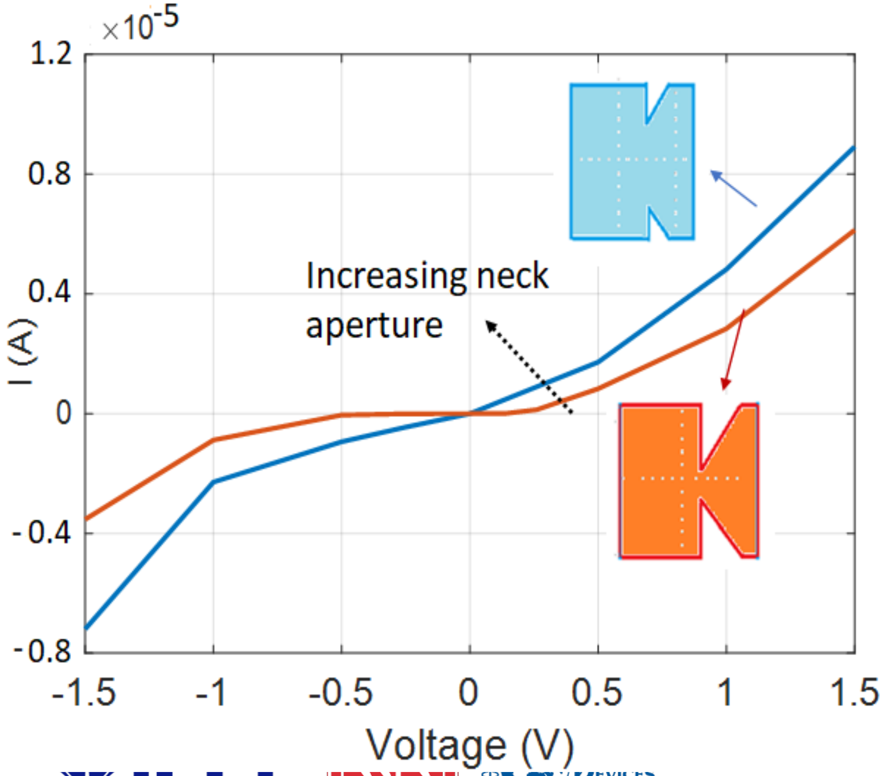
$$I_m^q = \frac{2e^2}{h}\int\left[\sum_{n=1,n\neq m}^{N}\sum_{p} T_{n,m}^{p,q}(E)\right]dE$$

$$I_m = \sum\nolimits_q I_m^q$$

Charge density

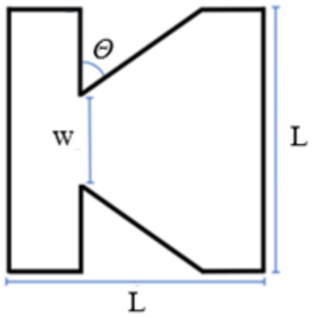
$$n = \int f(E,E_F)\,\frac{E}{\pi(h_t\,v_F)^2}$$

where $E_F \in [0.2\ eV - 0.3\ eV]$



L	≈ 15 nm
w	≈ 8 nm
Θ	60°

L	≈ 15 nm
w	≈ 4 nm
Θ	60°



Example : increasing neck size

a. the I-V asymmetry decreases

b. the amount of current increases (diode impedance decreases)

c. the reverse-bias current increases

#3 Modelling of geometric diodes: Scatt. Matrix

From 2-terminal devices to 3- (or more) terminal devices

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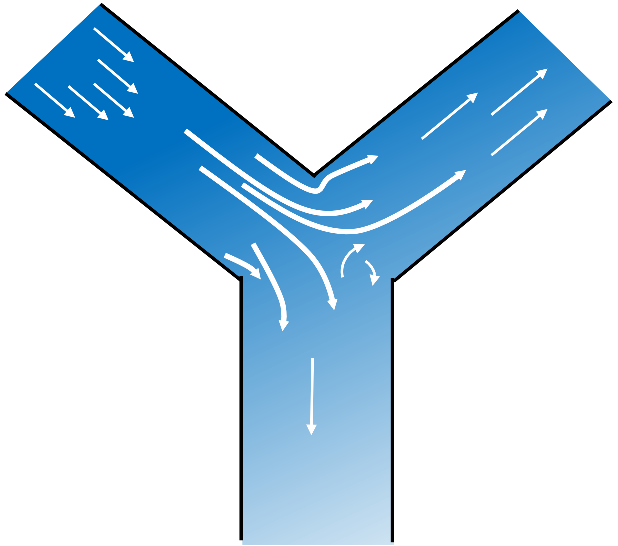
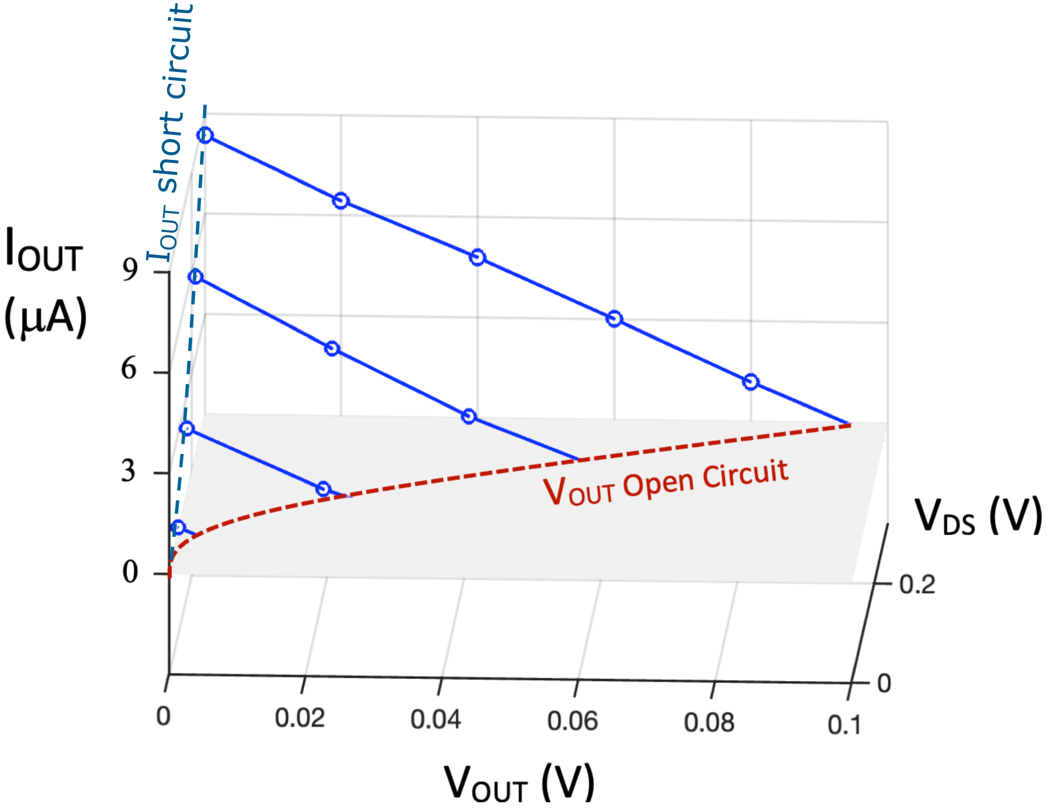
RESEARCH ARTICLE

Current-Voltage Characterization of Multi-Port Graphene Based Geometric Diodes for High-Frequency Electromagnetic Harvesting

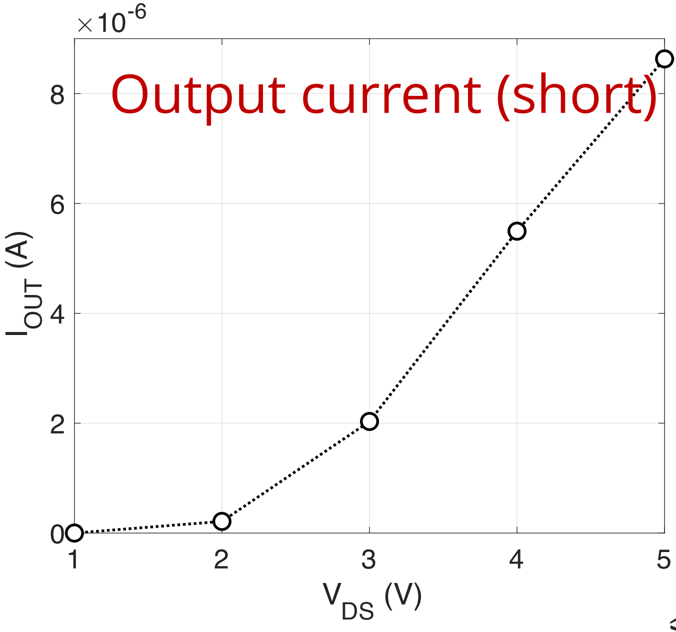
DAVIDE MENCARELLI[1,2], GIAN MARCO ZAMPA[1], (Graduate Student Member, IEEE), AND LUCA PIERANTONI[1,2]



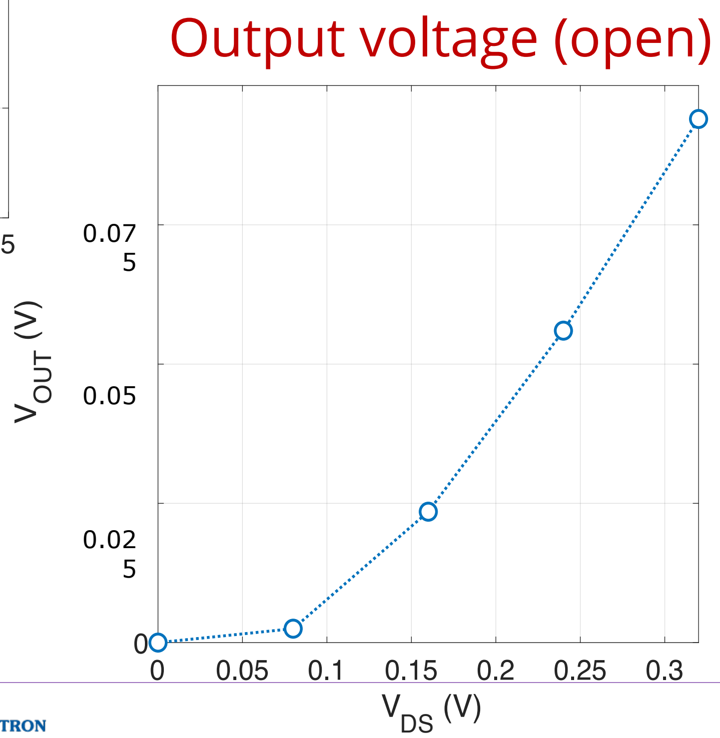


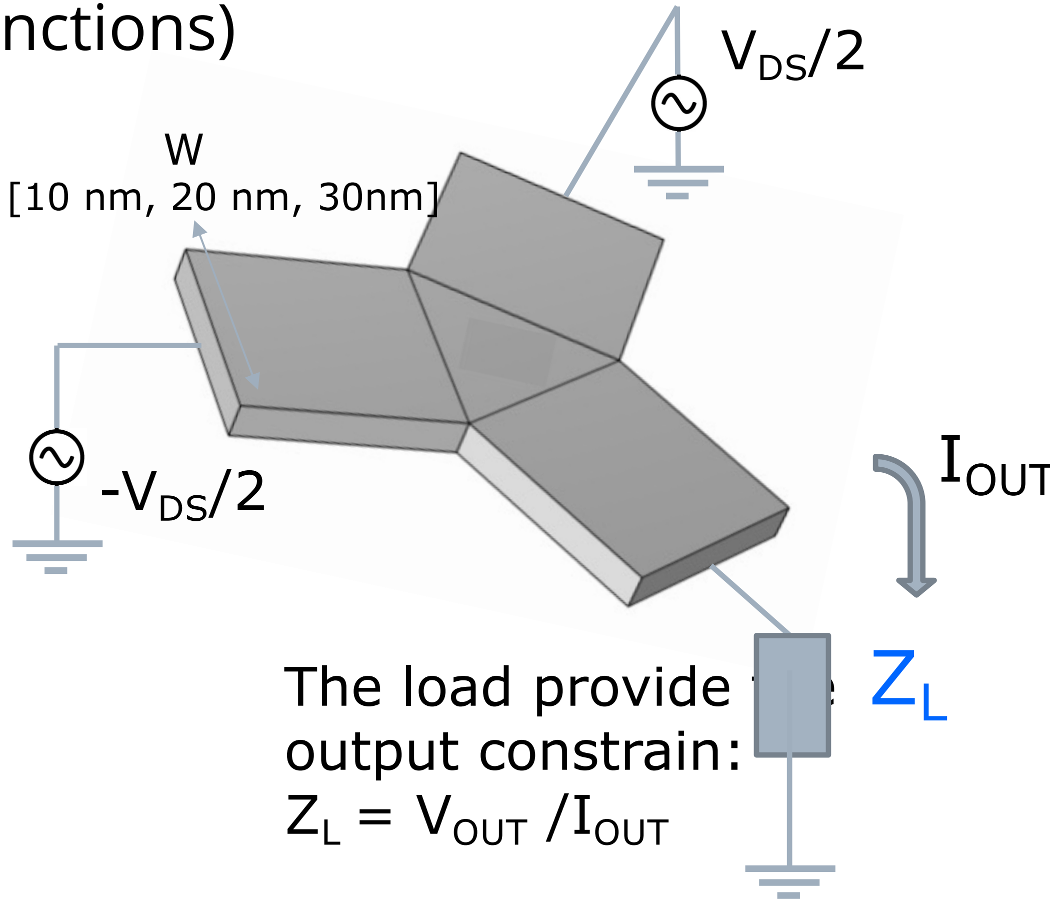
V_{DS}=0.16 V			
Width	**V_{OC}**	**I_{SC}**	**I_{DS}**
10 nm	25 mV	≈ 9 uA	≈ 18 uA
20 nm	18 mV	≈ 24 uA	≈ 50 uA

#3 Modelling of geometric diodes: Scatt. Matrix



Quantum coherent transport (Tight-Binding wave-functions)





The load provide the output constrain:
$Z_L = V_{OUT} / I_{OUT}$

#4 Modelling of geometric diodes: Drift-Diffusion

..the above methods require **very long simulation time**!

Can drift-diffusion of charges explain rectification from geometric diodes?

Electric potential $\nabla \cdot (\varepsilon \nabla V) = \rho = p - n$

Electron current $\nabla \circ (-D_n \cdot \nabla n - \alpha_n \cdot n + \gamma_n) = 0$

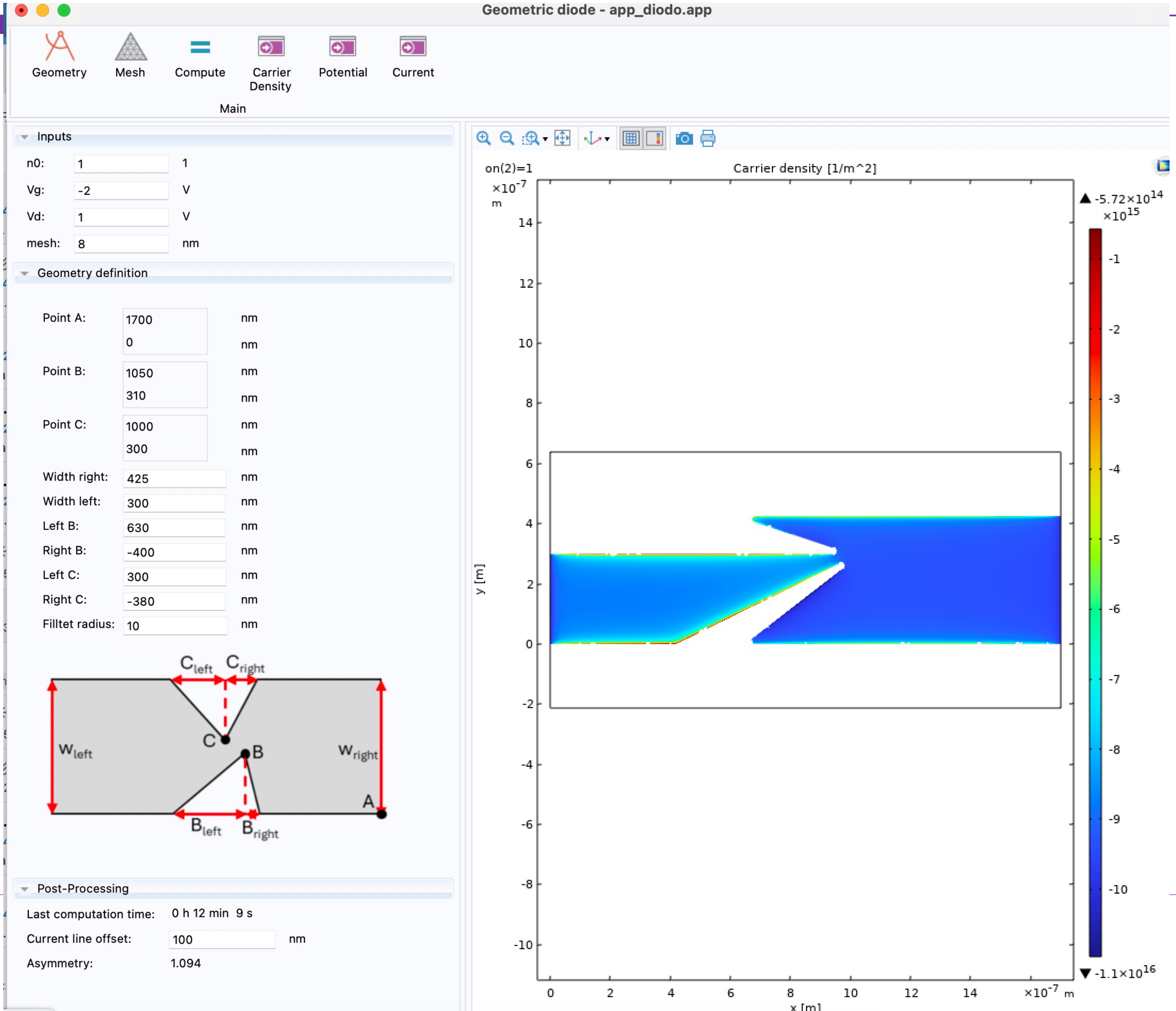
Hole current $\nabla \circ (-D_p \cdot \nabla p - \alpha_p \cdot p + \gamma_p) = 0$

$D_{n,p}$: diffusion coefficient

The interplay between (1) asymmetric potential and (2) diffusion in an asymmetric geometry provides an asymmetric response

#4 Modelling of geometric diodes: Drift-Diffusion

[Comsol portable application]

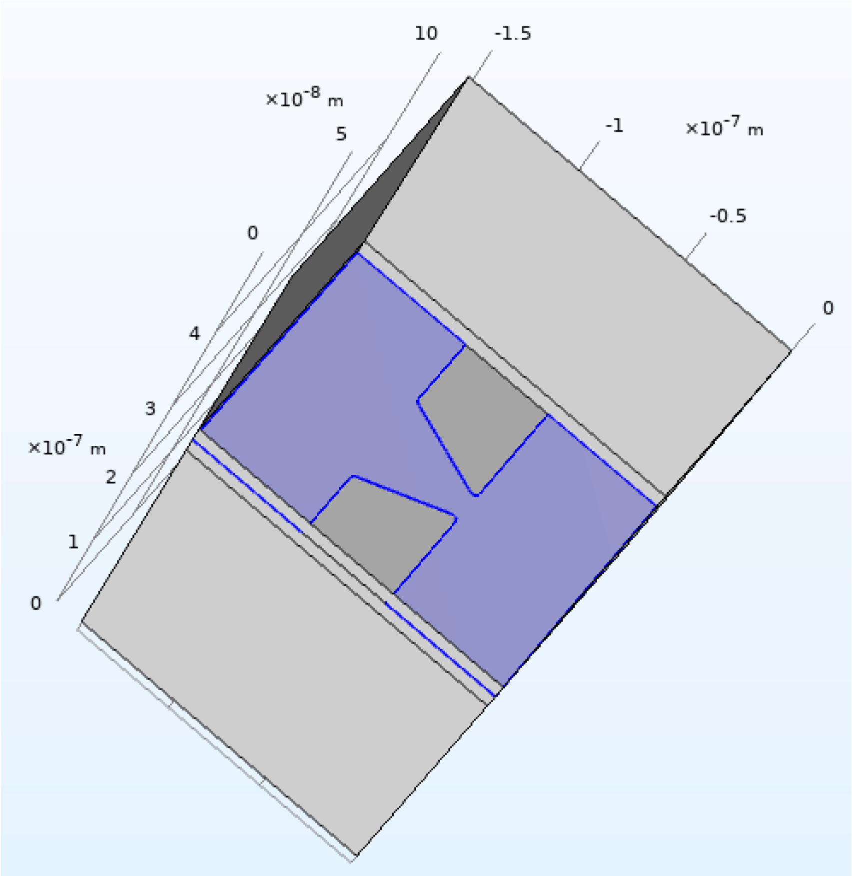


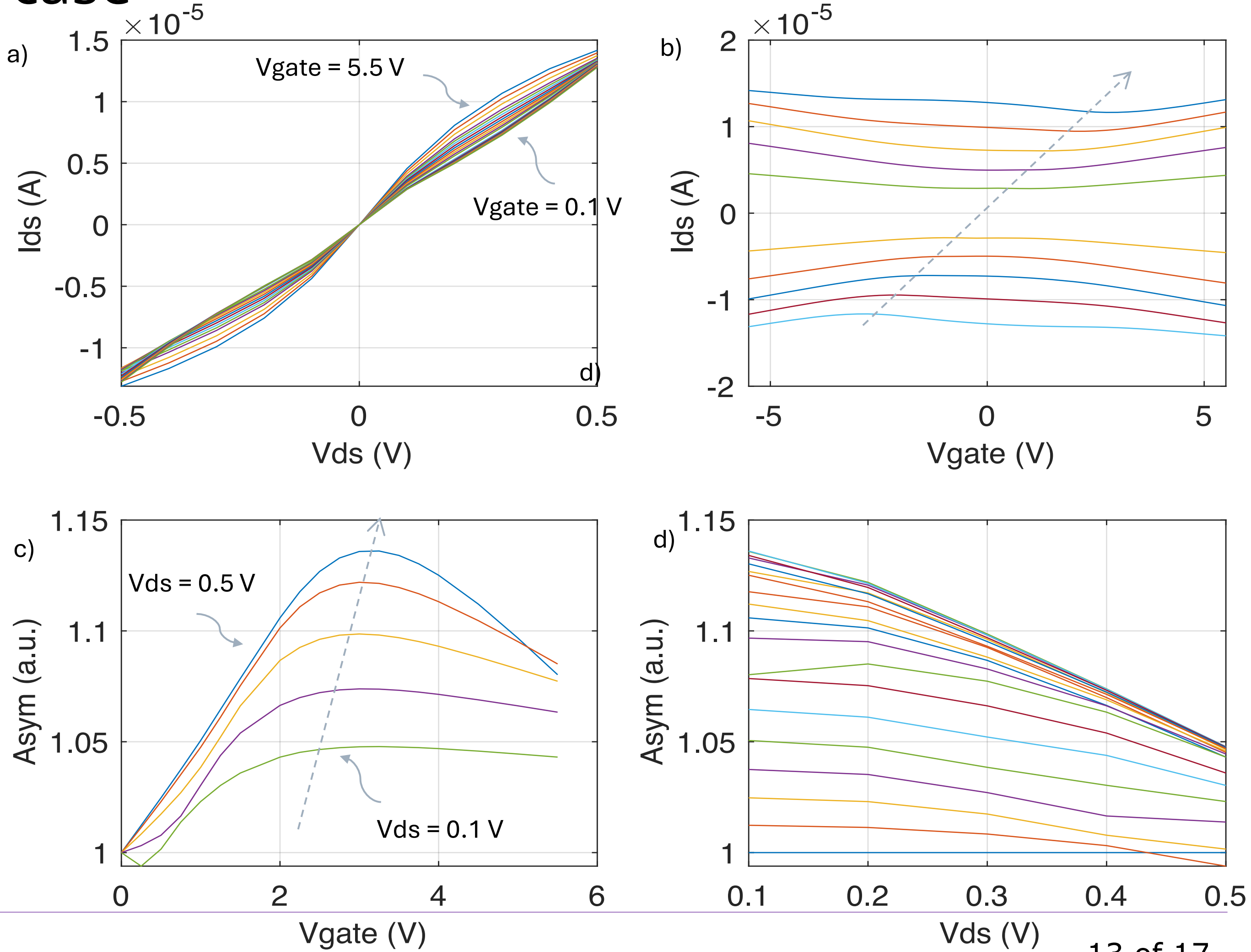
Arbitrary geometry

IEEE SSCS Electron Devices Society

#4 Modelling of geometric diodes: Drift-Diffusion

Example: 2-port bipolar transport case

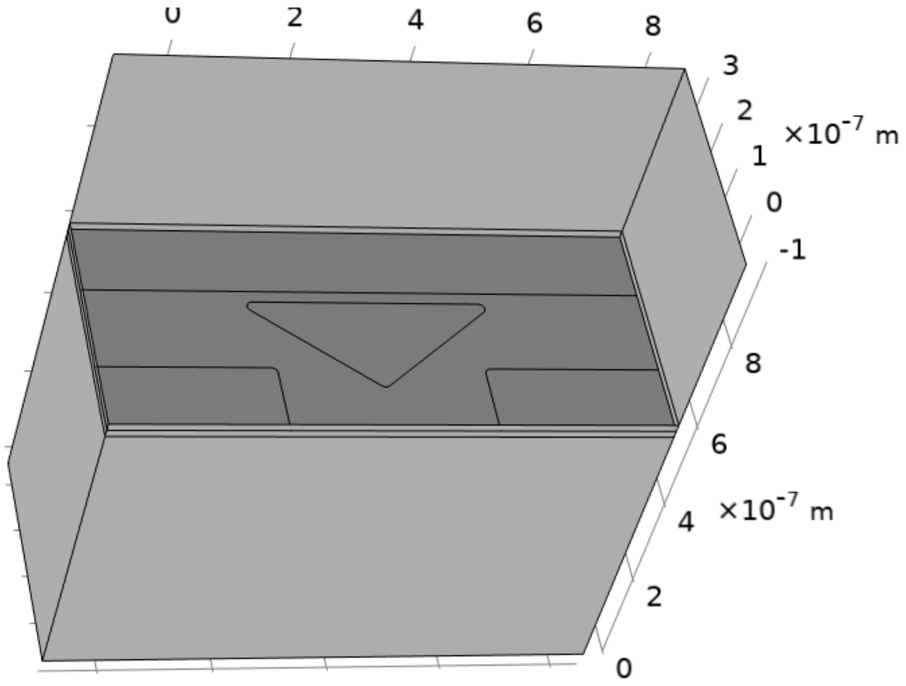


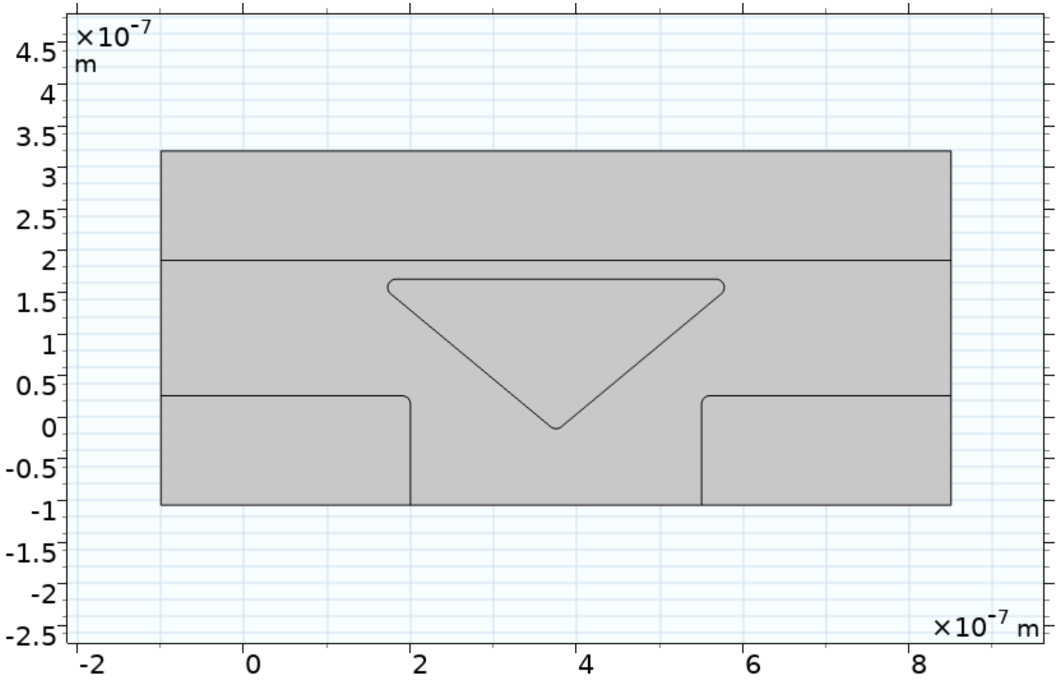


#4 Modelling of geometric diodes: Drift-Diffusion

Model extension to many port devices

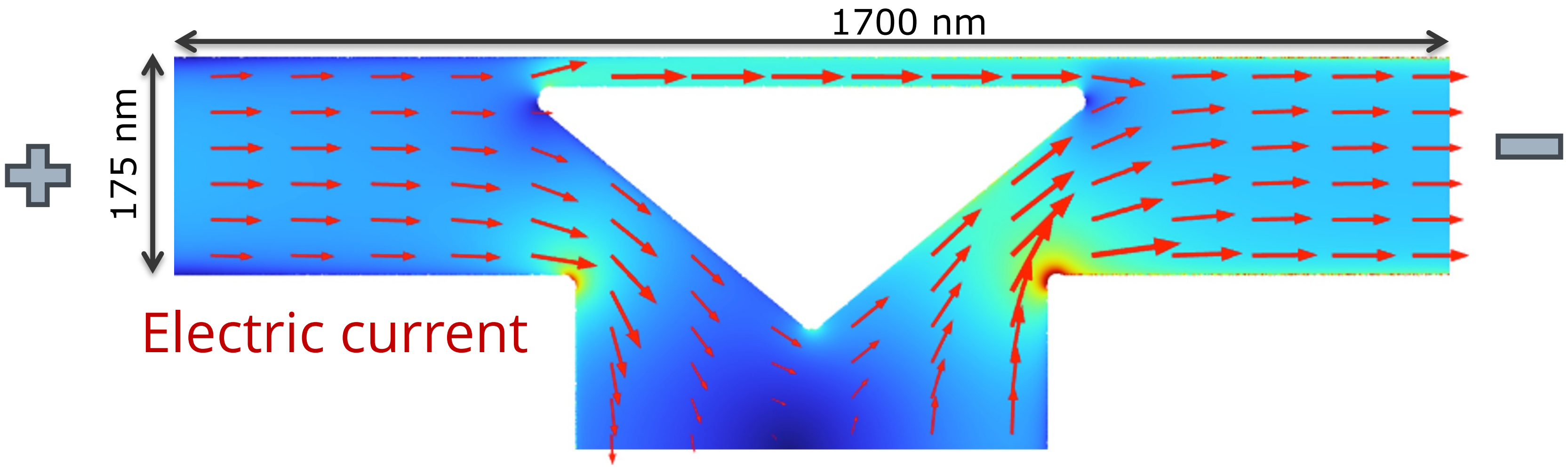
$$\nabla \cdot (\varepsilon \nabla V) = \rho \qquad \nabla \circ (-c \cdot \nabla n - \alpha \cdot n + \gamma) = 0$$



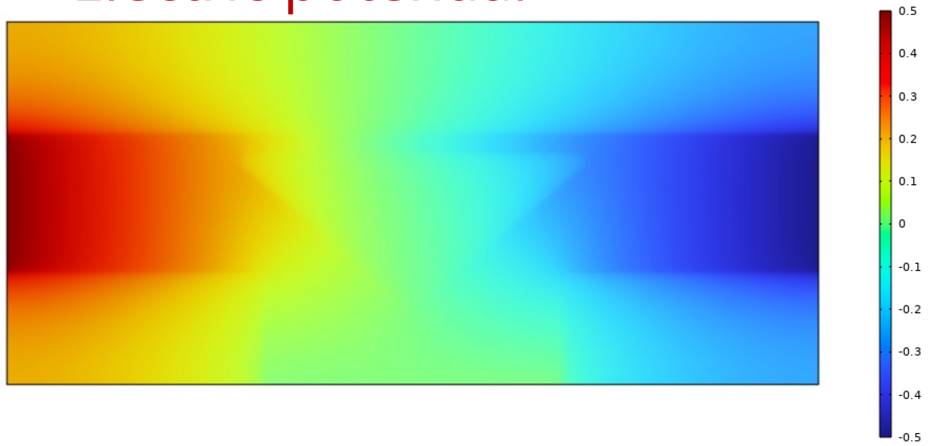


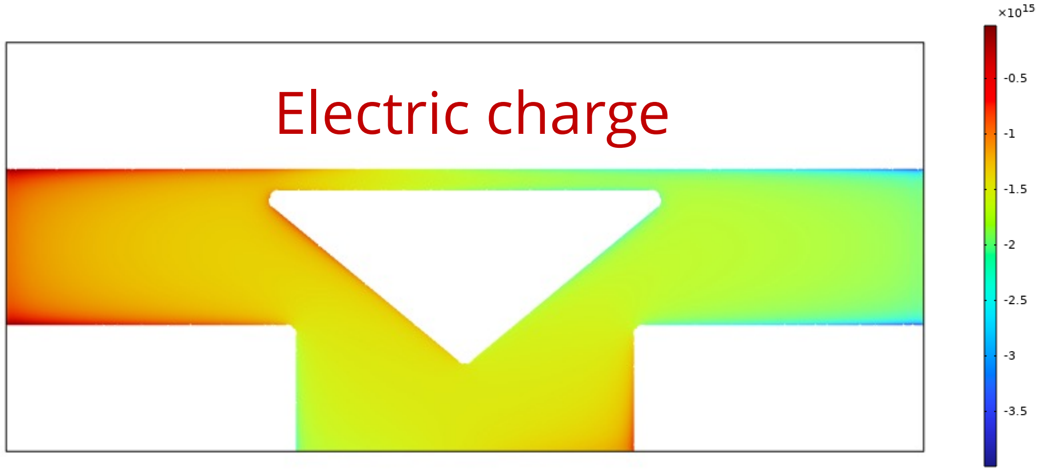
#4 Modelling of geometric diodes: Drift-Diffusion

Output physical observables



Electric potential





#4 Modelling of geometric diodes: Drift-Diffusion

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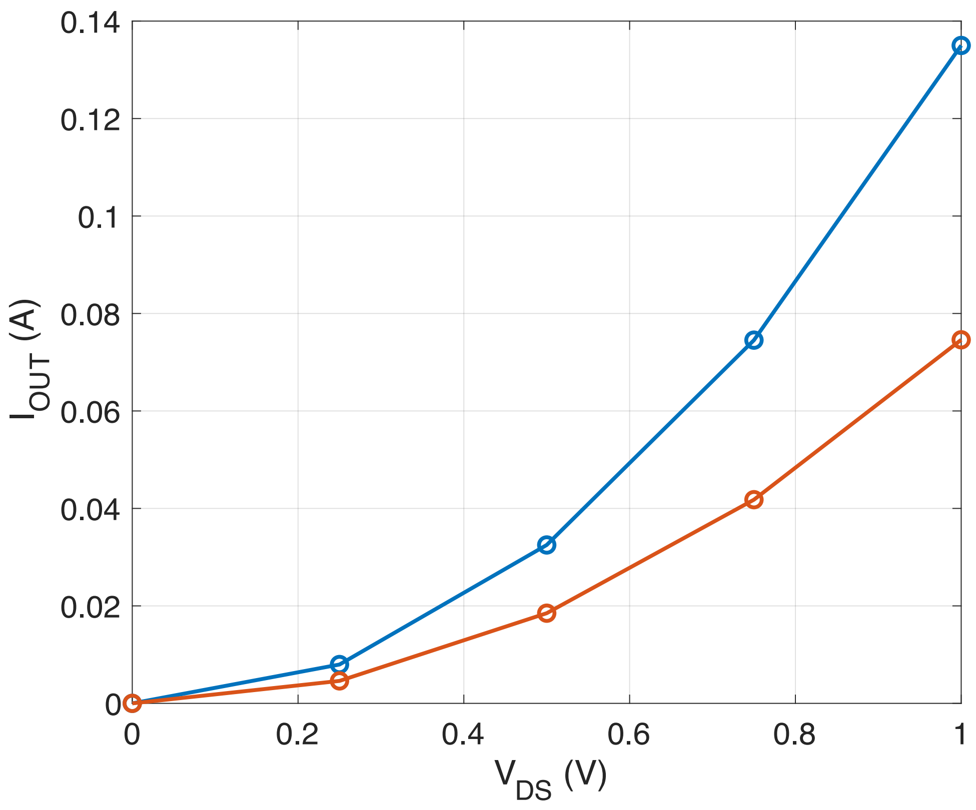
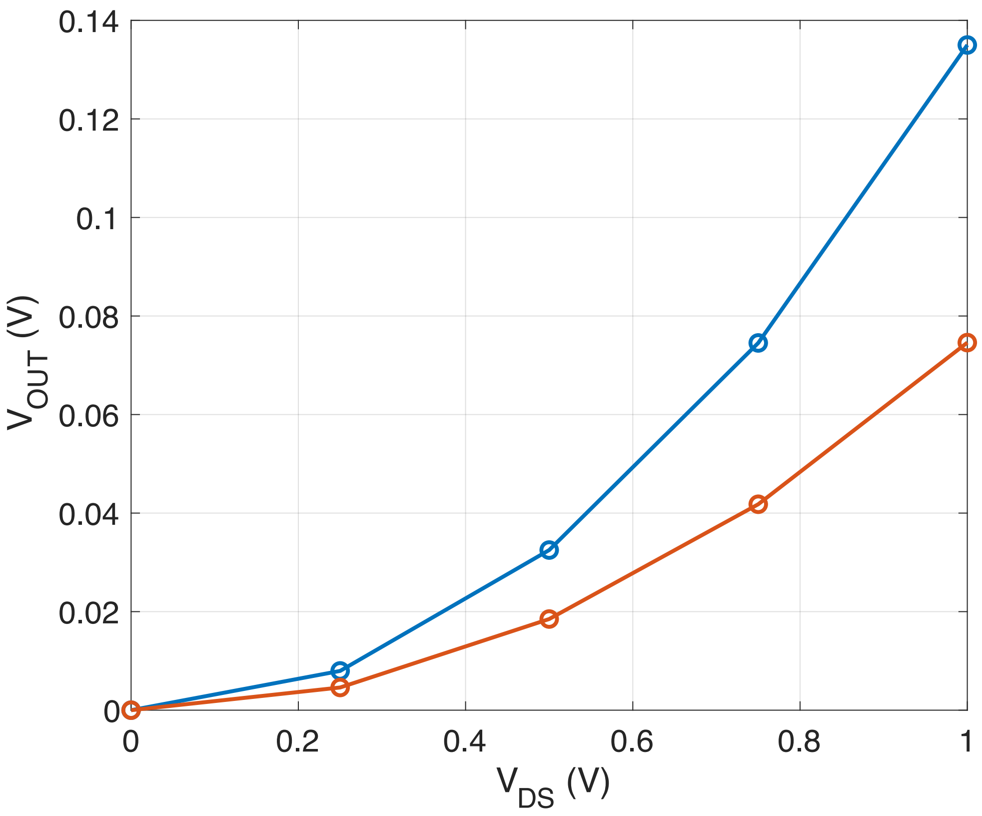
Output current (short)



Output voltage (open)



Diode of the previous slide

Diode scaled down 50%

Thank you!

GreEnergy
Power from optical antennas

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