Turbo Codes for Deep Space Communications: CCSDS 131.0-B-2 standard implementation

Final project for the Channel Coding course

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DEPARTMENT OF
INFORMATION
ENGINEERING
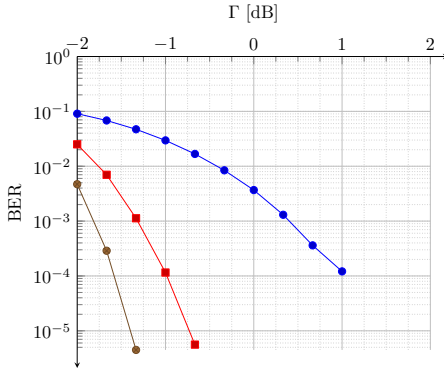UNIVERSITY OF PADOVA

Electro-optic modulators

Convert electronic signal to high bit-rate optical signal.

Desired features:

- high switching speed
- high bandwidth
- small footprint (*Nanoscale...*)
- compatibility with on-chip electronic components
- low insertion loss
- energy efficiency

- Flexible
- Robust
- Small footprint
- Great thermal characteristics
- High electron mobility
- Voltage-dependent optical conductivity

Great for high speed optical modulators!

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However...

...small dimensions of graphene can be a problem:

- operating wavelength (1550 nm) is huge in comparison
- need to enhance interaction with light
- new waveguide designs must be studied
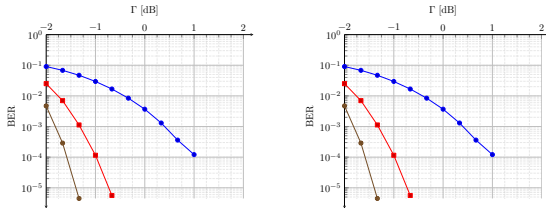
[Xu et al., 2004, Sun et al., 2007]
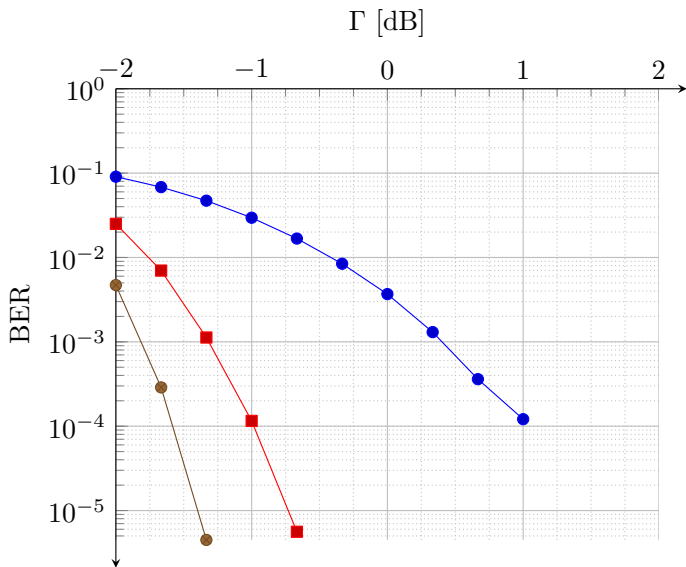
Light-graphene interaction

Two different phenomena:

- **Interband absorption:** photon get absorbed and electron moves to conduction band
- **Intraband absorption:** photon get absorbed and electron stays in same band but in a higher level
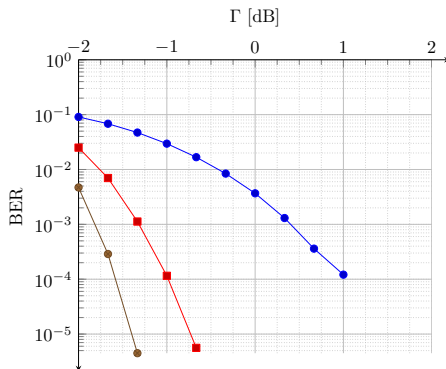
Conductivity

$$\sigma_g = \sigma_{inter}(\omega, \mu_c, T) + \sigma_{intra}(\omega, \mu_c, T)$$
$$\simeq \sigma_{inter}(\omega, \mu_c, T) \qquad \text{when } \mu_c < \hbar\omega/2$$
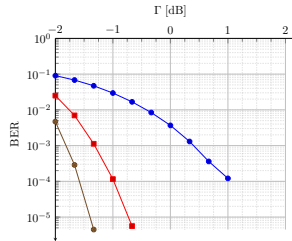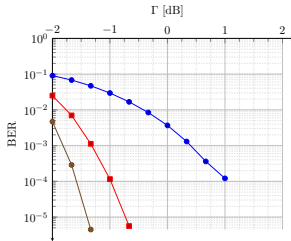
Conductivity of graphene

[Cho et al., 2011]

Large footprint required to obtain adequate modulation depth
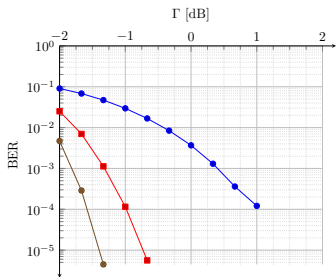
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Novel design: slot waveguides

$\lambda = 1550$ nm, $n_{co} = 1.46$, $n_{cl} = 3.48$, $w_{co} = 101$ nm. [Xu et al., 2004]

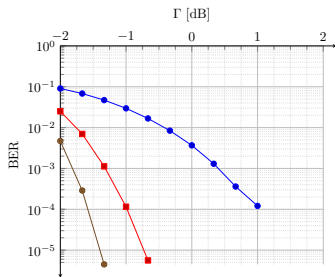**Absorbed power per unit area**

$$P \propto \frac{1}{2}|\mathbf{E}| \cdot \frac{Im\{\varepsilon_{eff}\}}{|\varepsilon_{eff}|}$$

Bandwidth > 1.25 THz

$\Delta V = 1.32\,V$

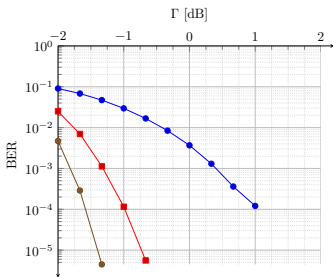Cu is preferred (CMOS compatible), but has higher losses than Au, Ag.

Plasmonic-graphene waveguide modulator

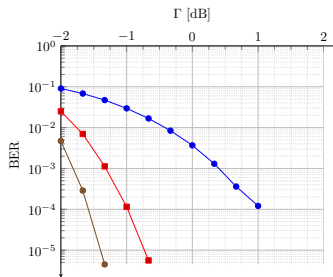200 nm wide, silicone nitride 10 nm thick (both layers), length 120 nm.
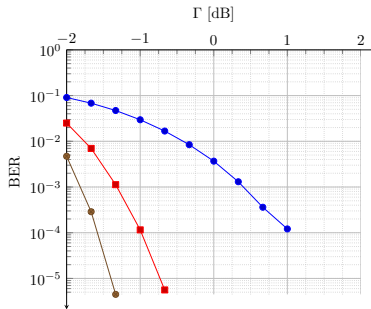
Footprint $\sim 2 - 3\ \mu m^2$

Bandwidth > 1 THz

$\Delta V = 1.38\,V$

Energy consumption $\sim$ 0.12-0.13 pJ/bit

Did we meet any requirement?

- high bandwidth   Yes
- energy efficiency   Yes
- compatibility with on-chip electronic components   Yes
- low insertion loss   Yes
- small footprint   Kinda
- high switching speed   Potentially

- Fix one arm in "dielectric state" (low loss) of graphene
- Exploit changes in $Re\{\varepsilon_{eff}\}$ wrt gate voltage to induce phase change
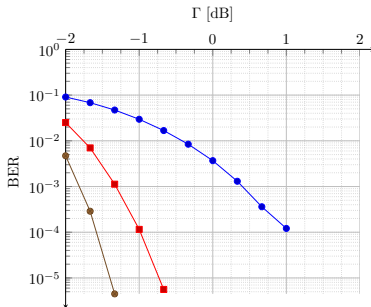
[Phatak et al., 2016]

Thank you!

📄 Cho, S., Yoon, M. C., Kim, K. S., Kim, P., Kim, D., Ulin-avila, E., and Zentgraf, T. (2011).
A graphene-based broadband optical modulator.
Nat. (UK), 474(7349):64–6767.

📄 Phatak, A., Cheng, Z., Qin, C., and Goda, K. (2016).
Design of electro-optic modulators based on graphene-on-silicon slot waveguides.
Optics Letters, 41(11):2501.

📄 Sun, R., Dong, P., Feng, N.-n., Hong, C.-y., Michel, J., Lipson, M., and Kimerling, L. (2007).
Horizontal single and multiple slot waveguides: optical transmission at lambda = 1550 nm.
Optics express, 15(26):17967–17972.

📄 Xu, Q., Almeida, V. R., Panepucci, R. R., and Lipson, M. (2004).
Experimental demonstration of guiding and confining light in nanometer-size low-refractive-index material.
Optics letters, 29(14):1626–1628.