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

Final project for the Channel Coding course

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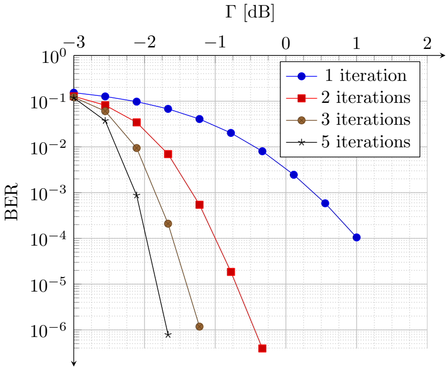
Electro-optic modulators

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

Graphene: why?



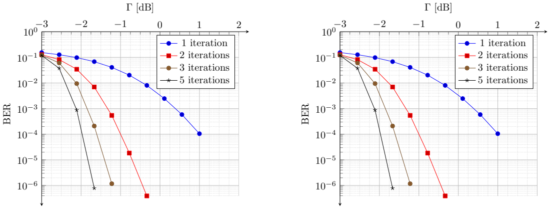
- Flexible
- Robust
- Small footprint
- Great thermal characteristics
- High electron mobility
- **Voltage-dependent optical conductivity**

Great for high speed optical modulators!

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

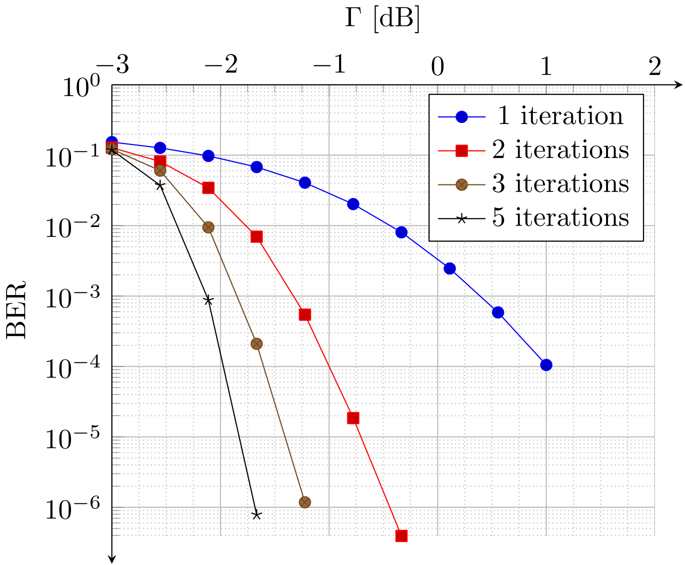
Two different phenomena:

- **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

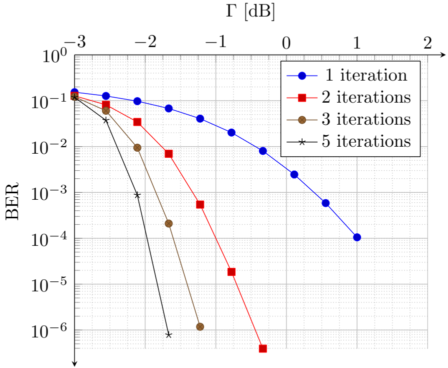
Conductivity

$$\begin{aligned}\sigma_g &= \sigma_{inter}(\omega, \mu_c, T) + \sigma_{intra}(\omega, \mu_c, T) \\ &\simeq \sigma_{inter}(\omega, \mu_c, T) \qquad \text{when } \mu_c < \hbar\omega/2\end{aligned}$$

Conductivity of graphene



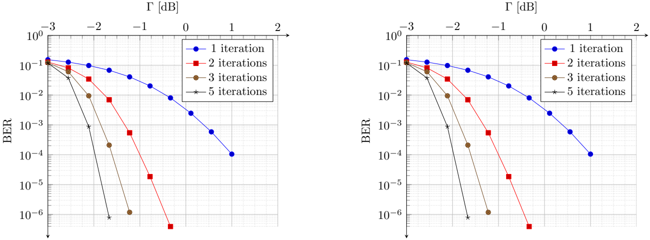
First type of modulator



[Cho et al., 2011]

Large footprint required to obtain adequate modulation depth

Novel design: slot waveguides

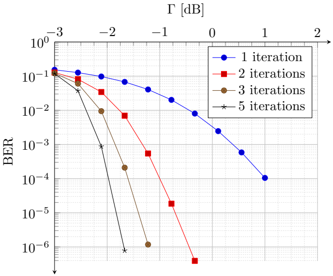


$\lambda = 1550$ nm, $n_{co} = 1.46$, $n_{cl} = 3.48$, $w_{co} = 101$ nm. [Xu et al., 2004]

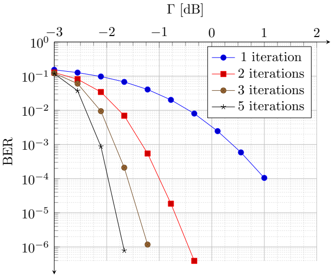
Absorbed power per unit area

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

Wavelength and Voltage dependency

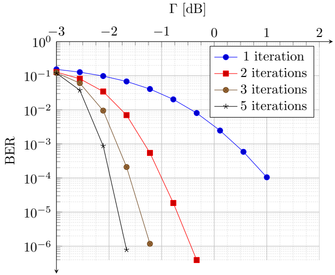


Bandwidth > 1.25 THz



$\Delta V = 1.32\,V$

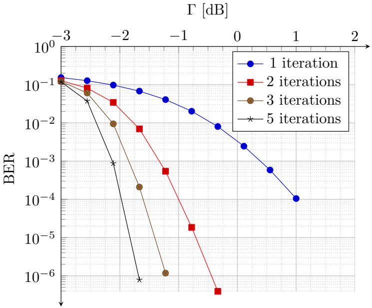
Plasmonic-graphene waveguide modulator



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

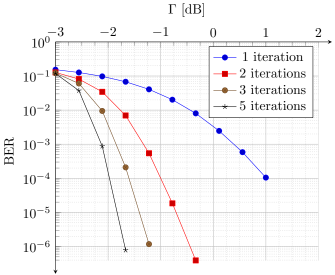
Plasmonic-graphene waveguide modulator

200 nm wide, silicone nitride 10 nm thick (both layers), length 120 nm.

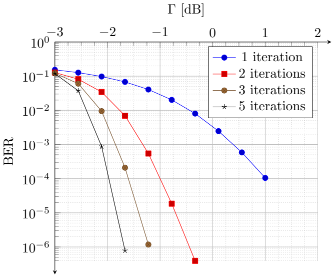


Footprint $\sim 2 - 3\ \mu m^2$

Wavelength and Voltage dependency



Bandwidth > 1 THz



$\Delta V = 1.38\, V$

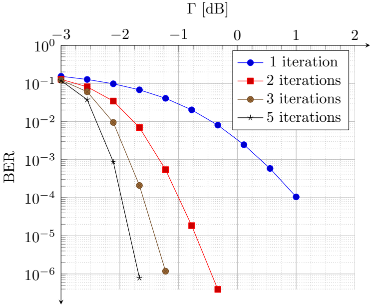
Energy consumption $\sim$ 0.12-0.13 pJ/bit

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

Recent advances: graphene-on-silicon MZI

- 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]

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Thank you!