Electronic Analog of Electro-Optic Modulator

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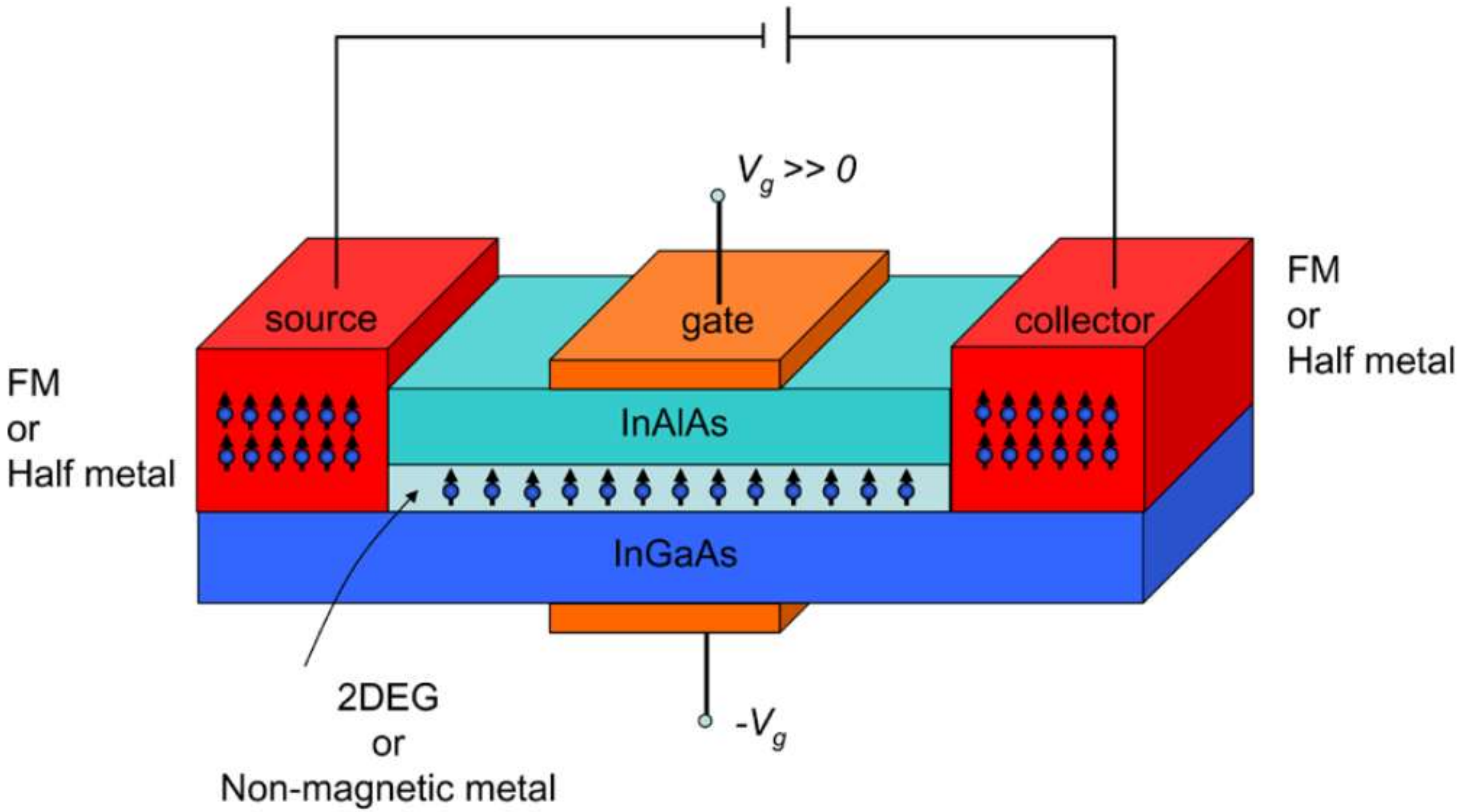
Contents

Motivation



Appl. Phys. Lett, Supriyo Datta and Biswajit Das 56, 665 (1990)

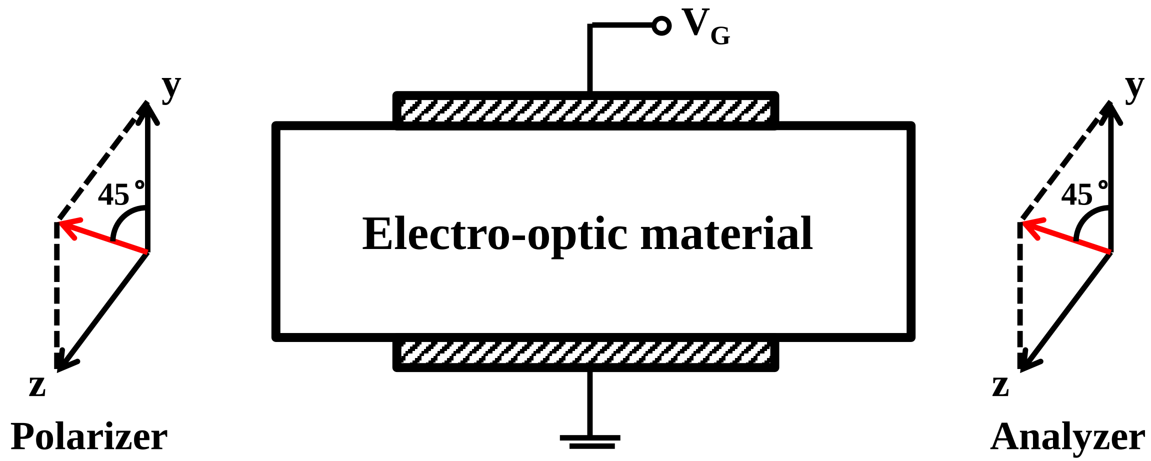
1. Electro-optic modulator

Electronic analog of the electro-optic modulator

- **Electro-optic modulator**

$$\begin{pmatrix}1\\1\end{pmatrix} = \begin{pmatrix}1\\0\end{pmatrix} + \begin{pmatrix}0\\1\end{pmatrix}$$

(45° pol.) (z pol.) (y pol.)



- $\begin{pmatrix}e^{ik_1L}\\e^{ik_2L}\end{pmatrix}$: The light emerging from the electro-optic material
- $\begin{pmatrix}1\\1\end{pmatrix}$: The analyzer at the output lets the component $\begin{pmatrix}1\\1\end{pmatrix}$ along to pass through
- The output power $P_0 \propto \left|(1\ 1)\begin{pmatrix}e^{ik_1L}\\e^{ik_2L}\end{pmatrix}\right|^2$

Electronic analog of the electro-optic modulator

- **Electro-optic modulator**
  - $P_0 \propto \left|(1\ 1)\begin{pmatrix} e^{ik_1L} \\ e^{ik_2L} \end{pmatrix}\right|^2$
  - $\left|(1\ 1)\begin{pmatrix} e^{ik_1L} \\ e^{ik_2L} \end{pmatrix}\right|^2 = \left|e^{ik_1L} + e^{ik_2L}\right|^2$

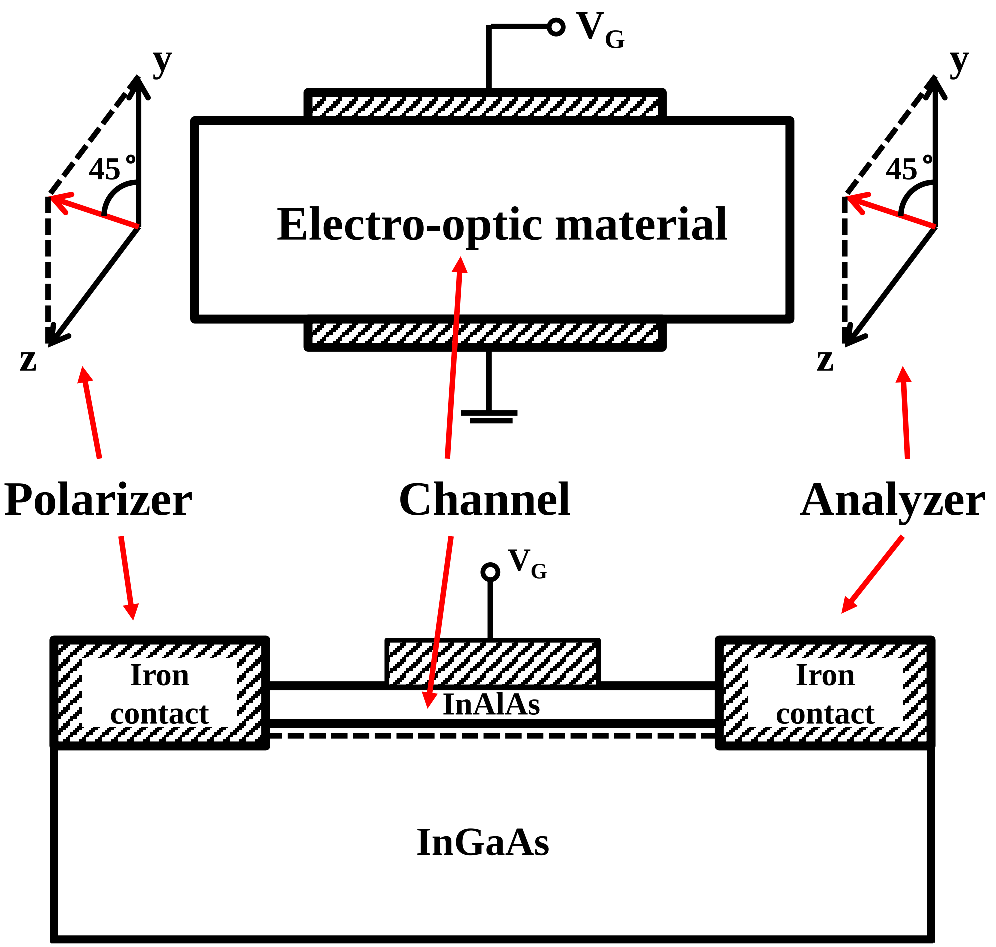
$$= \left(e^{ik_1L} + e^{ik_2L}\right)\left(e^{-ik_1L} + e^{-ik_2L}\right)$$
$$= 2 + e^{i(k_2-k_1)L} + e^{i(k_1-k_2)L}$$
$$= 2 + \cos\{(k_2 - k_1)L\} + \cos\{(k_1 - k_2)L\}$$
$$= 2 + 2\cos\{(k_1 - k_2)L\}$$
$$= 4\left(\frac{1+\cos\{(k_1-k_2)L\}}{2}\right) = 4\,cos^2\left\{\frac{(k_1-k_2)L}{2}\right\}$$

  - $P_0 \propto 4\,cos^2\left\{\frac{(k_1-k_2)L}{2}\right\}, \quad \{\Delta\theta = (k_1 - k_2)L\}$
  - The light output is modulated with a gate voltage that controls the differential phase shift $\Delta\theta = (k_1 - k_2)L$

2. Analogous device based on electron waves

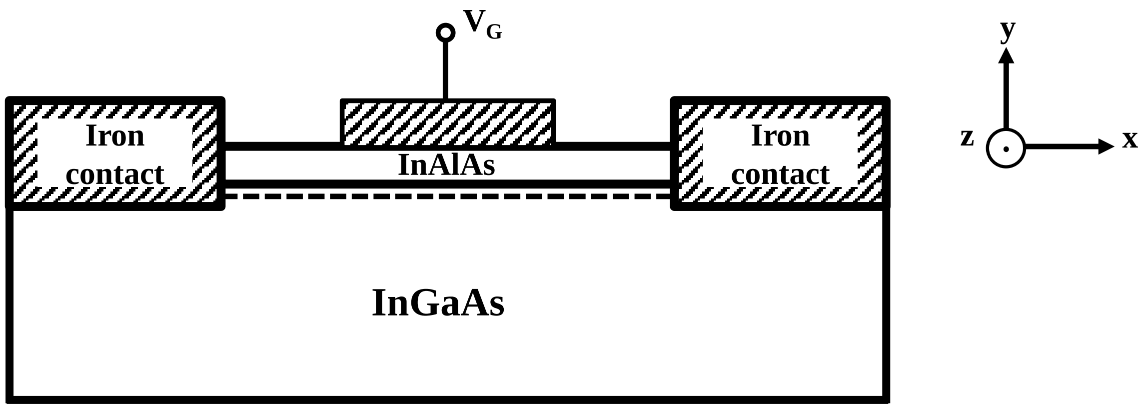
Electronic analog of the electro-optic modulator

- **Analogous device based on electron waves**



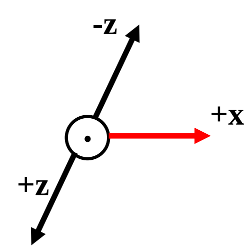
Electronic analog of the electro-optic modulator

- **Analogous device based on electron waves**



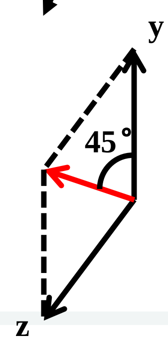
- Detect electrons $\begin{pmatrix}1\\1\end{pmatrix} = \begin{pmatrix}1\\0\end{pmatrix} + \begin{pmatrix}0\\1\end{pmatrix}$

  (+x pol.) (+z pol.) (-z pol.)



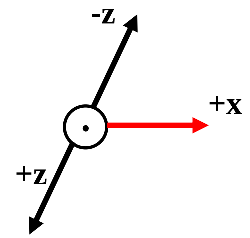
- Detect electrons $\begin{pmatrix}1\\1\end{pmatrix} = \begin{pmatrix}1\\0\end{pmatrix} + \begin{pmatrix}0\\1\end{pmatrix}$

  (45° pol.) (z pol.) (y pol.)



Electronic analog of the electro-optic modulator

- **Analogous device based on electron waves**
  - Consider an electron traveling in the x direction with $k_z = 0$, $k_x \neq 0$ (we assume that the electron forms a 2DEG in the x-z plane)
  - Rashba term $H_R = \eta(\sigma_z k_x - \sigma_x k_z) = \eta\sigma_z k_x$
  - $E(+z\text{ pol.}) = \dfrac{\hbar^2 {k_{x1}}^2}{2m^*} - \eta k_{x1}$
  - $E(-z\text{ pol.}) = \dfrac{\hbar^2 {k_{x2}}^2}{2m^*} + \eta k_{x2}$
  - $|E(+z\text{ pol.})| = |E(-z\text{ pol.})|$



$$\frac{\hbar^2 {k_{x1}}^2}{2m^*} - \eta k_{x1} = \frac{\hbar^2 {k_{x2}}^2}{2m^*} + \eta k_{x2}$$

$$\frac{\hbar^2 {k_{x1}}^2}{2m^*} - \frac{\hbar^2 {k_{x2}}^2}{2m^*} = \eta k_{x1} + \eta k_{x2}$$

$$k_{x1} - k_{x2} = \frac{2m^*\eta}{\hbar^2}$$

  - $\Delta\theta = (k_{x1} - k_{x2})L = \dfrac{2m^*\eta L}{\hbar^2} \propto \eta$ (spin-orbit coefficient)

Electronic analog of the electro-optic modulator

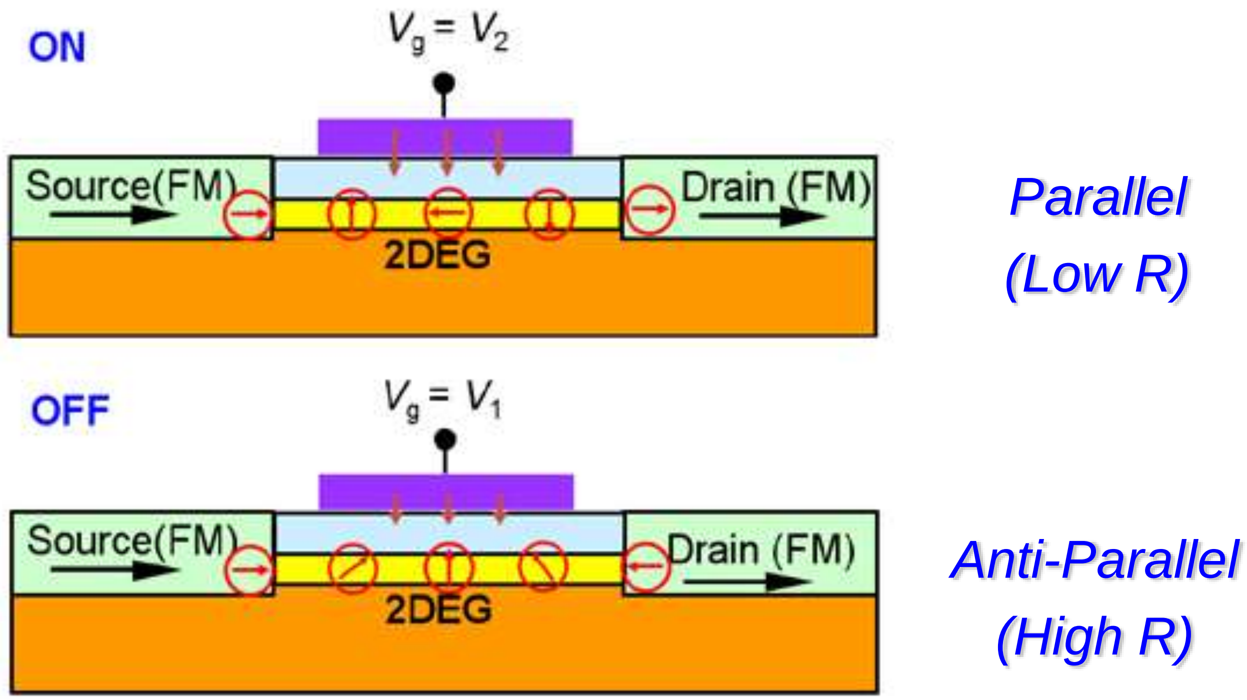
- **Analogous device based on electron waves**
  - $\Delta\theta = (k_{x1} - k_{x2})L = \frac{2m^*\eta L}{\hbar^2} \propto \eta$ (spin-orbit coefficient)

    λ = mean free path.
  - Is η large enough that a phase difference of π can be introduced within a mean free path?
  - $L(\theta = \pi) = \frac{\Delta\theta\hbar^2}{2m^*\eta} = \frac{\pi(1.05 \cdot 10^{-34} J \cdot s)^2}{2 \cdot 0.046 \cdot 9.1 \cdot 10^{-31} kg \cdot 3.9 \cdot 10^{-12} eV \cdot m} = 0.67\mu m < \lambda$
  - η is proportional to the expectation value of the electric field at the hetero-structure interface, and, in principle, can be controlled by the application of a gate voltage
  - $\Delta\theta = (k_{x1} - k_{x2})L = \frac{2m^*\eta L}{\hbar^2}$

3. Summary

Electronic analog of the electro-optic modulator

- **Summary**



- Challenges

  1) Source & drain : how well the spin polarizer and analyzer can be implemented.

  2) Channel : what extent η can be controlled with a gate voltage.

Thank you !