Spintronics in two-dimensional electron gas at metal-$SrTiO_3$ interfaces with various crystal orientations

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ABSTRACT

- High carrier density and gate-tunable two dimensional electron gases (2DEG) are obtained by depositing Ta on top of $SrTiO_3$ (STO with different orientations)
- 2DEG characterization: temperature dependent measurement and gate dependent magnetoresistance
- Through spin pumping, we inject a spin current from a Permalloy film into the 2DEG on top of STO(110) and detect the resulting charge current.

Formation of 2DEG

2DEG formation by Al deposition on top of STO(001) at room temperature.

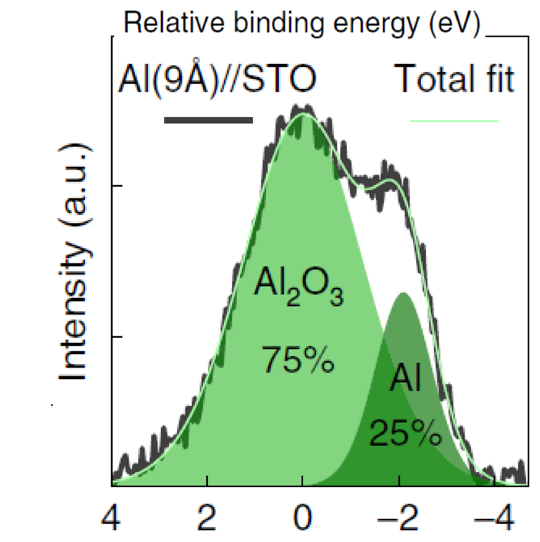
Rödel, T.C. et al., *Phys. Rev. Applied 1, 051002 (2014)*

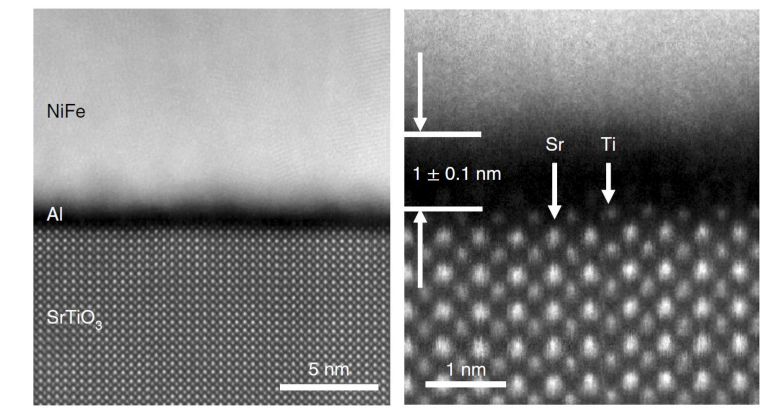
XPS peaks show the reduction of Al at interface, with consequent creation of oxygen vacancies.

Vaz, D.C., Noël, P., Johansson, A. et al., *Nat. Mater.* **18**, 1187–1193 (2019)

More generally, reactive metals induce STO reduction and 2DEG formation

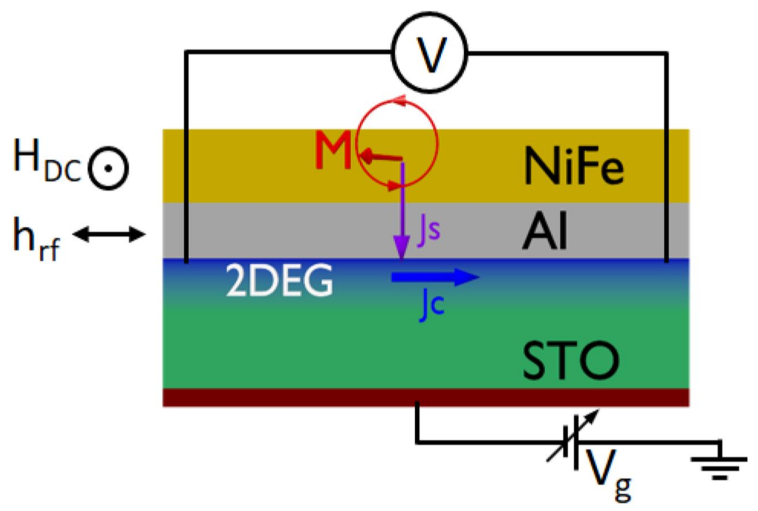
Vicente-Arche *et al*., *Phys. Rev. Lett* **5**, 064005 (2021)





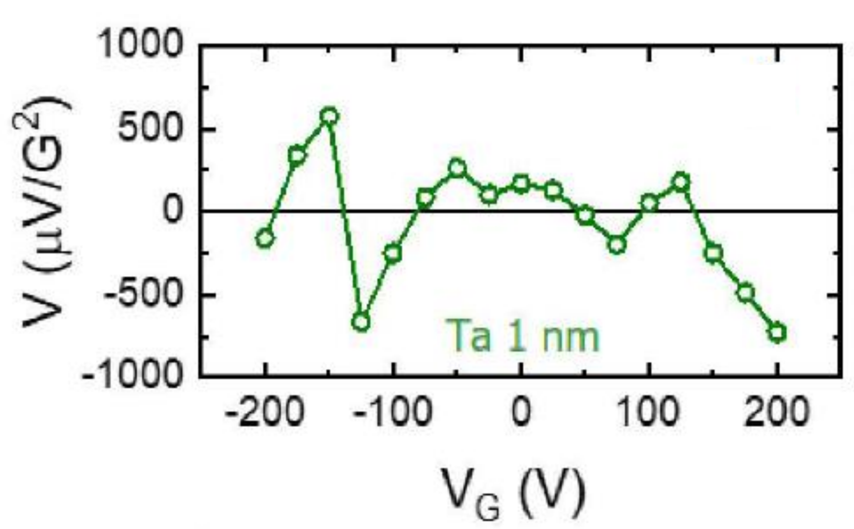
STEM images:
- Ti terminations
- Al barrier
- NiFe for spin injection

Interconversion measurement in STO(001)



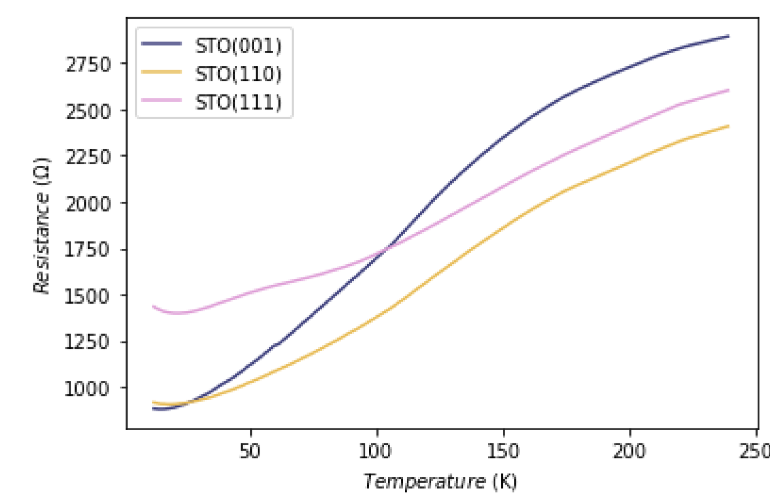
Spin pumping to investigate the presence of spin to charge interconversion

Efficient and gate tunable spin to charge conversion.

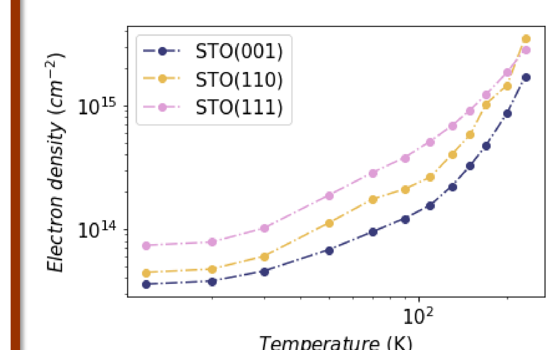


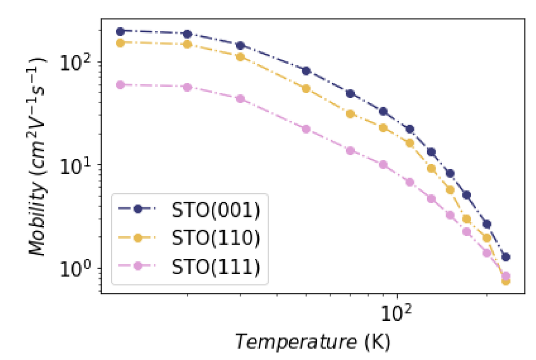
Vicente-Arche *et al*., *Phys. Rev. Lett* **5**, 064005 (2021)

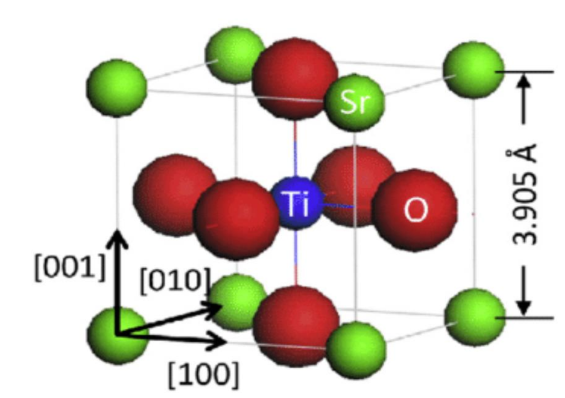
2DEG in STO(001), (111), (110)



Electron gas formation along the three orientations, electron density observed is $\sim 10^{14} cm^{-2}$

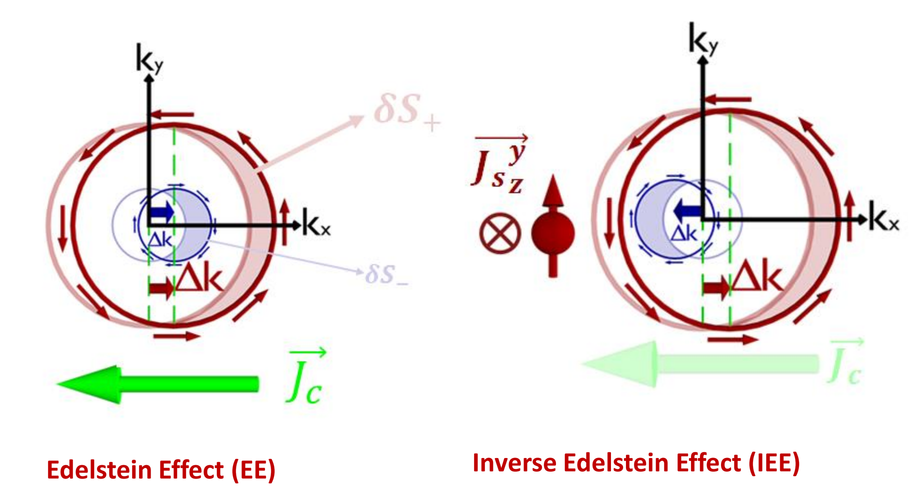






Chang, Y., & Phark, S.H. (2017) . *Current Applied Physics, 17, 640.*

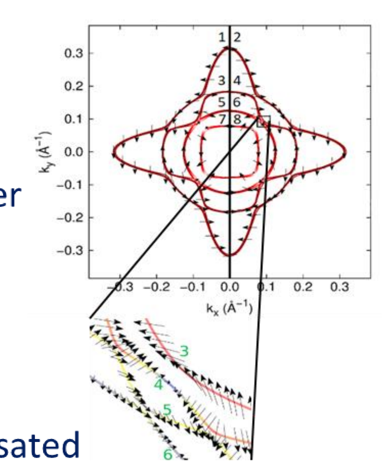
Principle of Edelstein Effect



The figure of merit is the inverse Edelstein length:

$$\lambda_{IEE}(m) = \frac{J_c^{2D}(A/m)}{J_s(A/m^2)} = \frac{\alpha_R \tau}{\hbar}$$

Depends on:
- spin-orbit coupling strength
- mobility



Bandstructure of STO(001):
- Several bands involved resulting from interfacial symmetry breaking
- Orientation and gate dependence

Spin-orbit coupling of an electron in motion under application of an electric field (along $\hat{z}$):

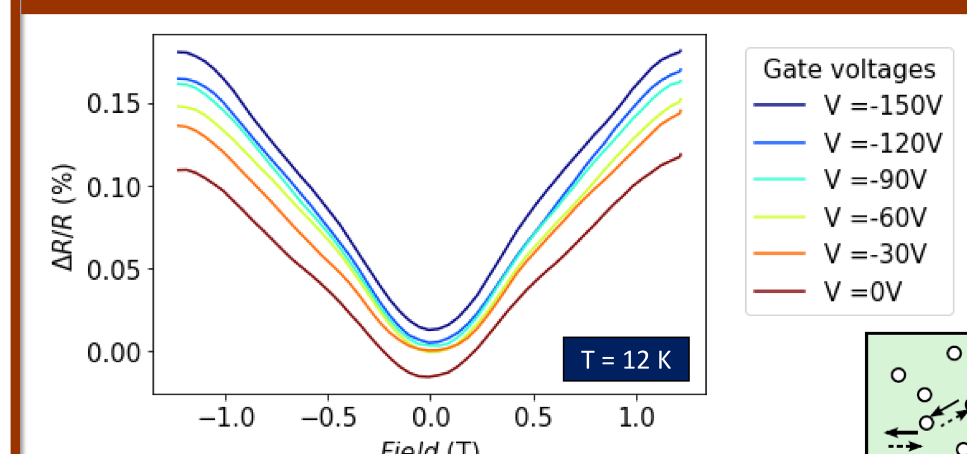
$$\mathcal{H}_R = \alpha_R(\boldsymbol{\sigma} \times \boldsymbol{p}) \cdot \hat{z}$$

spin-momentum locking

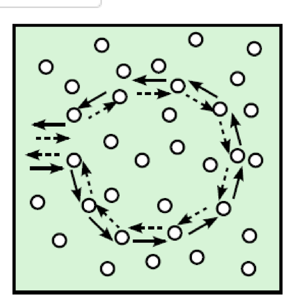
If a spin-polarized current is injected, the uncompensated spin-texture generates a charge current (**IEE**).

Vaz, D.C., Noël, P., Johansson, A. et al., *Nat. Mater.* **18**, 1187–1193 (2019)

Gate measurements and WAL

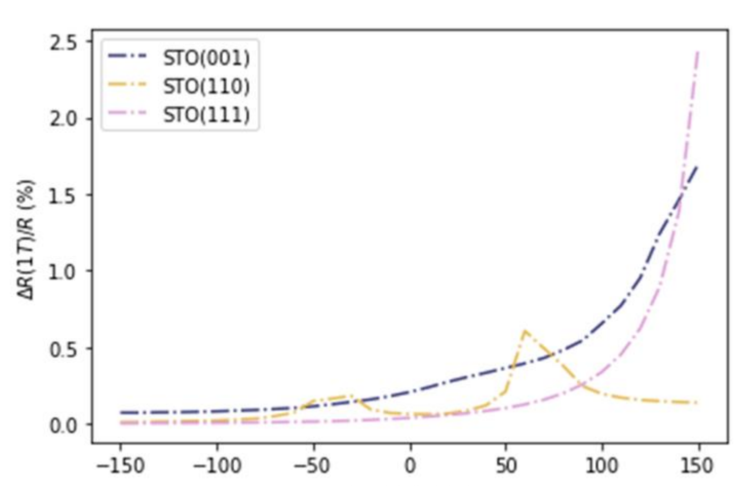


Hall measurement on STO(111) show a non-negligible symmetrical part.
- Weak antilocalization (WAL)
- Signature of a strong spin-orbit coupling.



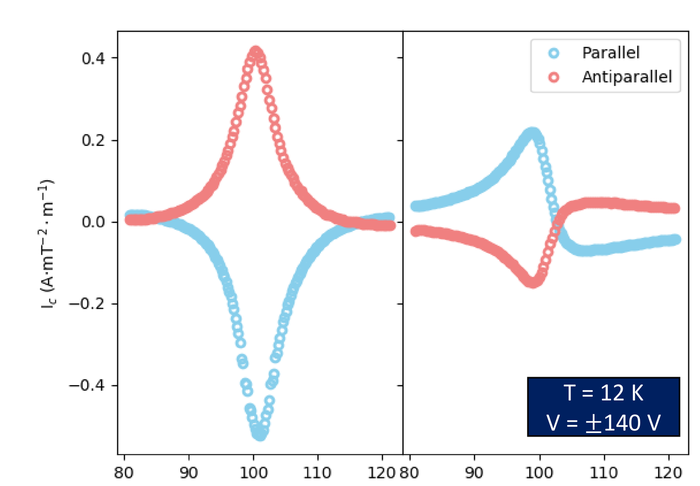
Caviglia, A. D., et al. *Phys. Rev. Lett.* 104.12 (2010): 126803.

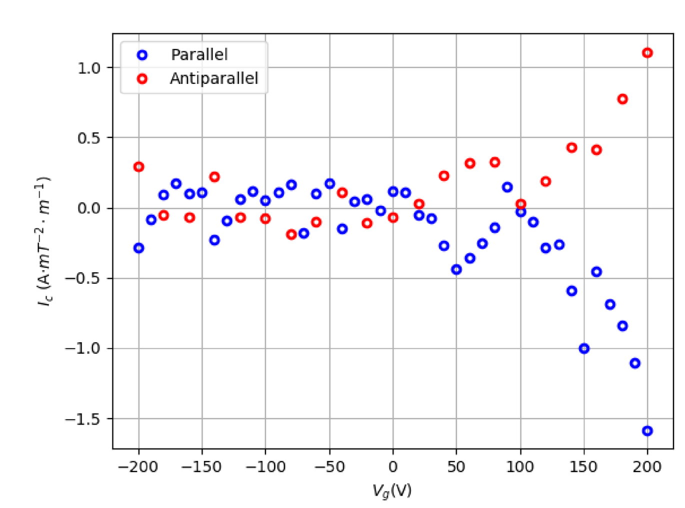
Lu, Hai-Zhou, and Shun-Qing Shen. *Spintronics VII*. Vol. 9167. Int. Soc. for Opt. and Phot., 2014.



Gate modulated magnetoresistance:
- Fermi level evolution for the three band structure orientations
- Strength of spin-orbit coupling along the three directions

Interconversion measurement in STO(111)





- Presence of efficient spin to charge conversion in STO(110)
- Different gate modulation with respect to STO(001) seen before
  - Possibility to track the Fermi level position

CONCLUSIONS

- A 2DEG can be formed at the surface of STO(001),(111),(110) by metal deposition
- Measurement by SP-FMR on (110) and (001) show a good interconversion efficiency and gate tunability
- The observation of WAL on STO(111) may be the indication of a stronger spin-orbit coupling

PROSPECTS

- Complete interconversion measurement with STO(111)
- Analysis of gate dependent interconversion in terms of Fermi level evolution on the different band structures
- Characterization and interconversion study of STO/Mg