Nonlinear response of 2DEG in the quantum Hall regime

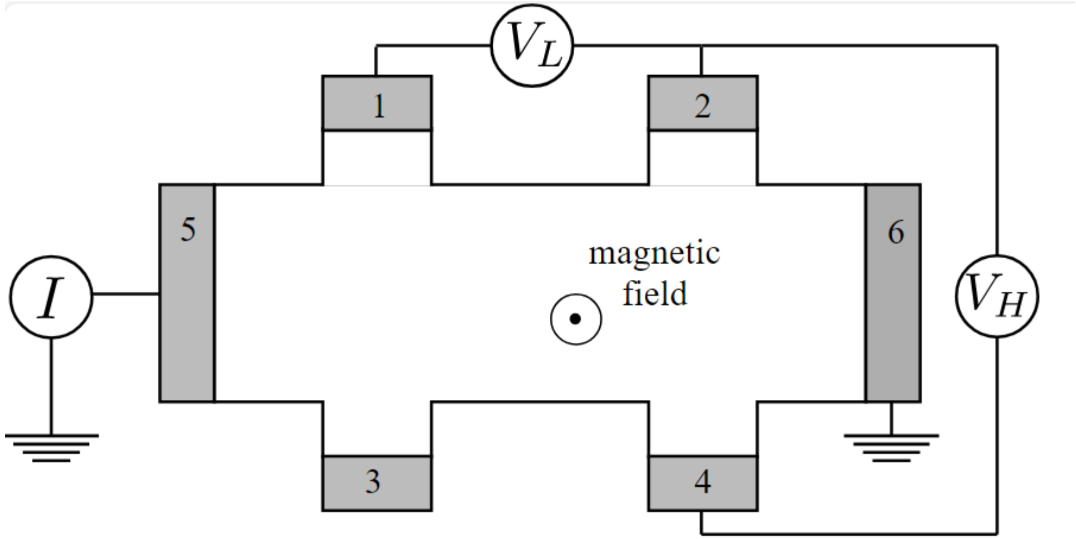
Shuichi Iwakiri,[1,*] Lev V. Ginzburg,[1] Marc P. Röösli,[1] Yigal Meir,[2] Ady Stern,[3] Christian Reichl,[1] Matthias Berl,[1] Werner Wegscheider,[1] Thomas Ihn,[1] and Klaus Ensslin[1]

[1]*Department of Physics, ETH Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland*
[2]*Department of Physics, Ben-Gurion University of the Negev, Beer-Sheva, 84105 Israel*
[3]*Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, Israel*

(Dated: June 19, 2023)

Breaking of inversion symmetry leads to nonlinear and nonreciprocal electron transport, in which the voltage response does not invert with the reversal of the current direction. Many systems have incorporated inversion symmetry breaking into their band or crystal structures. In this work, we demonstrate that a conventional two-dimensional electron gas (2DEG) system with a back gate shows non-reciprocal behavior (with voltage proportional to current squared) in the quantum Hall regime, which depends on the out-of-plane magnetic field and contact configuration. The inversion symmetry is broken due to the presence of the back gate and magnetic field, and our phenomenological model provides a qualitative explanation of the experimental data. Our results suggest a universal mechanism that gives rise to non-reciprocal behavior in gated samples.

Integer Quantum Hall Effect

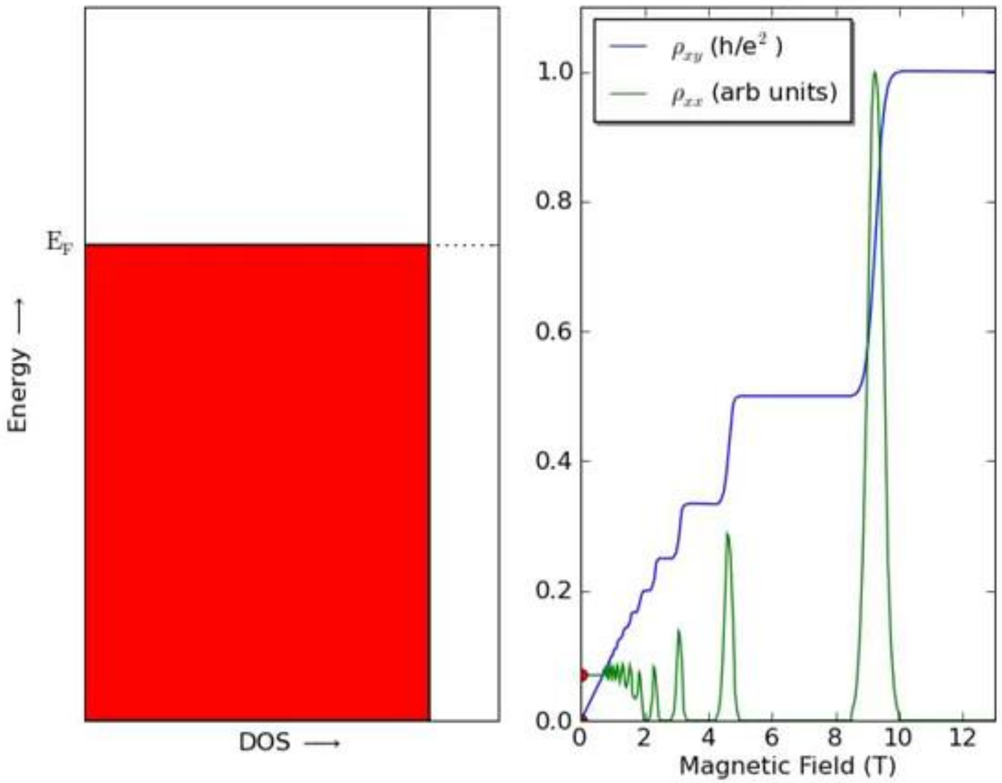


$$R_{xy} = \frac{V_{\text{Hall}}}{I_{\text{channel}}} = \frac{h}{e^2 \nu},$$

Linear resistance

Non-Linear resistances

$$V = RI + R^{(2)} I^2 + R^{(3)} I^3 \ldots$$



Device

- 2DEG buried 200 nm below the surface.
- Back gate located 1 μm below the 2DEG

  allows to vary the electron density from 1.5E11/cm2 to 2.7E11/cm2

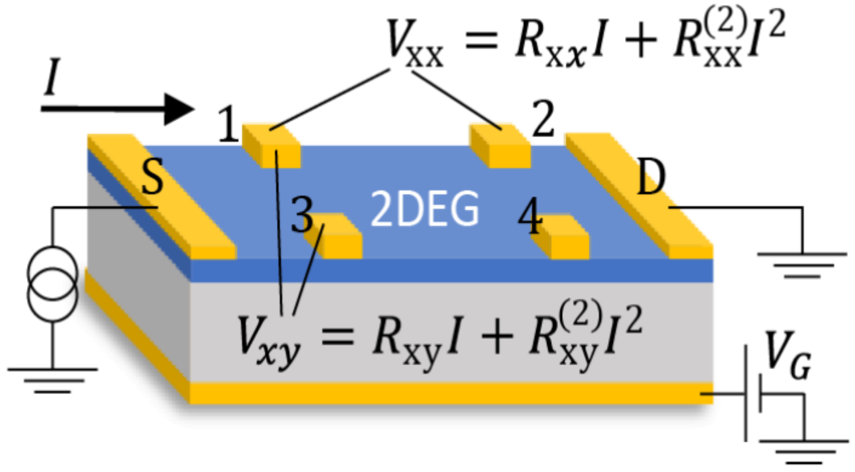
- Au/Ge Ohmic contacts
- Distance between:

  Source and Drain -> 1500 μm

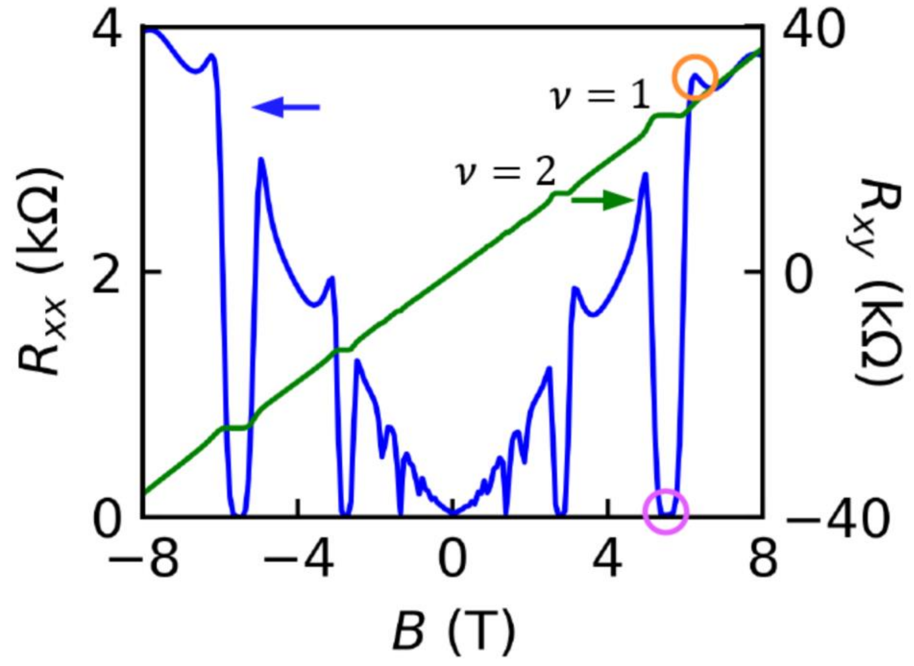
  Vxy probes -> 800 μm

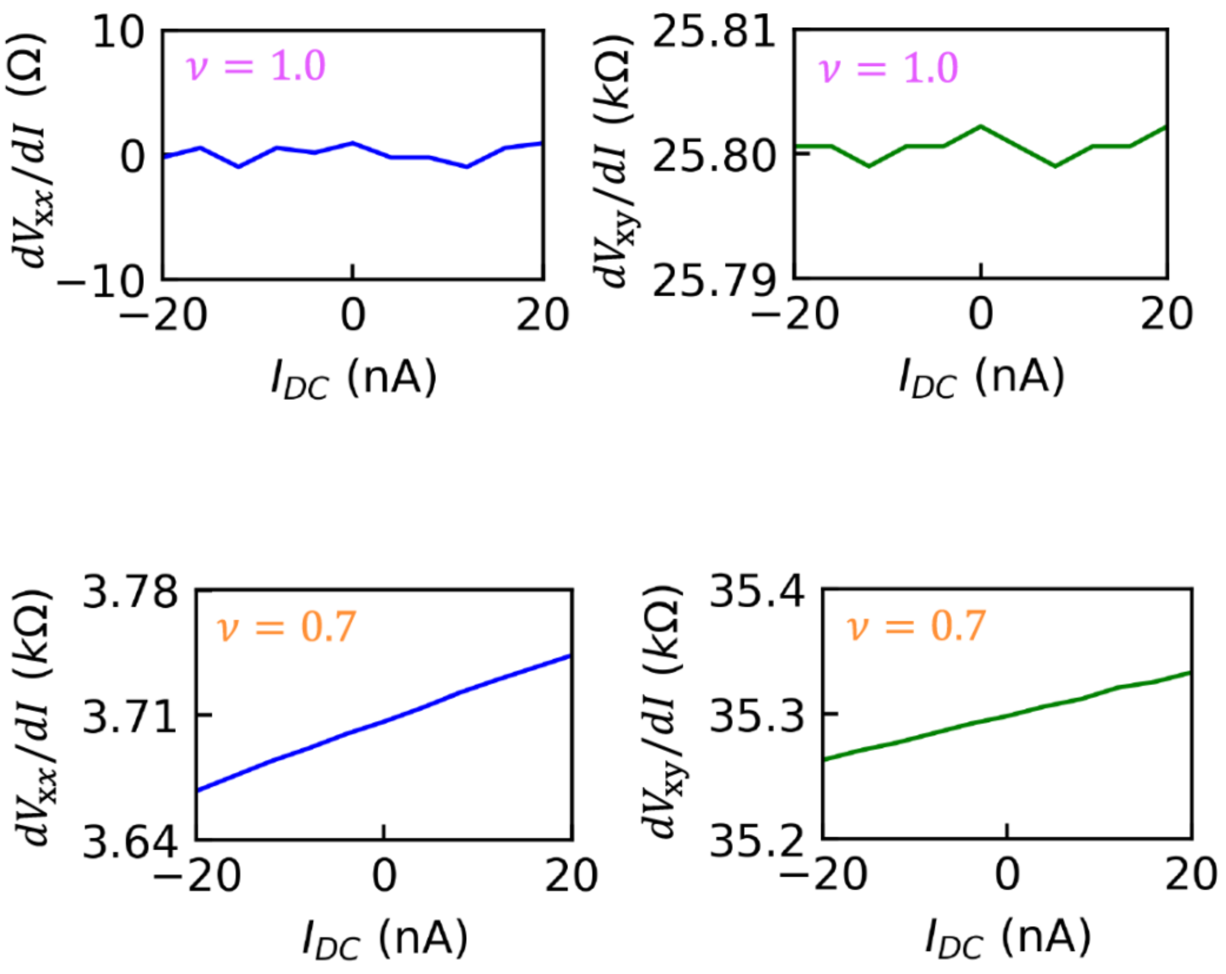
  Vxx probes -> 400 μm

- measurements performed at 60 mK.

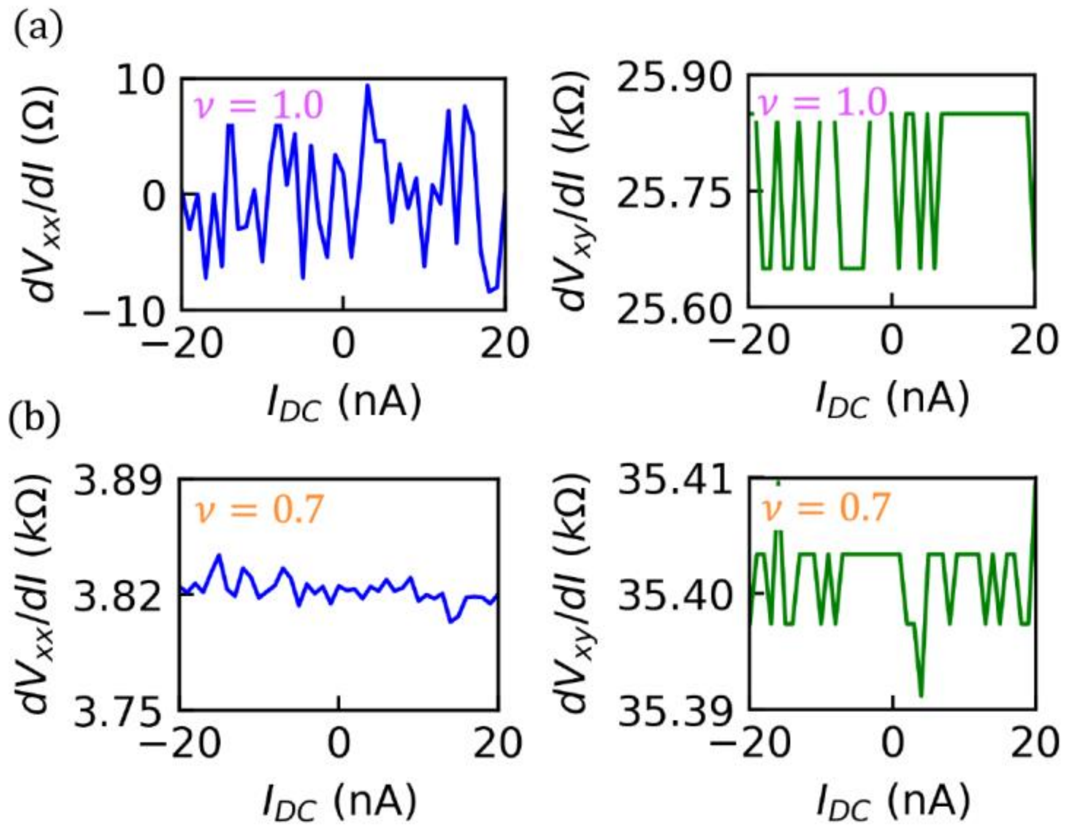


Nonlinear response of 2DEG (non-reciprocal responses**)**

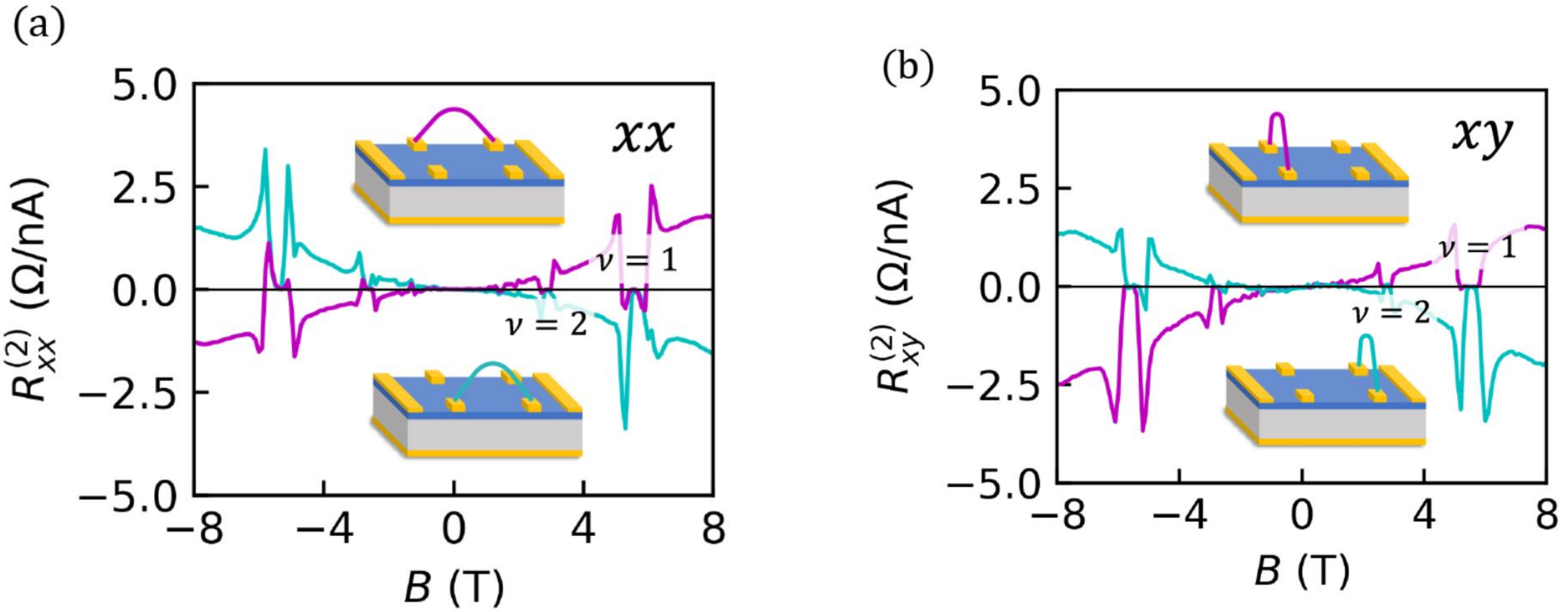


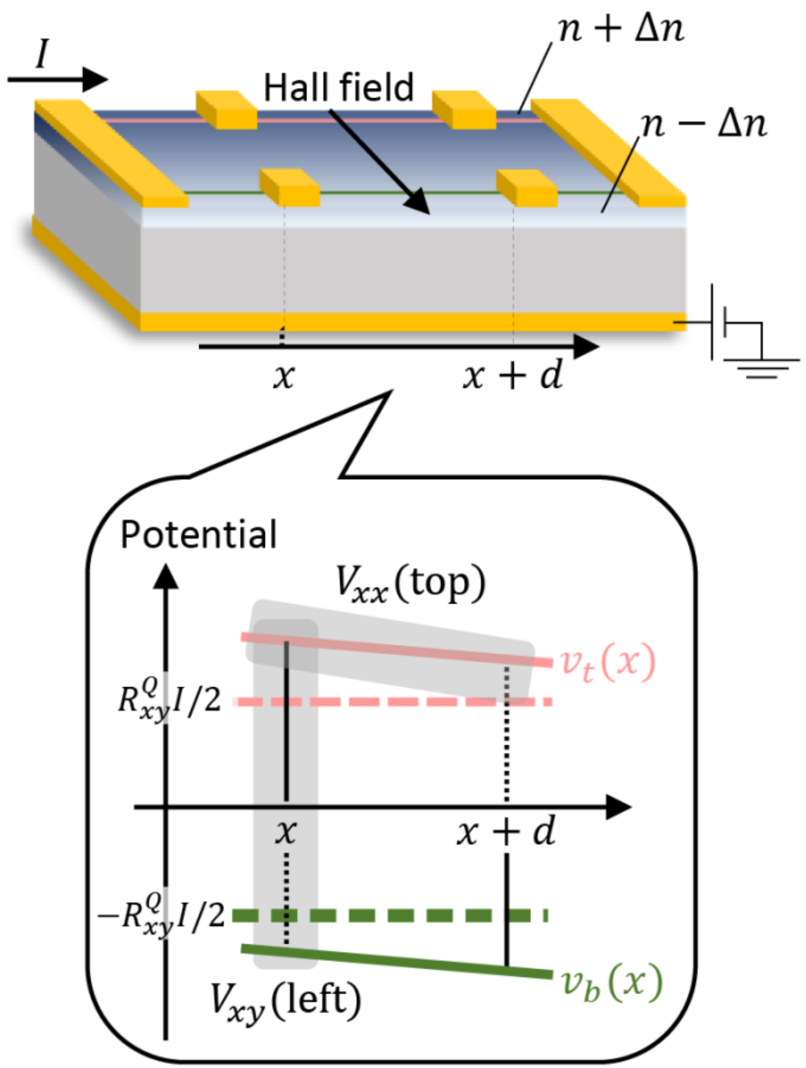


Sample with no backgate



Magnetic field dependence of the non-reciprocal component





$$v_t(x) = \rho_{xy}(\text{top}, x, n(x))I$$

$$n(x) = N + C\left[V_{\mathrm{G}} + v_t(x)\right] = n_0 + Cv_t(x)$$

$$\begin{aligned} v_t(x) &= \rho_{xy}\left(\text{top}, x, n\left(x\right)\right) I \\ &\simeq \rho_{xy}\left(\text{top}, x, n_0\right) I + \frac{\partial \rho_{xy}}{\partial n_0} C v_t\left(x\right) I \end{aligned}$$

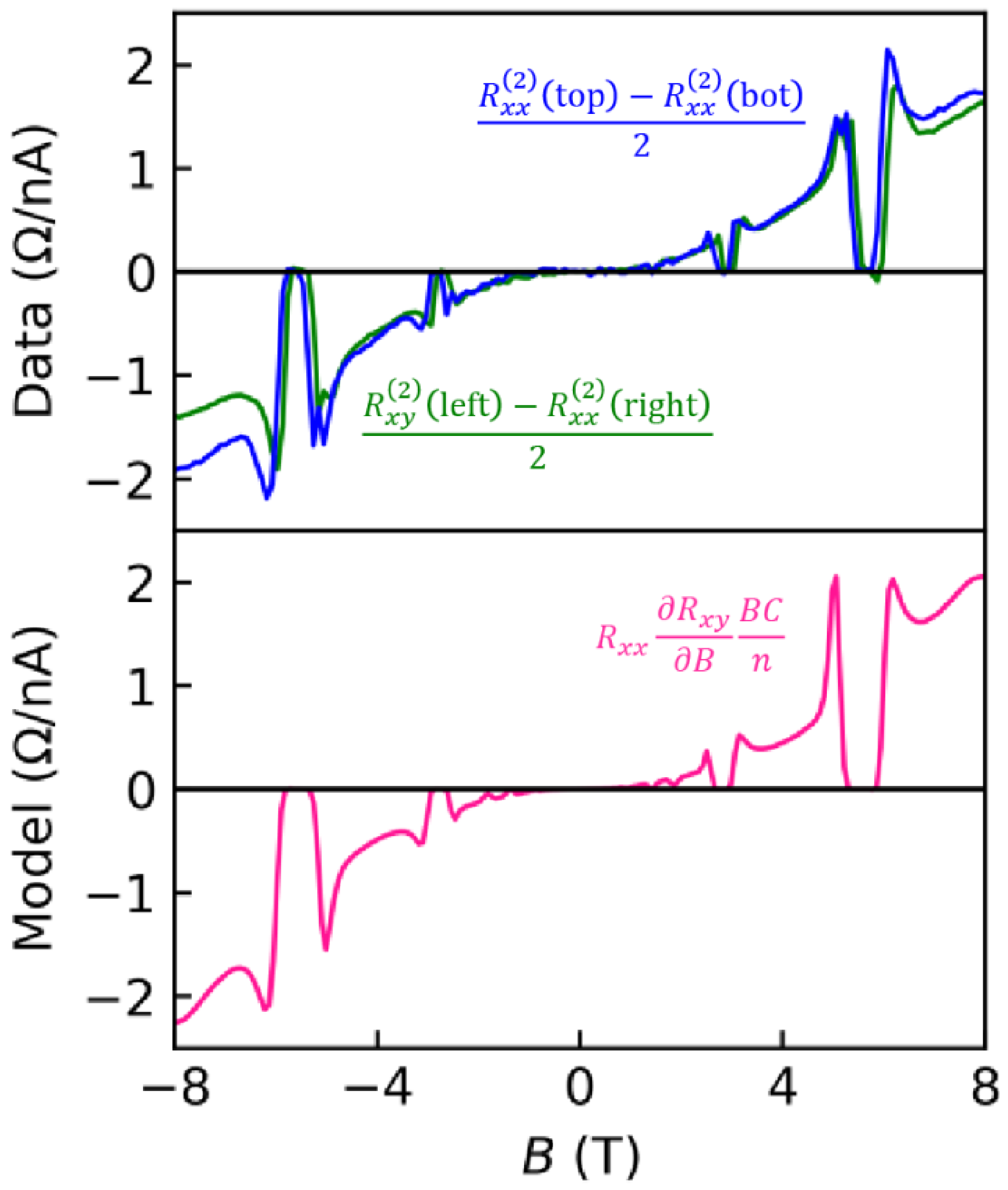
$$v_t(x) \simeq \frac{\rho_{xy}(\mathrm{top}, x, n_0)\, I}{1 - \frac{\partial \rho_{xy}}{\partial n_0} C I}$$

$$\simeq \rho^{\mathrm{t}}_{xy}(x) I + \rho^{\mathrm{t}}_{xy}(x) \frac{\partial \rho^{\mathrm{t}}_{xy}(x)}{\partial n_0} C I^2$$

$$v_t(x+d) = v_t(x) + \frac{\partial v_t(x)}{\partial x} d + o(d^2)$$

$$V_{xx}(\mathrm{top}) = v_t(x) - v_t(x+d)$$

R_{xx} and R_{xy}



Conclusion and Outlook

- Nonreciprocal response of the quantum hall effect

- Nonreciprocal response in fractional filling factors

Thank you for your attention!