Plasmon and magnon interaction & Landau level correlation

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The considered D/G/AFM Heterostructure

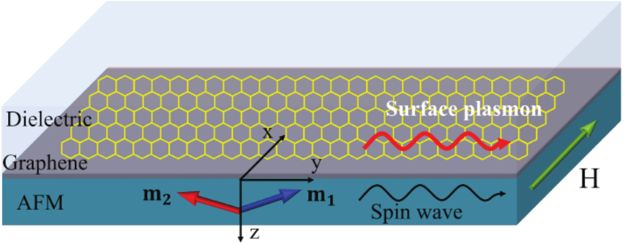


FIG. 1. Scheme of a dielectric/graphene/AFM structure. The surface spin waves excited in the AFM is strongly coupled to the transverse magnetic surface plasmons excited in the graphene layer. The blue and red arrows represent the sub-lattice magnetizations of the antiferromagnetic layer.

Landau-Lifschtiz-Gilbert Equations

$$\partial_t m_1 = -\gamma m_1 \times H_{1,eff} + \alpha m_1 \times \partial_t m_1$$
$$\partial_t m_2 = -\gamma m_2 \times H_{2,eff} + \alpha m_2 \times \partial_t m_2$$

- 1,2 are the sublattices
- γ: Gyromagnetic ratio (magnetic moment/angular moment)
- α: Gilbert damping
- $H_{1,eff}$: Effective field (exchange,anisotropy,external,dipolar)

Application of external field

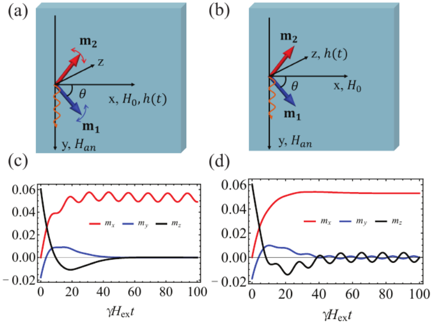


FIG. 2. Scheme of the two sublattice antiferromagnet under a perpendicular magnetic field with driving field parallel (a) and perpendicular (b) to the static magnetic field (x−axis). (c-d) Time evolution of the total magnetization $\mathbf{m} = \mathbf{m}_1 + \mathbf{m}_2$. Magnetic parameters of NiO are used with $H_{ex} = 524$ T, $H_{an} = 1.47$ T, $M_s = 0.32$ T [15], $\gamma H_0 = 0.5\omega_{sp}$. α is taken to be 0.1 to accelerate the relaxation process.

Numerical calculations

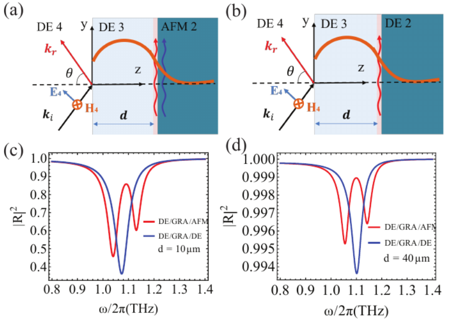
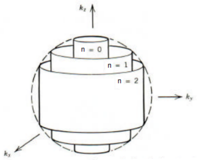


FIG. 4. (a-b) Scheme of the two setups to measure the reflection rate of the hybrid DE/GRA/AFM and DE/GRA/DE structures. (c-d) Reflection rate of the hybrid system as a function of incident wave frequency for $d = 10$ μm and 40 μm, respectively. Parameters are $E_F = 2$ eV, $\Gamma = 0.1$ meV, $\alpha = 10^{-3}$, $\theta = 39.4°$.

Landau Levels



In Landau gauge the energy of electrons:

$$E = k_z^2 + (\nu + \frac{1}{2})\hbar\omega_c.$$

- $\nu \in Z$: Landau levels
- $\omega_c = eH/mc$: Cyclotron frequency

N-body wave function for LLL

- In symmetric gauge single particle wave function:

$$\langle r|m\rangle = \sqrt{\frac{1}{2\pi l_B m!}} \left(\frac{r}{\sqrt{2} l_b}\right)^m \exp\left(-\frac{r^2}{4l_B^2} e^{im\theta}\right).$$

$l_B = \sqrt{\hbar/eB}$: magnetic length
$r = (r, \theta)$: polar coordinates
$m \in Z$: angular momentum

- First quantized N-body state in Lowest Landau levels (LLL):

$$|\Psi_{LLL}\rangle = \sum_{m_i} c_{m_1, m_2, \ldots, m_N} |m_1\rangle |m_2\rangle \ldots |m_N\rangle .$$

m_i : Single particle state
$c_{m_1, m_2, \ldots, m_N}$: Complex symmetric (anti-symmetric) coefficients for bosons (fermions)

Correlation function

- Number density:

$$\rho(r) = \sum_{i=1}^{N} \rho_i(r) = \sum_{i=1}^{N} \delta(r - r_i).$$

- Current density:

$$j(r) = \sum_{i}^{N} j_i(r) = \sum_{i}^{N} \frac{1}{2} \left\{ \frac{p_i - eA(r_i)}{M}, \rho_i(r) \right\}.$$

- The matrix elements of single particle wave function is:

$$\langle m_i | \, j_{\alpha,i} \, | m_i' \rangle = \frac{\hbar}{2M} \epsilon_{\alpha\beta} \frac{\partial}{\partial r_\beta} \langle m_i | \, \rho_{\alpha,i} \, | m_i' \rangle$$

- The correlation function derived is:

$$\langle \rho(r') j_\alpha(r) \rangle_{LLL} = \frac{\hbar}{2M} \epsilon_{\alpha\beta} \frac{\partial}{\partial r_\beta} \langle \rho(r') \rho(r) \rangle_{LLL}$$

- When the interaction with other Landau level is present then the deviation from the LLL correlation function gives the interaction parameters.
- For a system of bosons and weak contact interaction $g \ll \hbar\omega_c l_B^2$ (hence, perturbation theory) the deviation from LLL is:

$$\Delta_\alpha(r) = \epsilon_{\alpha\beta}\frac{\partial}{\partial r_\beta}\left\langle \rho(0)\phi(r)\right\rangle - \frac{2M}{r}\left\langle \rho(r) j_\alpha(r)\right\rangle .$$

- It was cross checked using two-body interaction bosons (Kohn's thereom), N-body interacting bosons (Schimdt decomposition), Laughling boson states.

Numerical Montecarlo simulation

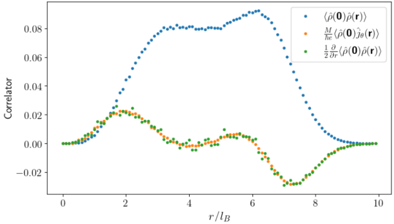


FIG. 2. Plot of current density-number density and number density-number density correlators obtained numerically using the Metropolis Monte Carlo method for the filling fraction $\nu = \frac{1}{2}$ Laughlin state in a disc geometry with particle number $N = 15$, after 500000 iterations and discarding the first 80000 "thermalisation" runs. The radial derivative of $\langle\hat{\rho}(\mathbf{0})\hat{\rho}(\mathbf{r})\rangle$ can be seen to coincide with the angular component of the current density-number density correlator, $\langle\hat{\rho}(\mathbf{0})\hat{j}_\theta(\mathbf{r})\rangle$, demonstrating the correspondence in Equation (6).