Mid-Infrared Ellipsometry Spectroscopy of Electronic and Spin Phenomena in Spintronic Devices

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Spectroscopic ellipsometry (SE) is a non-destructive optical technique widely used to characterize thin-film heterostructures. While it is best known for accurately determining film thickness and surface roughness, broadband SE performed over a wide spectral range and multiple angles of incidence can also provide detailed information on the optical properties of individual layers and buried interfaces, particularly in the far-infrared (1–24 meV) and mid-infrared (25–500 meV) regions.

Since 2019, we have collaborated on applying mid-infrared SE to investigate the two-dimensional electron gas (2DEG) formed at the interface between polycrystalline Cu and Bi_2O_3. From these measurements, we extracted the interfacial conductivity, carrier relaxation time, and spin-orbit coupling strength [1]. Although similar information can be obtained by angle-resolved photoemission spectroscopy (ARPES), ARPES requires high-quality crystalline samples, making it unsuitable for many polycrystalline or amorphous heterostructures.

Notably, mid-infrared SE also offers more opportunities for spintronics and magnetism. In the late 1960s, Professor Toru Moriya highlighted the importance of studying the frequency-dependent optical conductivity of magnetic materials, including deviations from the Drude model, alongside light scattering phenomena [2, 3]. Motivated by this work, we applied mid-infrared SE to the archetypal heavy metal/CoFeB/MgO heterostructure [4]. Our study yielded (i) the mid-infrared dielectric function of $Co_{20}Fe_{60}B_{20}$, previously unavailable in the literature [5]; (ii) the dielectric tensor of the interfacial 2DEG; and (iii) the identification of a discrete optical feature associated with spin-orbit coupling. An intriguing next step is to uncover spectroscopic ellipsometry (SE) signatures of the Dzyaloshinskii-Moriya interaction (DMI), a key antisymmetric exchange interaction responsible for stabilizing non-collinear magnetic textures, including chiral spin structures.

If time permits, I will also present our latest results on a unified anisotropic TO-LO dielectric function model for $LiNbO_3$ in the mid-infrared [6].

References

[1] J. M. Flores-Camacho, J. Puebla, F. Auvray, A. Lastras-Martinez, Y. Otani, R. E. Balderas-Navarro, Phys. Rev. B 100 235449 (2019)

[2] T. Moriya, Theory of Absorption and Scattering of Light by Magnetic Crystals, J. Appl. Phys. 39, 2 (1968)

[3] T. Moriya, M. Inoue, Frequency-dependent electrical conductivity of dilute magnetic alloys, J. Phys. Soc. Jap., 27, 2 (1969)

[4] J. M. Flores-Camacho, B. Rana, R. E. Balderas-Navarro, A. Lastras-Martinez, Y. Otani, J. Puebla, J. Phys. D: Appl. Phys. 56, 315301 (2023)

[5] A. Santos-Amador, J. Puebla, O. Del Pozo-Zamudio, S. Vazquez-Miranda, R.E. Balderas-Navarro, Thin Solid Films, 839, 140903 (2026)

[6] A. Santos-Amador, J. Puebla, O. Del Pozo-Zamudio, and R.E. Balderas-Navarro, under preparation (2026)