Development of Spin-ARPES for Electric-Field Response

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Spin-ARPES using synchrotron radiation is a well-established and powerful method for observing spin-dependent electronic structures in equilibrium conditions. Recently, *operando* spin-ARPES under static electric fields has been reported [1], demonstrating the possibility of probing electronic structures under an applied electric bias.

However, expanding such approaches to dynamic measurements remains highly challenging. This is because only a very small fraction of electrons participates in spin-transport dynamics, whereas most electrons contribute only to the equilibrium electronic background. As a result, the electric-field-induced spin accumulation, for example in spin Hall effect, appears as an extremely weak component buried in a large equilibrium background, making its direct detection intrinsically difficult.

To overcome this limitation, we developed a spin-ARPES system capable of probing electric-field-induced spin accumulation in spin Hall effect under current modulation. To extract the minute spin-dependent response synchronized with the applied periodic electric field, we implemented a digital lock-in analysis scheme in both hardware and software. This approach enables selective detection of the periodic component associated with the spin accumulation while suppressing the overwhelming equilibrium background.

To demonstrate the feasibility of this approach, we applied this methodology to a polycrystalline Pt thin film, a prototypical material exhibiting a strong spin Hall effect [2]. By analyzing the synchronized signal in the complex plane, we extracted both its amplitude and phase. Experimental results and quantitative analysis will be presented in the poster.

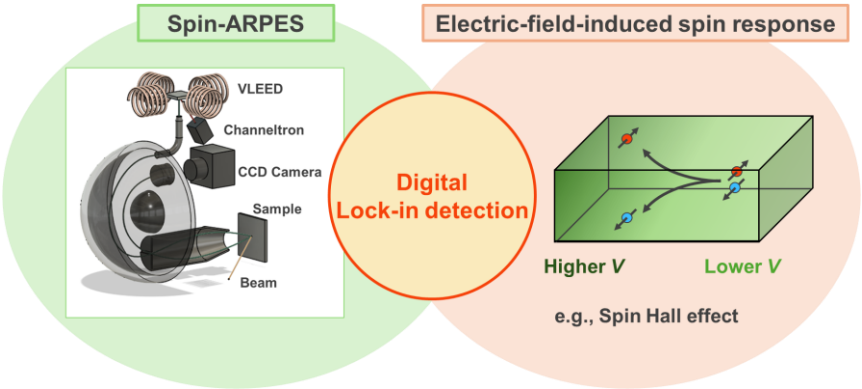

FIGURE 1. Conceptual diagram of current-modulated spin-ARPES.
Digital lock-in detection bridges spin-ARPES measurements and electric-field-induced spin accumulation associated with the

Spin Hall effect.

REFERENCES

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