High-Frequency Bulk Acoustic Wave Resonator with Ferromagnetic Electrodes for Magnetic Field Sensing

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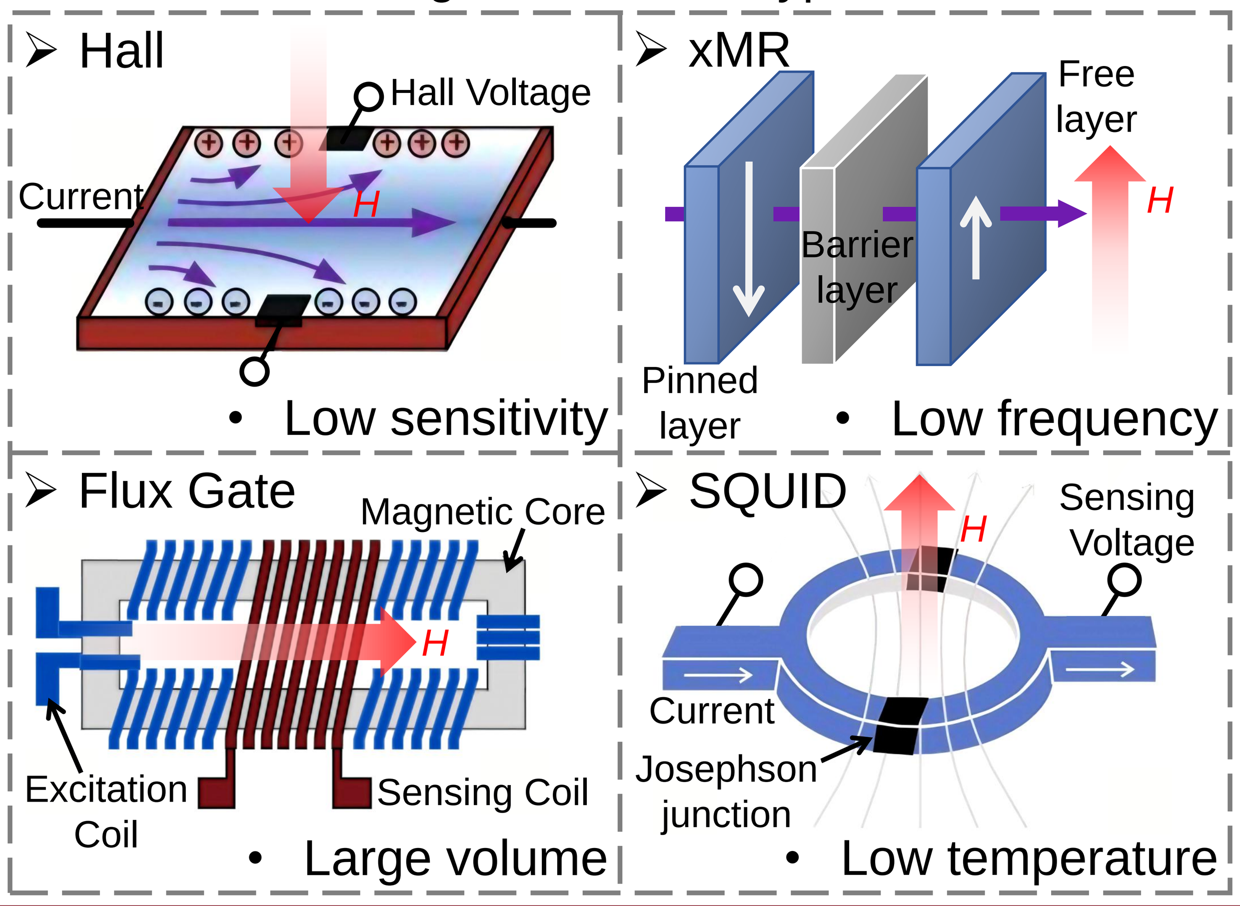
IEEE IUS 2025
Poster No. A1P-26

BACKGROUND

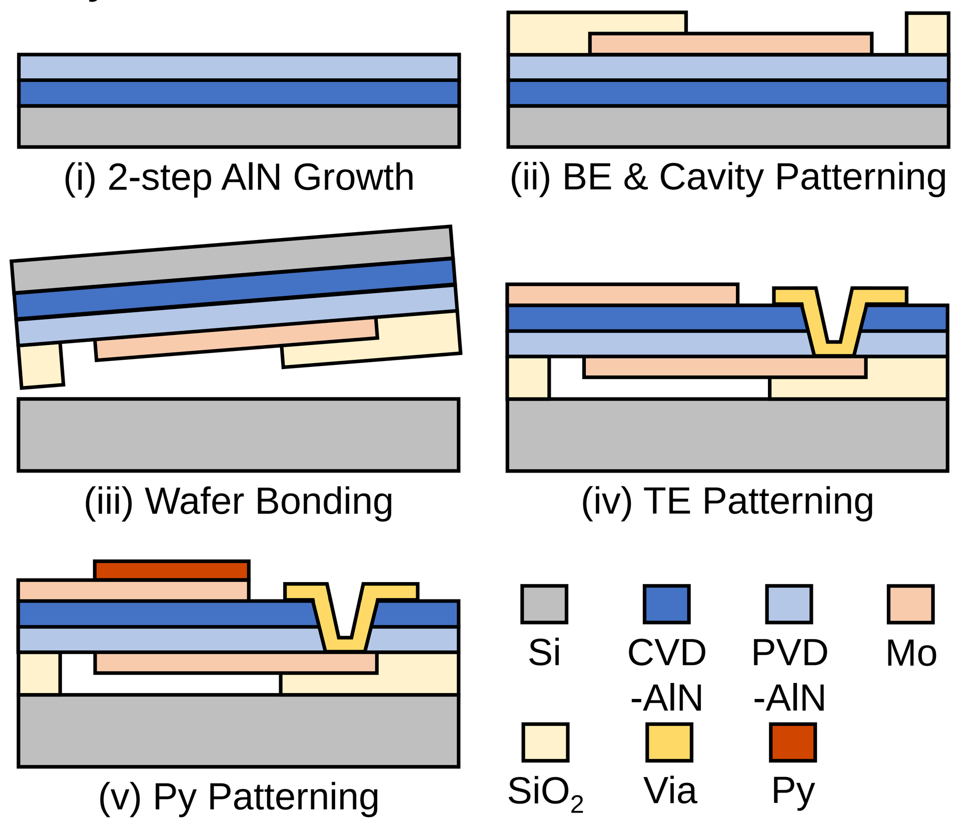
Magnetic Sensor Types

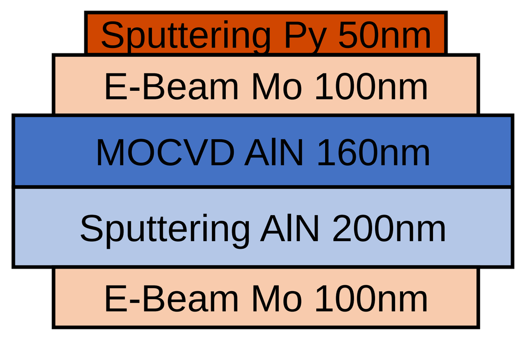


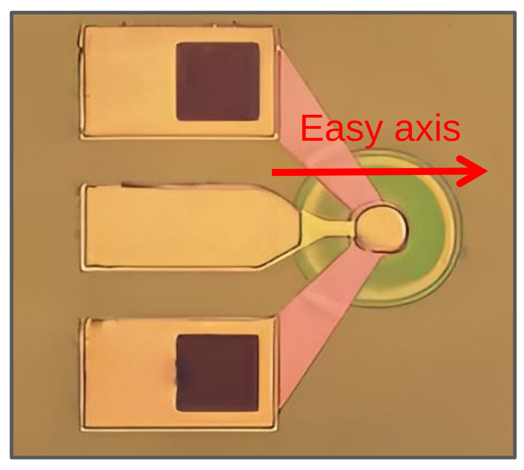
- Bulk Acoustic Wave (BAW) Resonator
  - High Frequency – GHz range
  - High Q – Sharp resonance
  - Compact – On-chip integration
- Magnetic BAW sensor
  - Magneto–Acoustic Coupling
  - High frequency
  - low noise(1/f)
  - RF Circuit integration

DEVICE FABRICATION

- Device stack and process flow for Py/AlN BAW resonator.

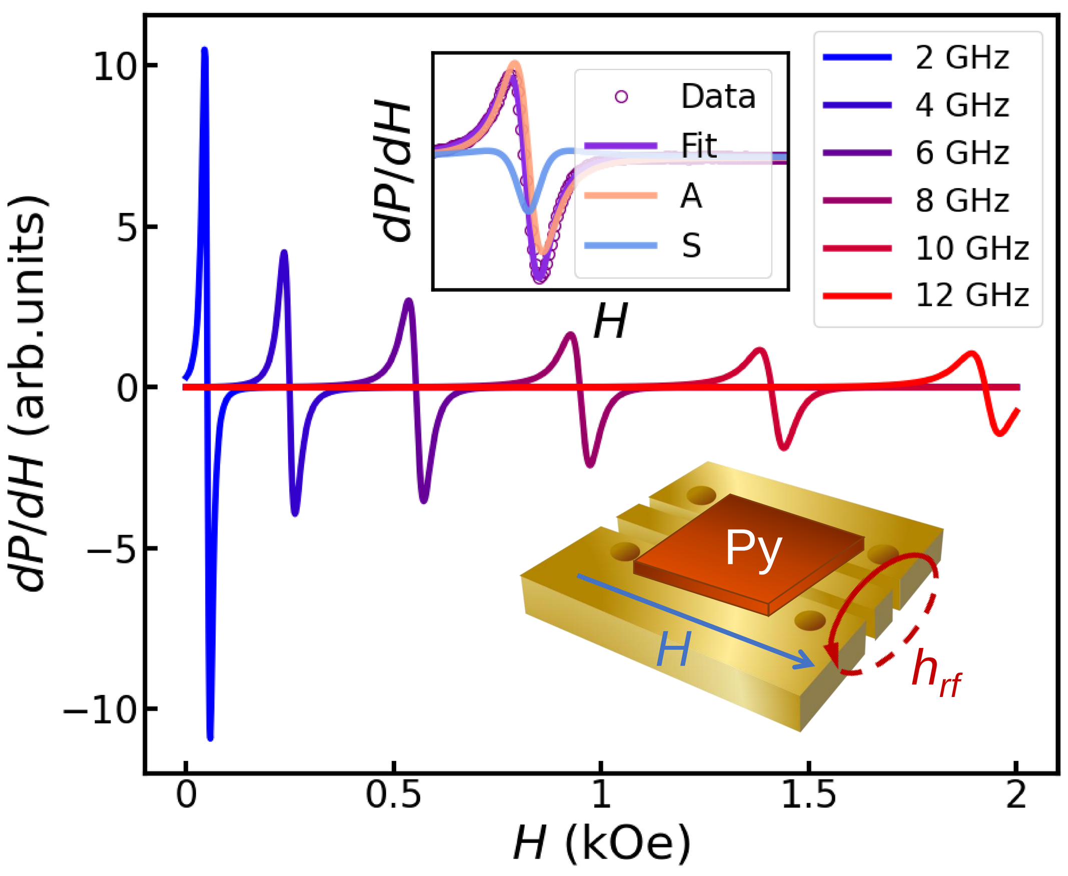






The easy axis is defined during Py sputtering

FERROMAGNETIC RESONANCE MEASUREMENT



- The FMR curves are fitted using a derivative Lorentzian: (Antisymmetric + Symmetric + Offset)

$$\frac{dP}{dH} = A\frac{4\Delta H(H-H_{res})}{[4(H-H_{res})^2+(\Delta H)^2]^2} + S\frac{(\Delta H)^2-4(H-H_{res})^2}{[4(H-H_{res})^2+(\Delta H)^2]^2} + C$$

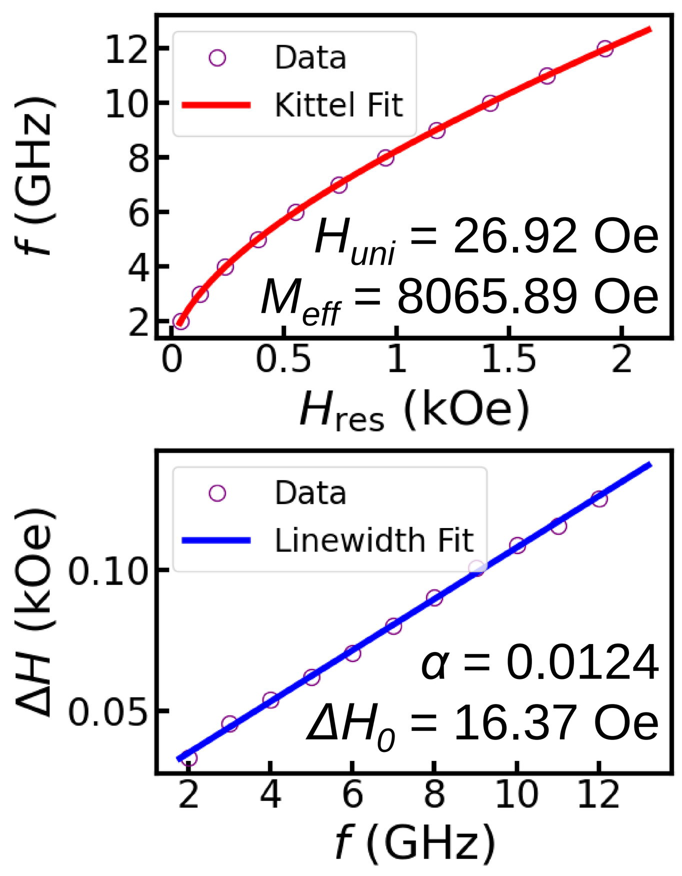
H_{res} : resonance field
ΔH : FMR linewidth
γ : gyromagnetic ratio
μ_0 : vacuum permeability

- Resonance and linewidth are analyzed using the Kittel relation and linear damping model:

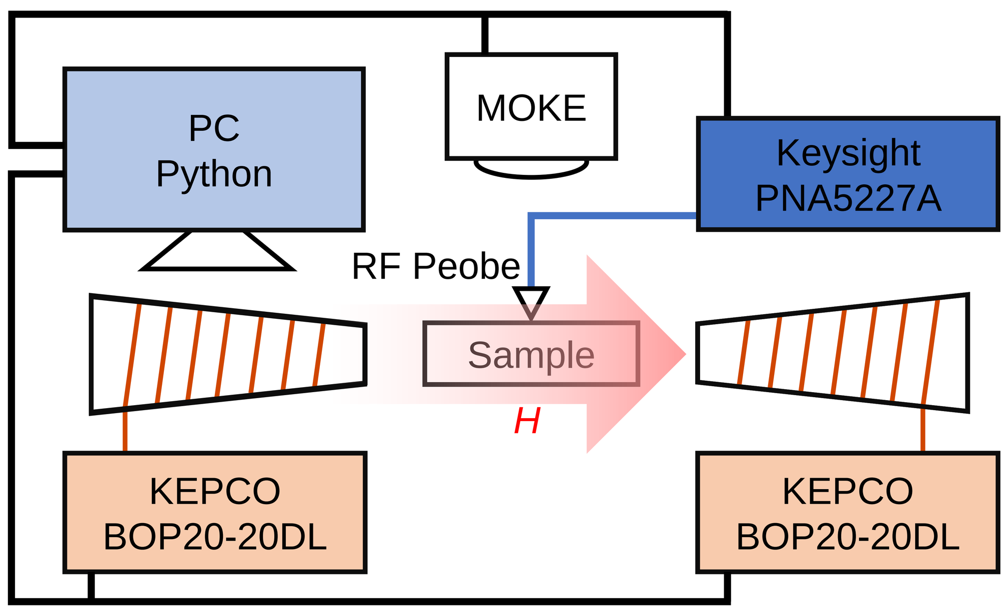
$$f = \frac{\gamma\mu_0}{2\pi}\sqrt{(H+H_{uni}+M_{eff})(H+H_{uni})}$$

$$\Delta H(f) = \Delta H_0 + \frac{4\pi\alpha}{\gamma} f$$

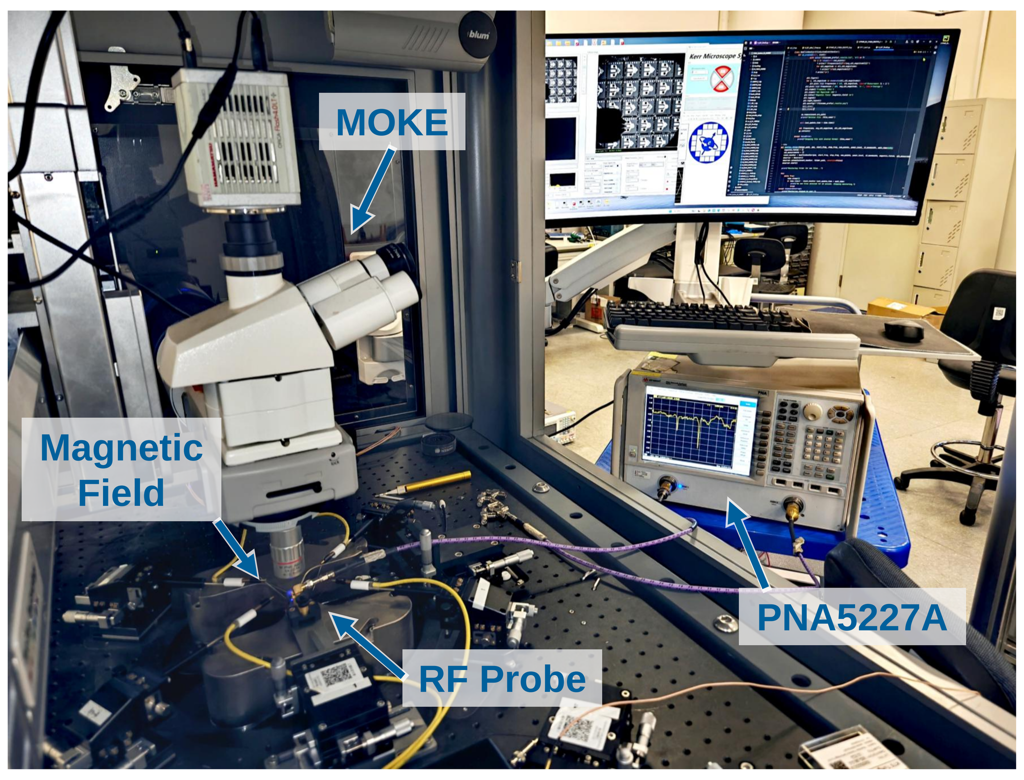
H_{uni} : uniaxial anisotropy field
M_{eff} : effective magnetization
α : Gilbert damping
ΔH_0 : inhomogeneous broadening



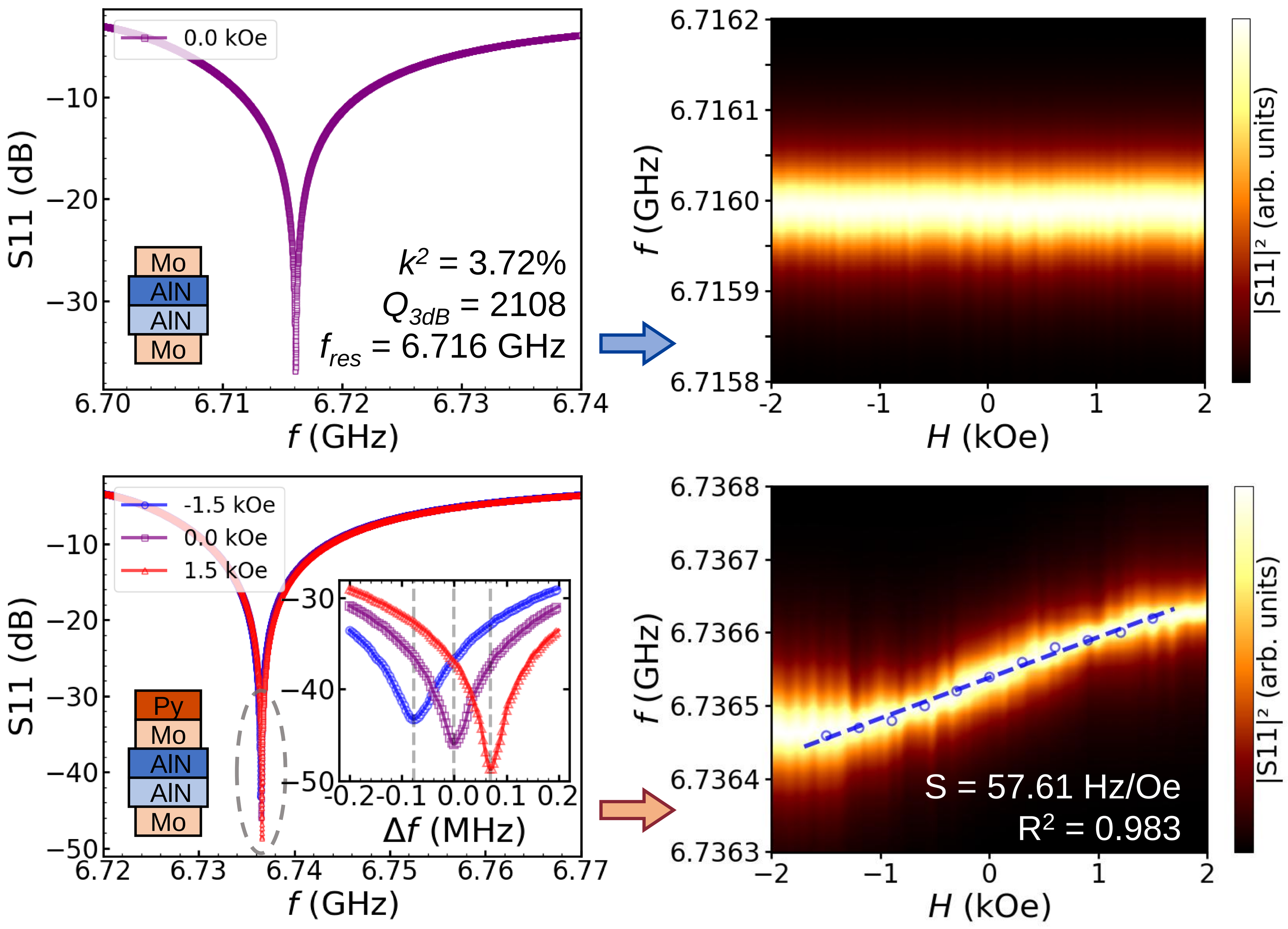
EXPERIMENTAL SETUP



One-port S11 measured on a probe station with in-plane dc field applied along the easy axis. All measurements were carried out at room temperature.



RESULTS



- Py-free BAW resonator: field-independent near 6.7 GHz
- Py/AlN BAW resonator: clear resonance shift with field. Linear response: $f(H) = f_0 + S \cdot H$
- Qualitative analysis: Magnetic field ↓ Interfacial stress ↓ Acoustoelastic stiffness ↓ Resonance frequency
- Py/AlN BAW: high frequency, large range, vector-field sensor

Resonator type	Piezoelectric Material	Magnetic Material	Frequency (GHz)	Sensitivity (Hz/Oe)	Working Range (kOe)	Ref
BAW	AlN	FeGa	2.47	270	0.567	1
BAW	AlN	FeGaB	0.093	~ 4500	0.06	2
BAW	Diamond	FeGaB	0.147	7.1	0.02	3
BAW	ZnO	FeCo	0.879	357	0.35	4
BAW	AlN	FeNi	6.737	57.61	± 1.52	This work

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[2] H. Lin *et al.*, *IEEE MTT-S International Microwave Symposium* (2016).
[3] Z. Zhang *et al.*, *ACS Appl. Mater. Interfaces* (2020).
[4] Vinita *et al.*, *Sensors and Actuators A: Physical* (2023).

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