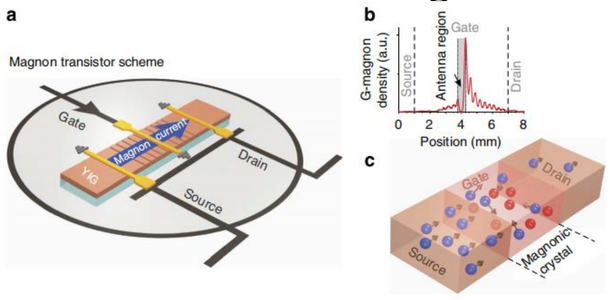
Magnon-Magnon Coupling in Permalloy Stripes

Nan Jiang, Zhicheng Jin, Haoran Chen, Hongyue Xu, Yunzhuo Wu, Wentao Qin, Yizheng Wu*

Department of Physics, Fudan University, Shanghai, China

Background

Candidate in CMOS : magnon

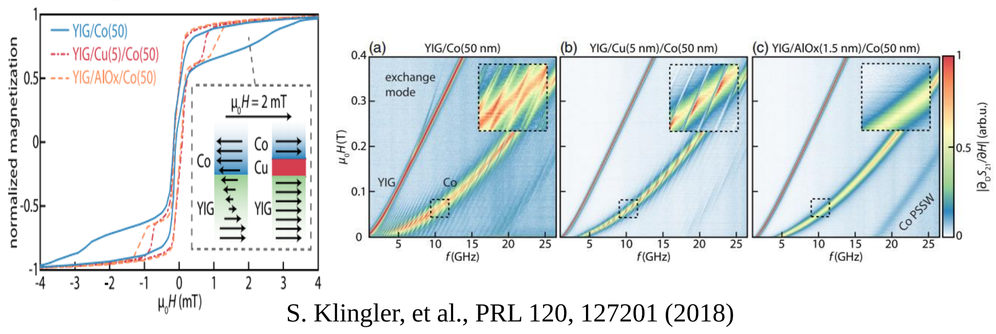


A. V. Chumak, et al., Nat.Commun. 5, 4700 (2014).

CMOS in electronics :waste heat during switching

Magnons(quanta of spin waves) : low dissipation

Magnon-magnon coupling between two adjacent magnetic layers



S. Klingler, et al., PRL 120, 127201 (2018)

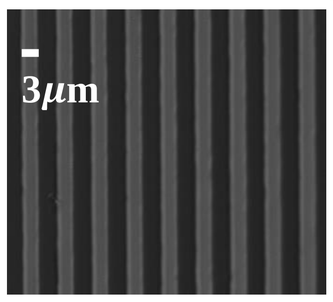
Magnon-magnon coupling : YIG(PSSW mode)+Co(FMR mode)

Single ferromagnetic material layer

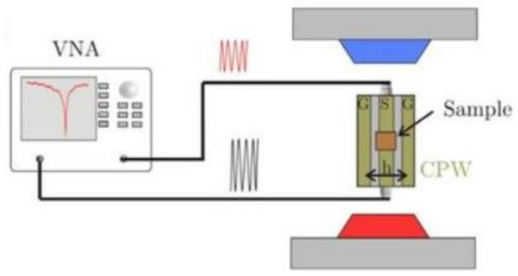
So how about magnon-magnon coupling in a single ferromagnetic material between different modes?

Sample and measurement system

Sample morphology

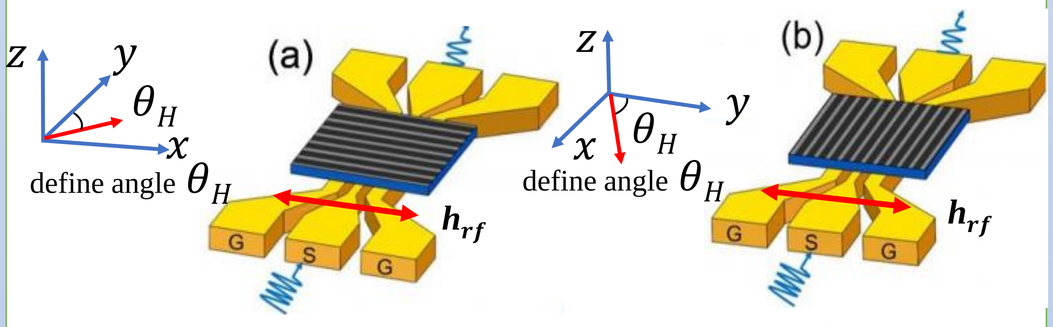


Schematic diagram



$MgO(001)|Py(50nm)|Al_2O_3(5nm)$ **FMR measurement based on VNA**

Two types of placement positions

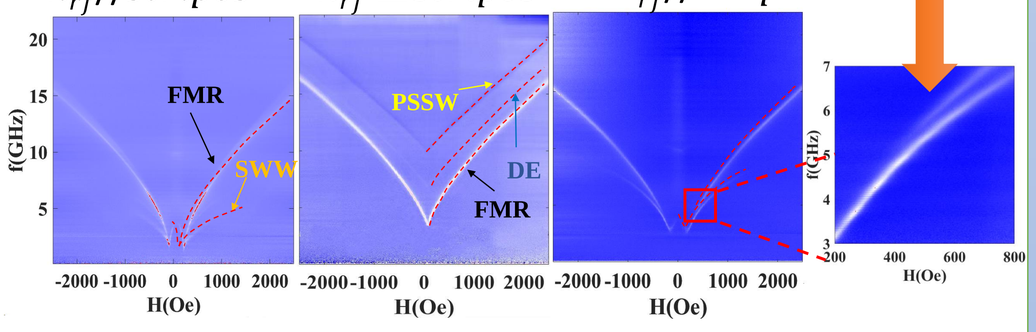


position1: h_{rf} // Py stripes **position2: h_{rf} ⊥ Py stripes**

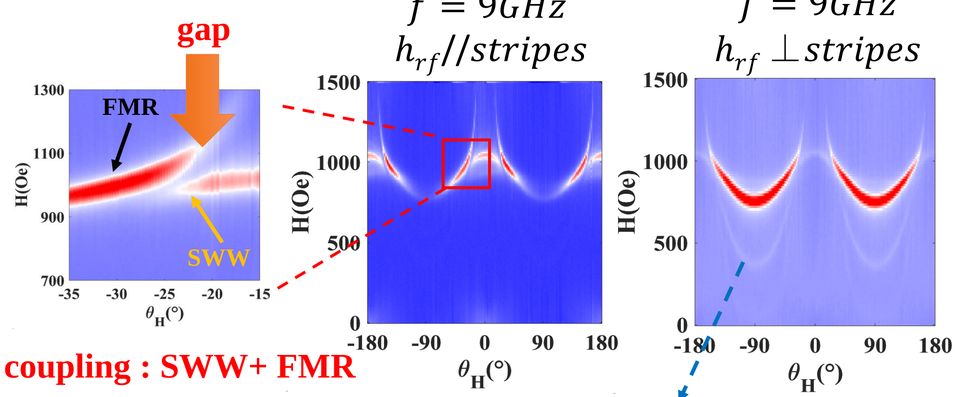
VNA-FMR measurement

- **Magnetic field dependent(fix θ)**

H_{ext}//y, $\theta = 0°$ h_{rf}//stripes | H_{ext}//x, $\theta = 90°$ h_{rf} ⊥stripes | H_{ext}//y, $\theta = 15°$ h_{rf}//stripes



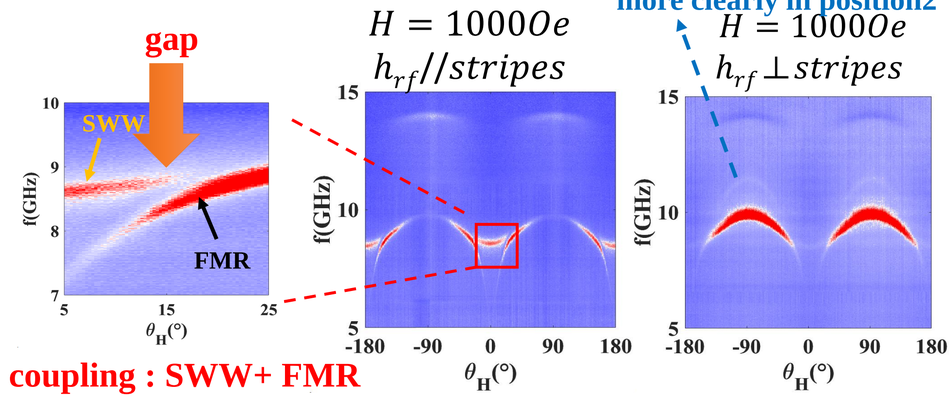
- **Angular dependent (fix f)**



coupling : SWW+ FMR

DE mode can be seen more clearly in position2

- **Angular dependent (fix H)**

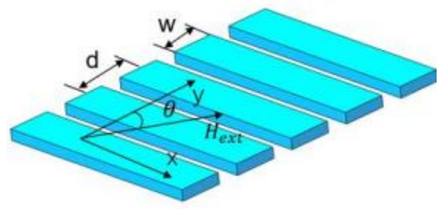


coupling : SWW+ FMR

Micromagnetic simulation

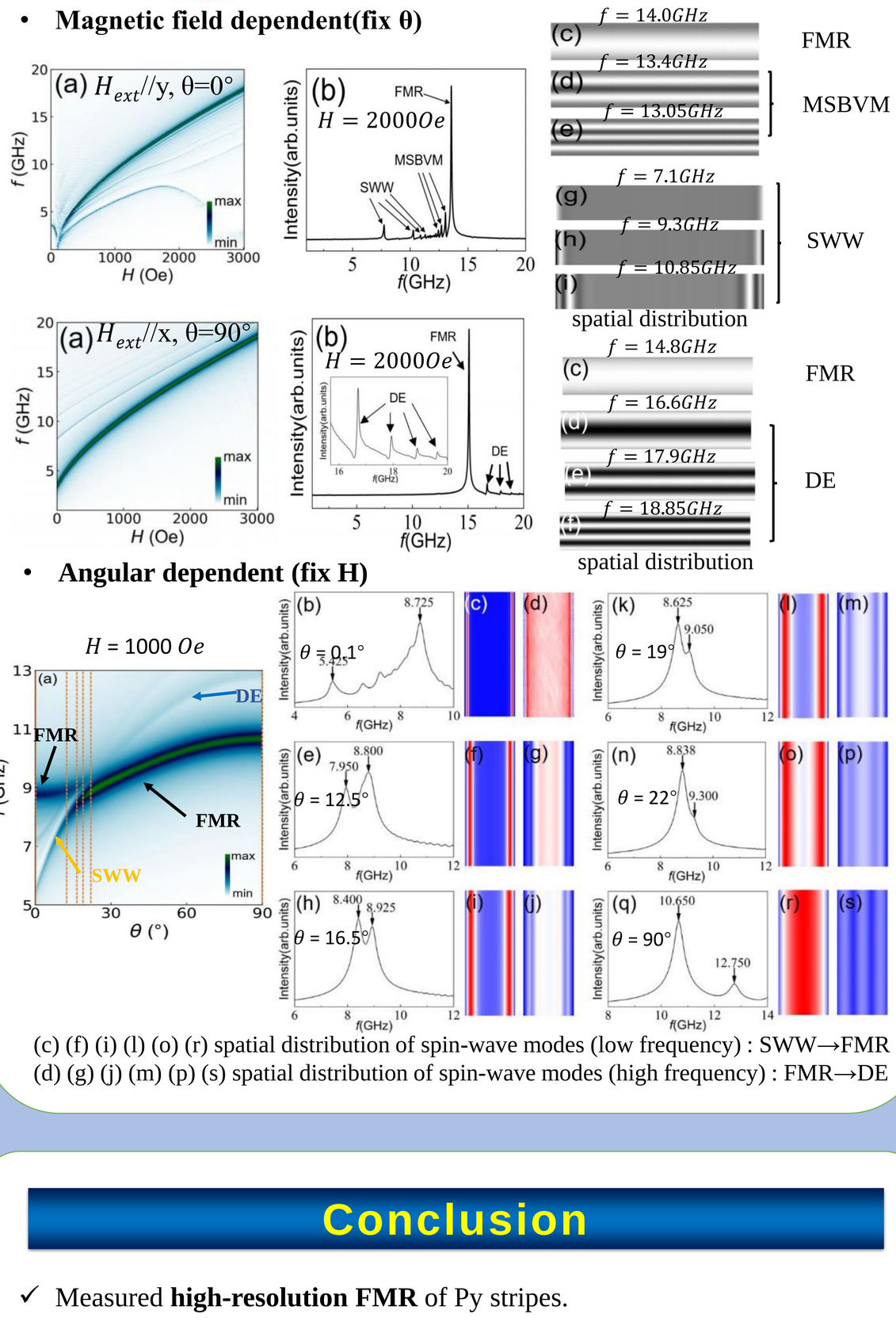
Micromagnetic simulation through mumax3

- **Model and parameters**



saturation magnetization M_s = 866 k A/m
exchange strength coefficient $A = 13\times10^{-12}$ J / m
damping coefficient $\alpha = 0.01$
single stripe size : $10\mu m \times w \times 40nm$, $w = 2\ \mu m$
$d = 2.2\mu m$

- **Magnetic field dependent(fix θ)**



- **Angular dependent (fix H)**

(c) (f) (i) (l) (o) (r) spatial distribution of spin-wave modes (low frequency) : SWW→FMR
(d) (g) (j) (m) (p) (s) spatial distribution of spin-wave modes (high frequency) : FMR→DE

Conclusion

- ✓ Measured **high-resolution FMR** of Py stripes.
- ✓ Discovered **magnon-magnon coupling (FMR and SWW)** in single ferromagnetic material between different modes, which is **beneficial for particle-less technology**, where information will be carried and processed by magnons rather than by electrons.
- ✓ Verified the experimental results through **micromagnetic simulation** by mumax3.

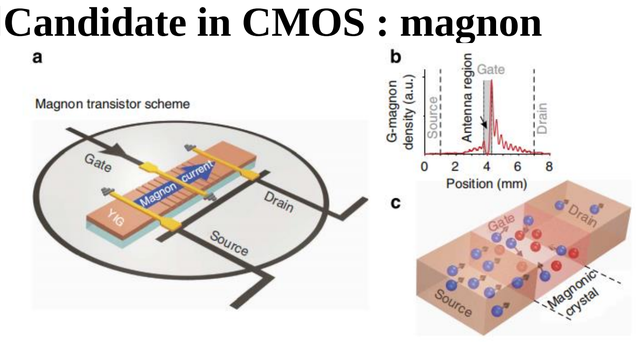
Magnon-Magnon Coupling in Permalloy Stripes

Nan Jiang, Zhicheng Jin, Haoran Chen, Hongyue Xu, Yunzhuo Wu, Wentao Qin, Yizheng Wu*

Department of Physics, Fudan University, Shanghai, China

Background

☐Candidate in CMOS : magnon

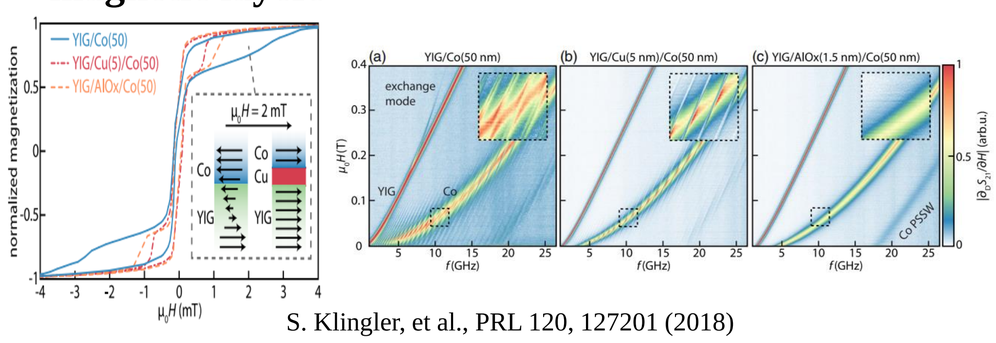


A. V. Chumak, et al., Nat.Commun. 5, 4700 (2014).

CMOS in electronics :waste heat during switching

Magnons(quanta of spin waves) : low dissipation

☐Magnon-magnon coupling between two adjacent magnetic layers



S. Klingler, et al., PRL 120, 127201 (2018)

Magnon-magnon coupling : YIG(PSSW mode)+Co(FMR mode)

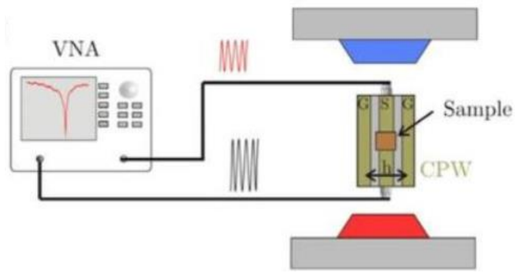
☐Single ferromagnetic material layer

So how about magnon-magnon coupling in a single ferromagnetic material between different modes?

Sample and measurement system

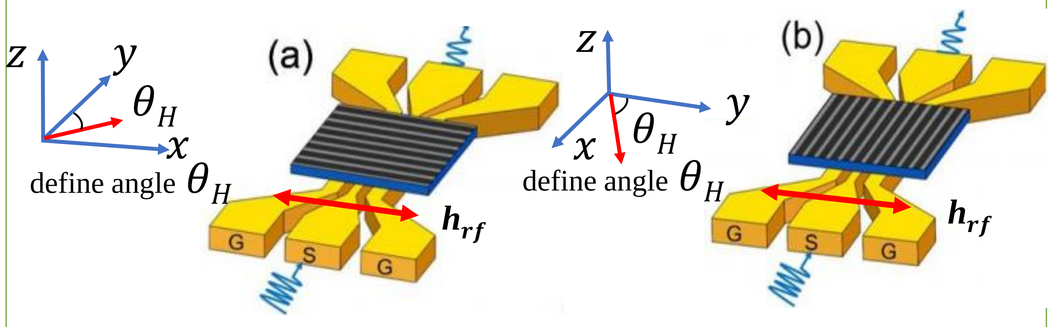
☐ Sample morphology

☐ Schematic diagram



$MgO(001)|Py(50nm)|Al_2O_3(5nm)$ **FMR measurement based on VNA**

☐ Two types of placement positions

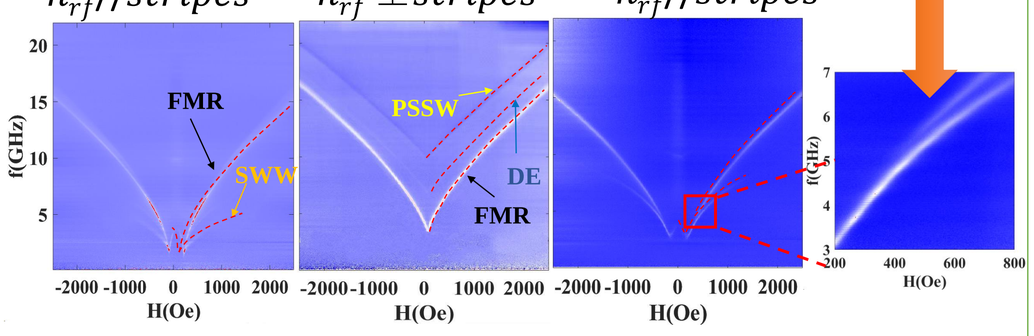


position1: h_{rf} // Py stripes **position2: h_{rf} ⊥ Py stripes**

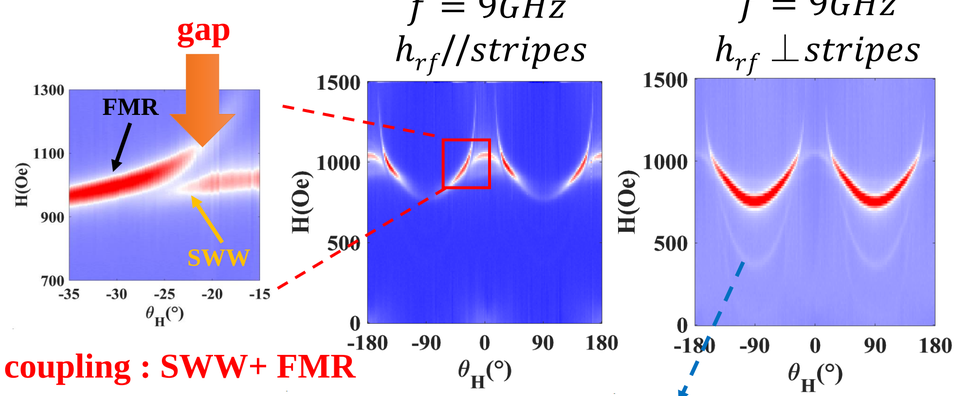
VNA-FMR measurement

- **Magnetic field dependent(fix θ)**

H_{ext}//y, $\theta = 0°$ h_{rf}//stripes | H_{ext}//x, $\theta = 90°$ h_{rf} ⊥stripes | H_{ext}//y, $\theta = 15°$ h_{rf}//stripes



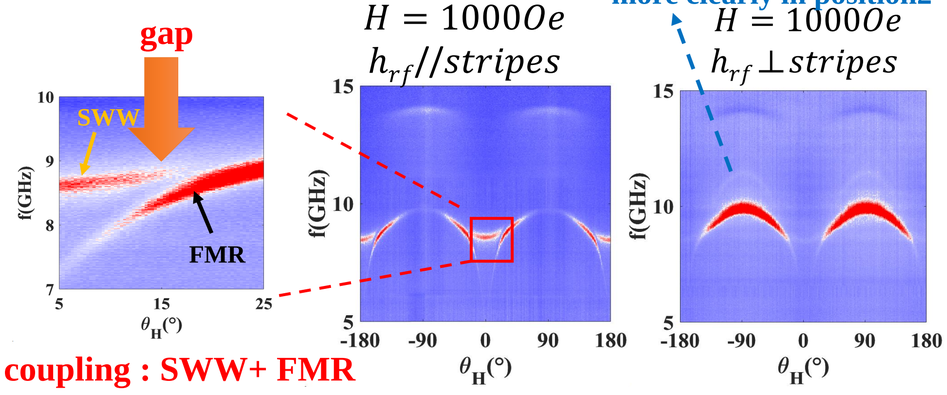
- **Angular dependent (fix f)**



coupling : SWW+ FMR

DE mode can be seen more clearly in position2

- **Angular dependent (fix H)**

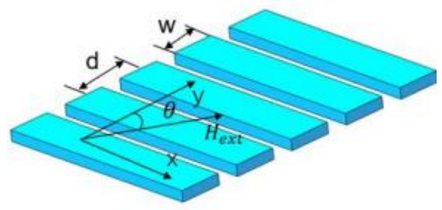


coupling : SWW+ FMR

Micromagnetic simulation

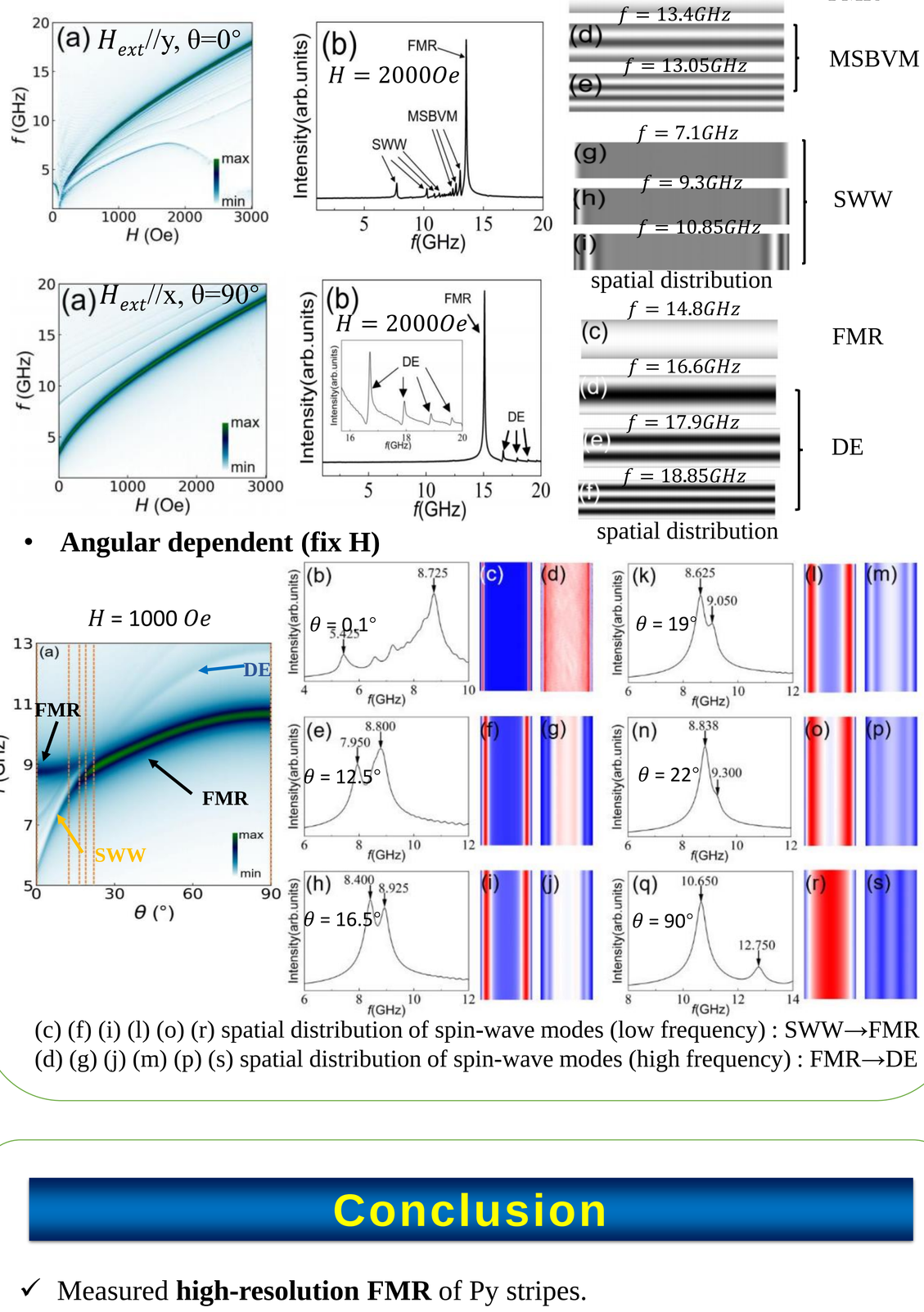
☐ Micromagnetic simulation through mumax3

- **Model and parameters**



saturation magnetization M_s = 866 k A/m
exchange strength coefficient $A = 13\times10^{-12}$ J / m
damping coefficient $\alpha = 0.01$
single stripe size : $10\mu m \times w \times 40nm$, $w = 2\ \mu m$
$d = 2.2\mu m$

- **Magnetic field dependent(fix θ)**



- **Angular dependent (fix H)**

(c) (f) (i) (l) (o) (r) spatial distribution of spin-wave modes (low frequency) : SWW→FMR
(d) (g) (j) (m) (p) (s) spatial distribution of spin-wave modes (high frequency) : FMR→DE

Conclusion

- ✓ Measured **high-resolution FMR** of Py stripes.
- ✓ Discovered **magnon-magnon coupling (FMR and SWW)** in single ferromagnetic material between different modes, which is **beneficial for particle-less technology**, where information will be carried and processed by magnons rather than by electrons.
- ✓ Verified the experimental results through **micromagnetic simulation** by mumax3.