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高周波スピントロニクスと磁化ダイナミクス ー高感度スピントルクダイオードー

鈴木義茂[1,2], 石橋翔太[1,*], 野崎隆行[1,**], 久保田均[2],
薬師寺啓[2], 福島章雄[2], 湯浅新治[2]
[1]大阪大学基礎工学研究科物性物理工学領域
[2]産業技術総合研究所ナノスピントロニクス研究センター
**Present address: Toshiba Corporation*
*** Present address: AIST, NanoSpintronics Research Center, Tsukuba, Japan*

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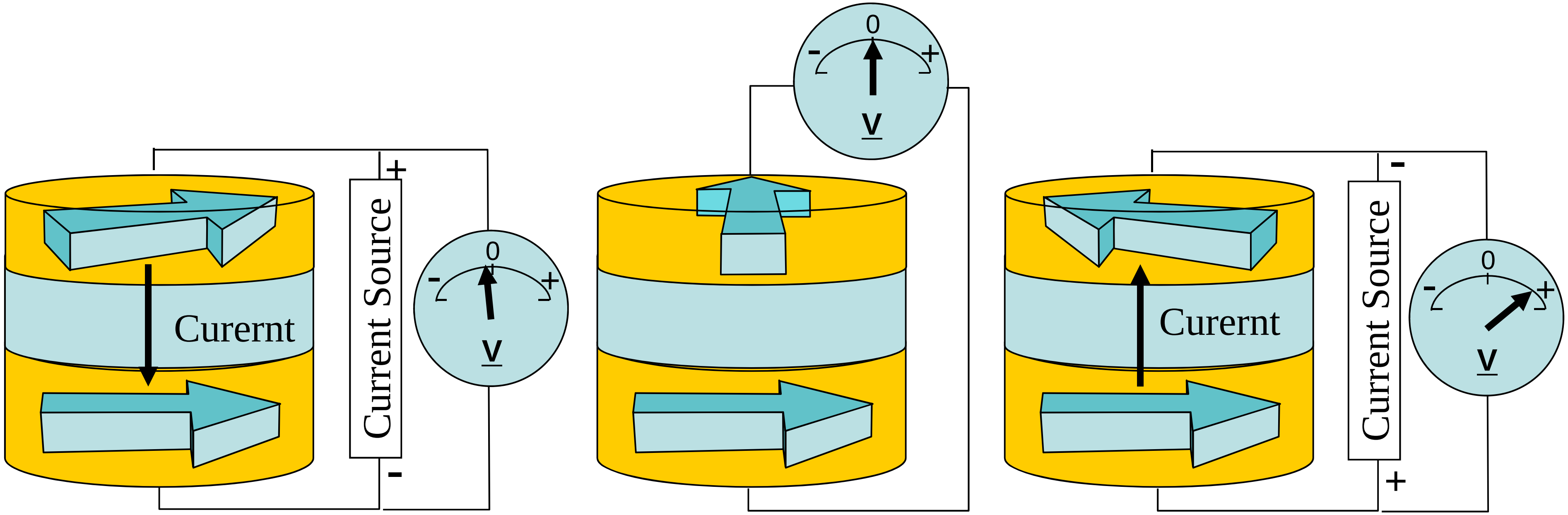
Spin-torque diode effect

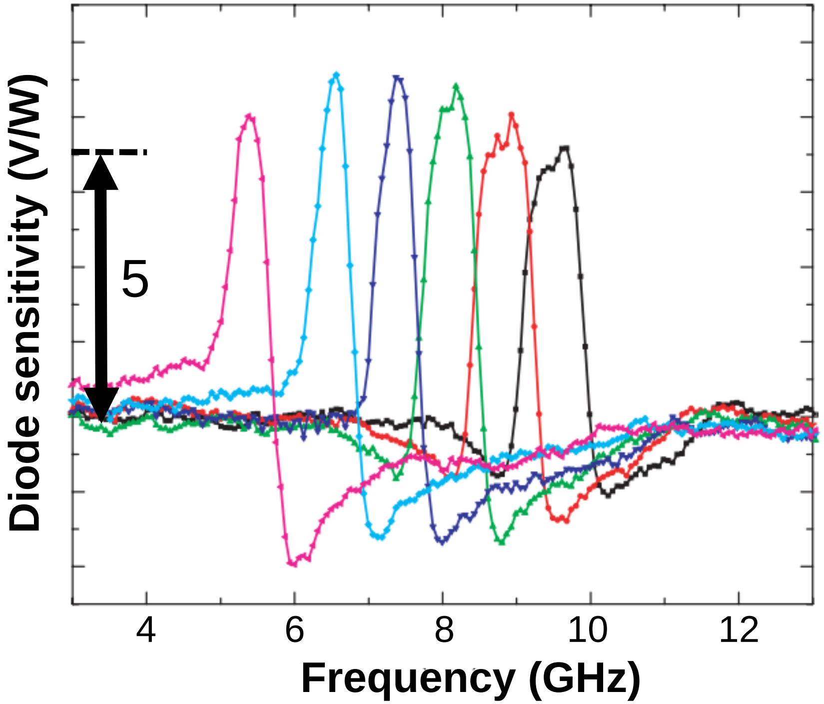


(A) Up to down current makes magnetization parallel and resistance small. Thus it produces small negative voltage.

(B) No current : Shape anisotropy prefers vertical alignment

(C) Down to up current makes magnetization anti-parallel and resistance large. Thus it produces large positive voltage.

Spin torque diode effect



A. A. Tulapurkar *et al.*, Nature, **438,** 339 (2005)

RF current

⇒ Magnetic resonance

⇒ DC voltage

Rectification

$$Diode\ sensitivity = \frac{V_{DC}(\mathrm{V})}{P_{RF}(\mathrm{W})} \approx 5\left[\frac{V}{W}\right]$$

(*p-n* junction diode

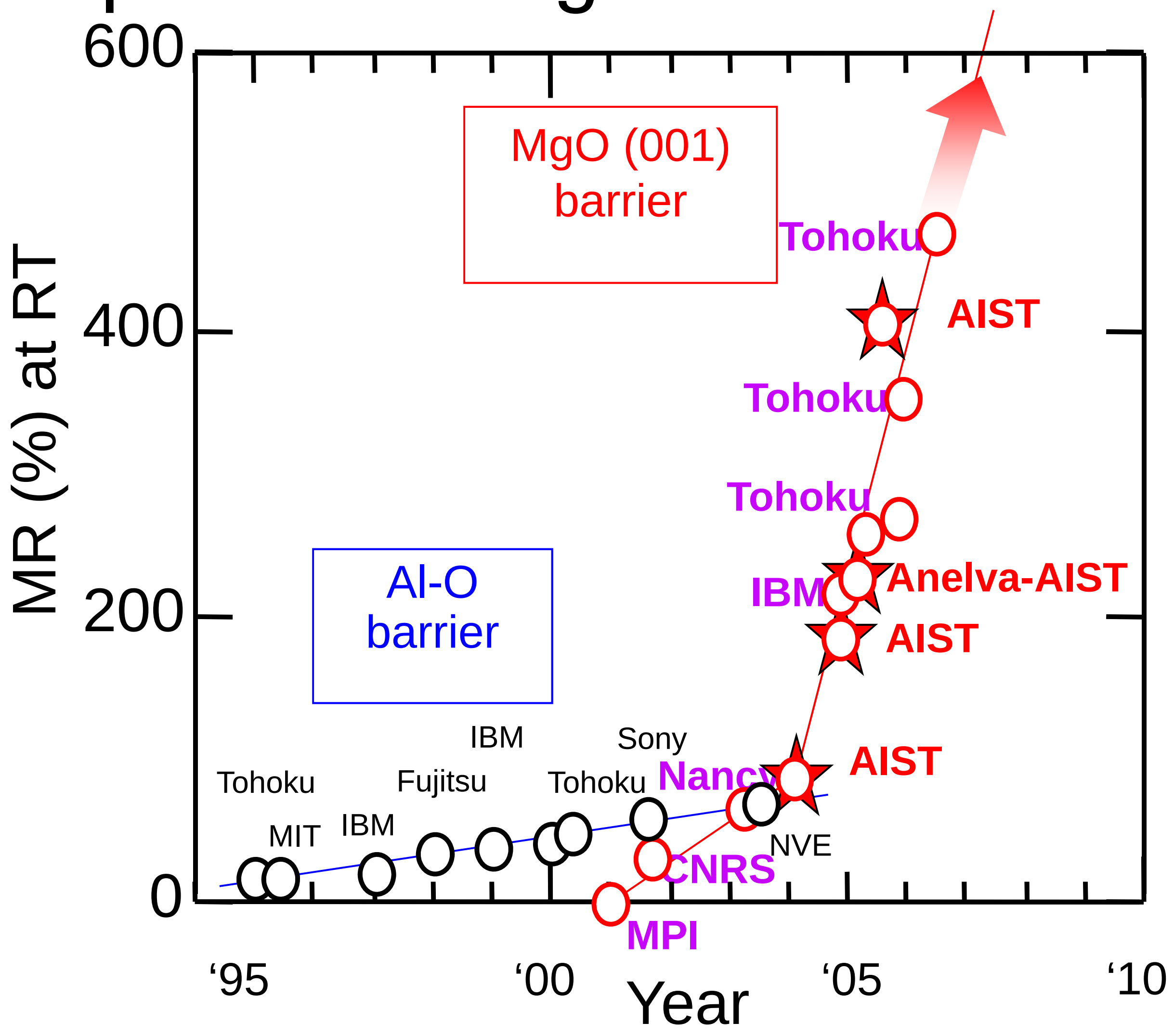
$$Diode\ sensitivity = \frac{eZ_0}{2k_B T}$$

≈ 1000 V/W (50 Ω)

≈ 4000 V/W (High resistance))

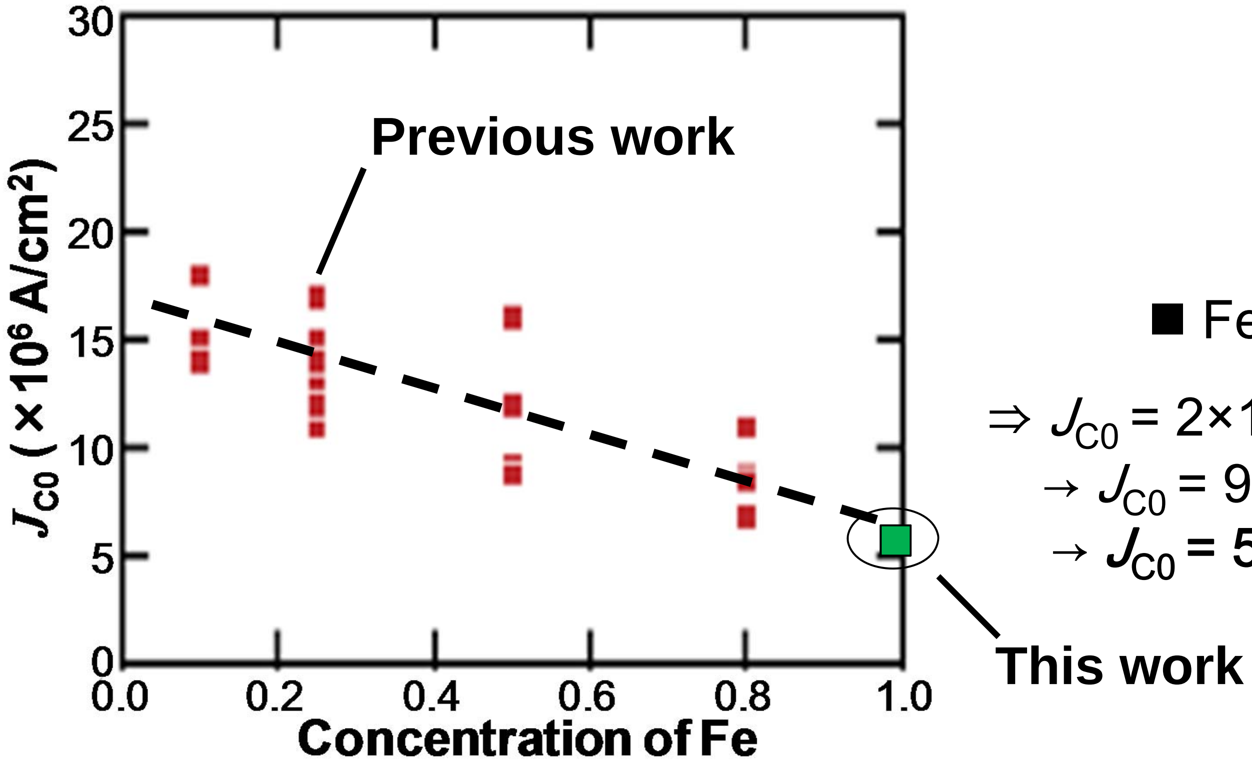
Purpose :To enhance the diode sensitivity

Development of Magnetic Tunnel Junctions



FeB free layer

The CoFe conposition dependence of J_{C0}

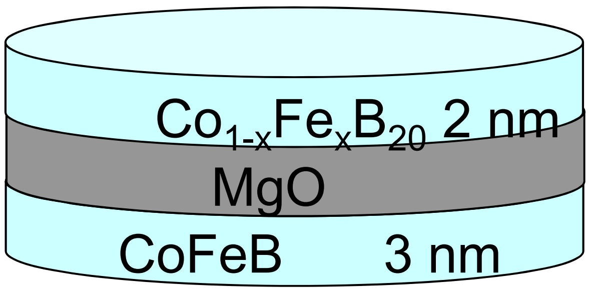


■ Fe-rich CoFeB free layer

⇒ J_{C0} = 2×10⁷ A/cm²($Co_{60}Fe_{20}B_{20}$)
→ J_{C0} = 9×10⁶ A/cm²($Co_{16}Fe_{64}B_{20}$)
→ **J_{C0} = 5×10⁶ A/cm²($Fe_{80}B_{20}$)**

S. Yakata, Y. S. *et.al*., J. Appl. Phys. 105, 07D131 (2009).

Sample structure



Three mechanisms of the effect

■ Homodyne detection：A. Tulapurkar et.al., Nature (2005)

Linear FMR $\Rightarrow \delta\theta(\omega) \Rightarrow \delta R(\omega) \times \delta I(\omega) \Rightarrow V_{dc}$

■ Nonlinear FMR + I_{dc} ：C. Wang et.al., Phys. Rev. B (2009)

Nonlinear FMR $\Rightarrow \delta\theta(\omega) \Rightarrow R = R_0 + \delta R(\omega) + \delta R_{dc}(P_{rf})$

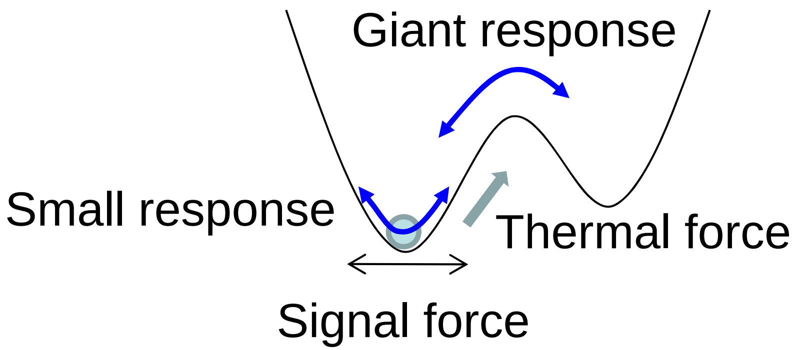
$$\Rightarrow \delta R_{dc}(P_{rf}) \times I_{dc} \Rightarrow V_{dc}$$

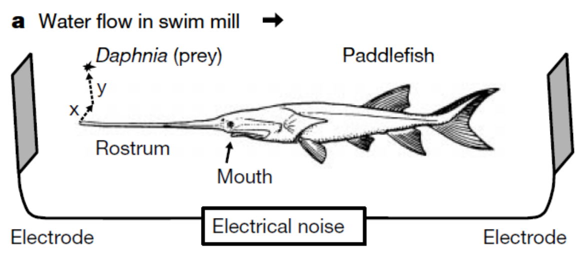
Dominant under large bias

■Stochastic resonance：Xiao Cheng et al., Phys. Rev. Lett. (2010)

RF torque + thermal fluctuation ⇒ Giant response

Dominant for unstable system under finite temperature



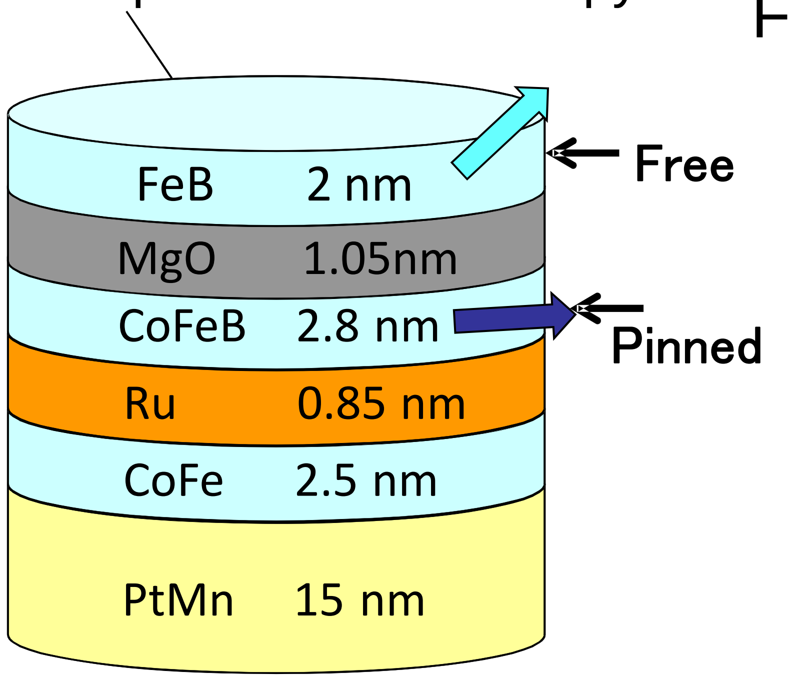


D. F. Russell, et al., Nature (1999)

Sample structure & FMR frequency

MTJ Structure

■Perpendicular anisotropy



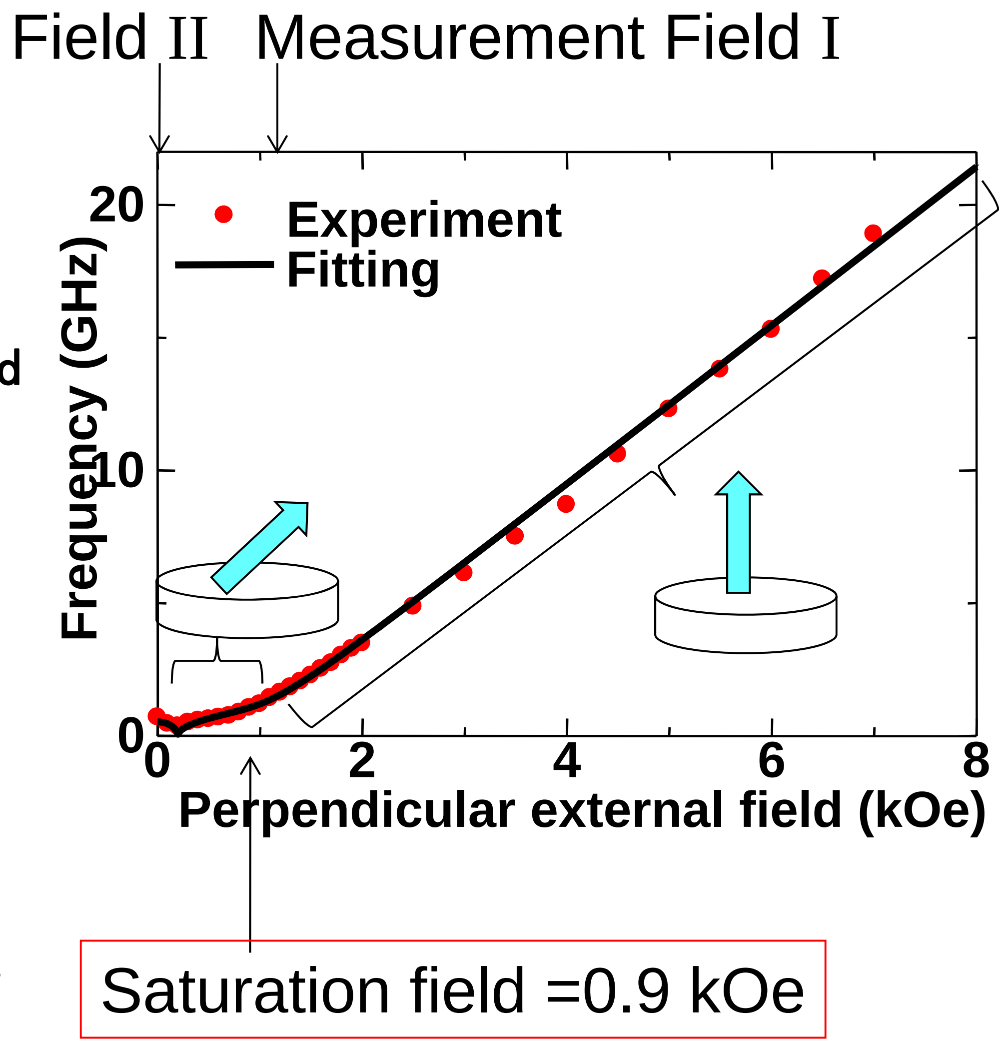
■ CoFeB/MgO/**FeB**

■RP=210 Ω

■MR=86 %

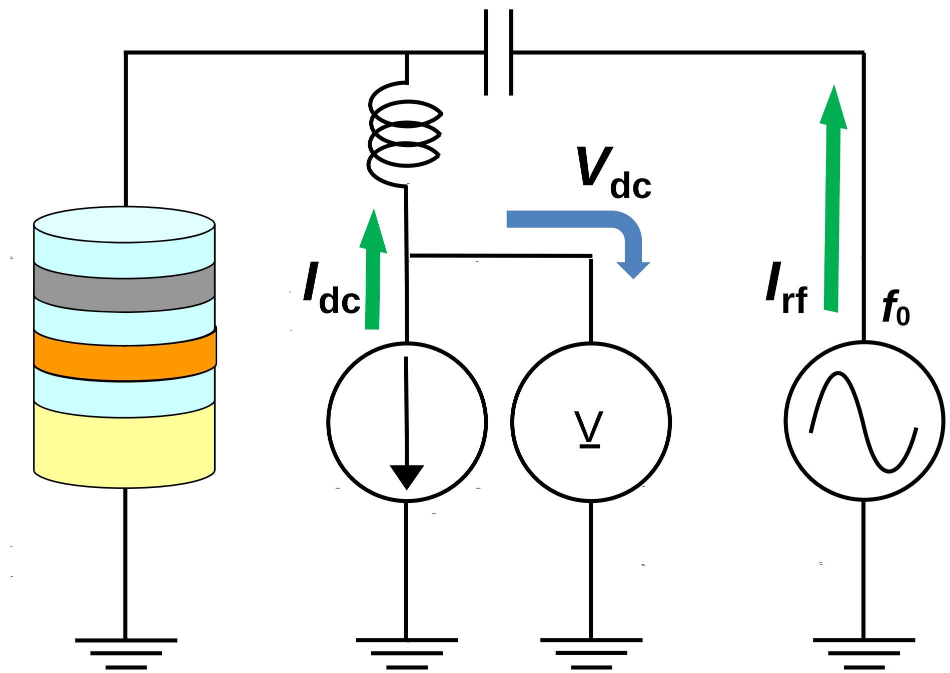
■Junction size= 100×100 nm^2

FMR frequency



Setup & Measurement condition

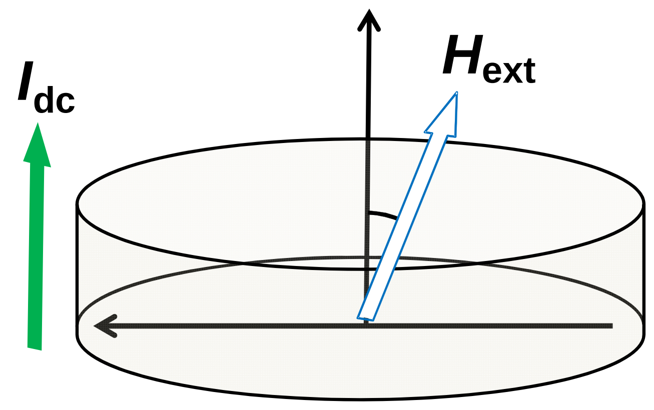
Setup



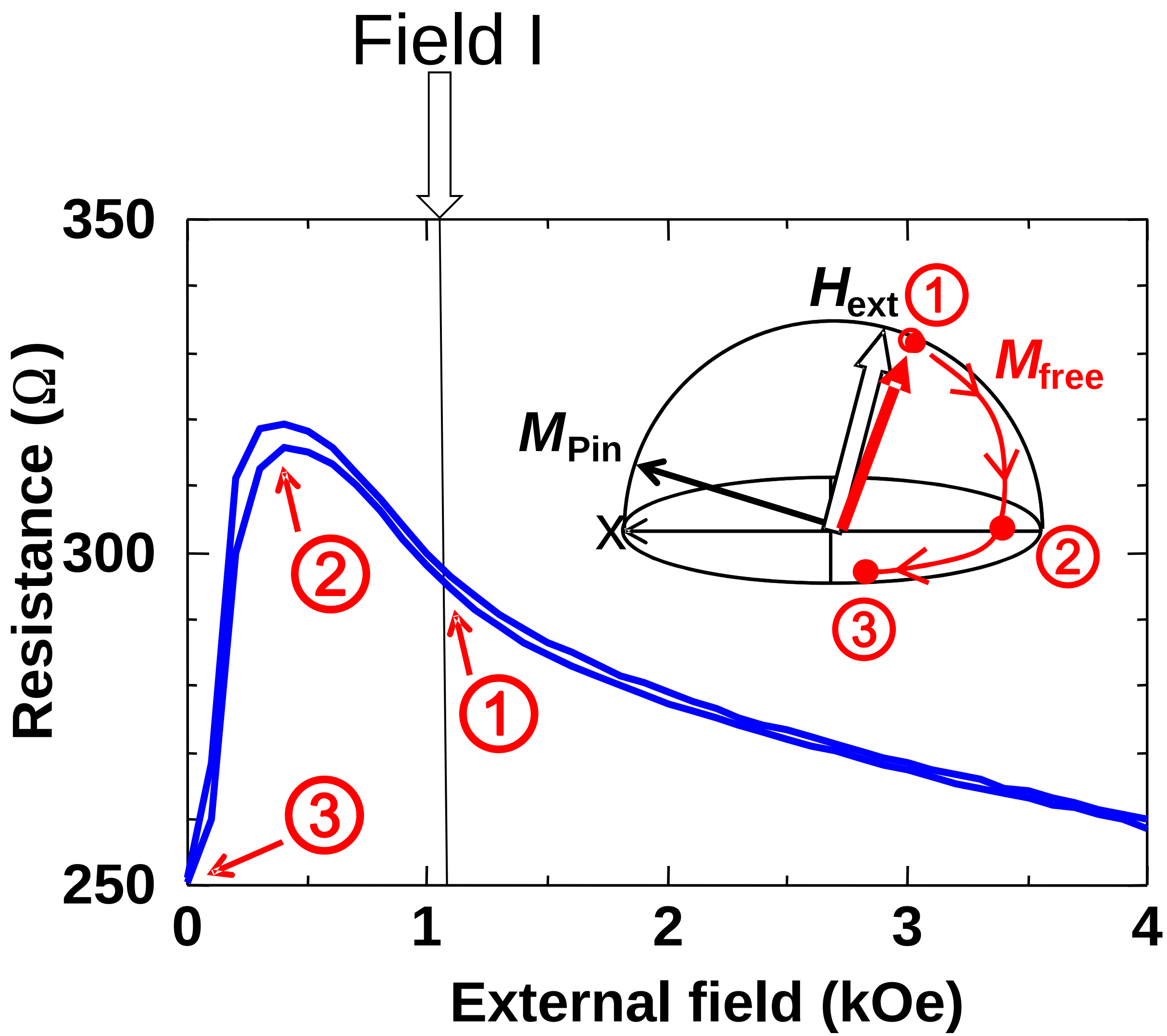
Measurement condition

① Tilted field (8 deg)

② +DC current (-0.4~0.4 mA)



MR curve and measurement field I



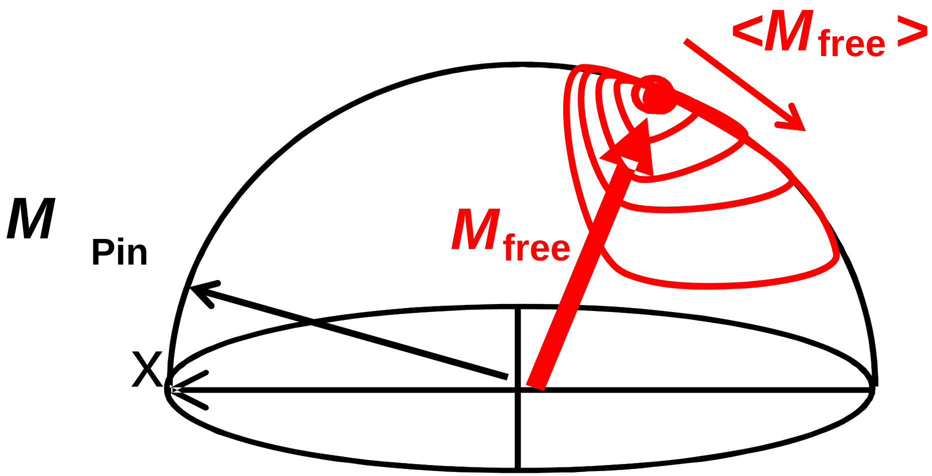
Spectrum under dc bias (Field I)

Large enhancement of the dc signal was observed for the negative bias (unti-damping)

The result is well explained by a macro-spin simulation at 0 K

Maximum sensitivity = 12000 V/W (Much larger than that of *p-n* junction !)

Mechanism of the RF detection



Non harmonic potential
+
Energy pumping

⇩

Shift in the oscillation center
(Resistance change)

$$R = R_0 + \delta R(\omega) + \delta R_{dc}(P_{rf})$$

$$\delta V_{dc} = I_{dc} \times \delta R_{dc}(P_{rf})$$

Power detection

Non-linear FMR vs Homodyne detection

Non-linear FMR

$$R = R_0 + \delta R(\omega) + \delta R_{dc} P_{rf}$$

$$\delta V_{dc} = I_{dc} \times \delta R_{dc} P_{rf} \propto P_{rf}$$

⇒ δV_{dc} may exceed V_{rf}

Amplification function

Homodyne detection

$$R = R_0 + \delta R_{rf}(\omega) V_{rf}$$

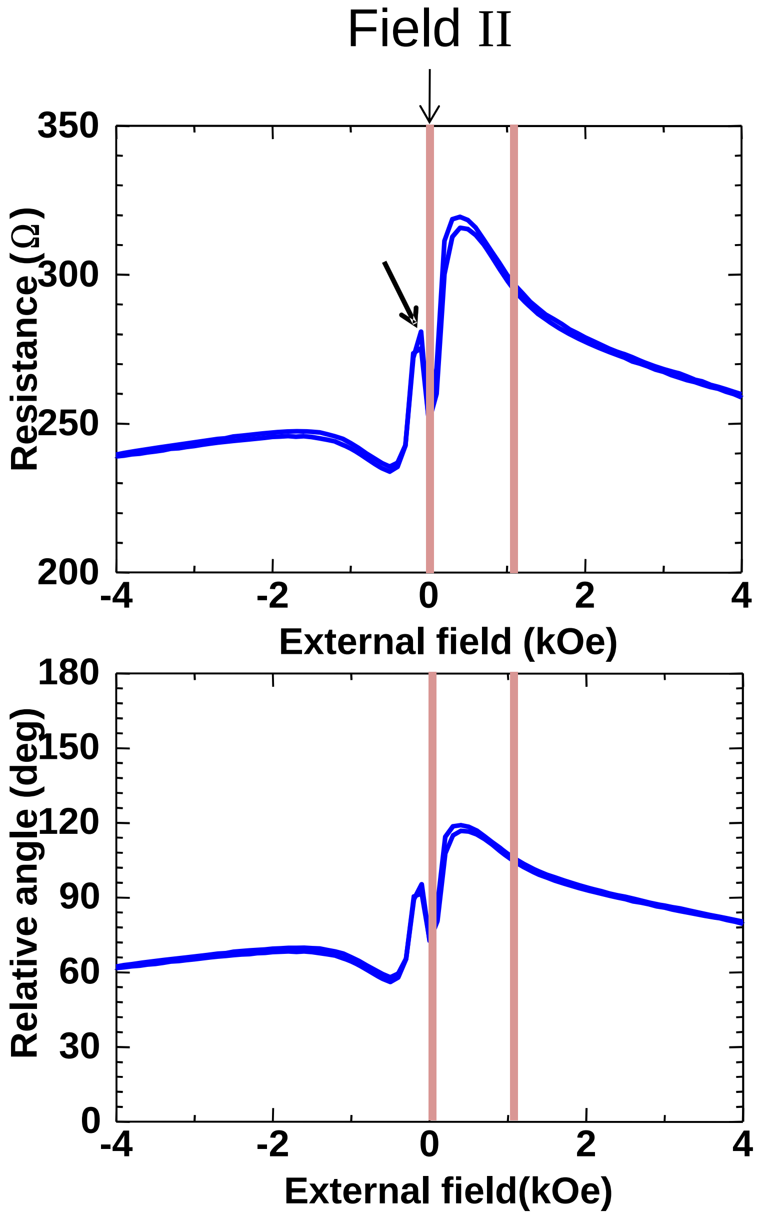
$$\delta V_{dc} = I_{rf}(\omega) \times \delta R_{rf}(\omega) V_{rf} \propto P_{rf}$$

⇒ $\delta V_{dc} < V_{rf}$

Enhancement factor

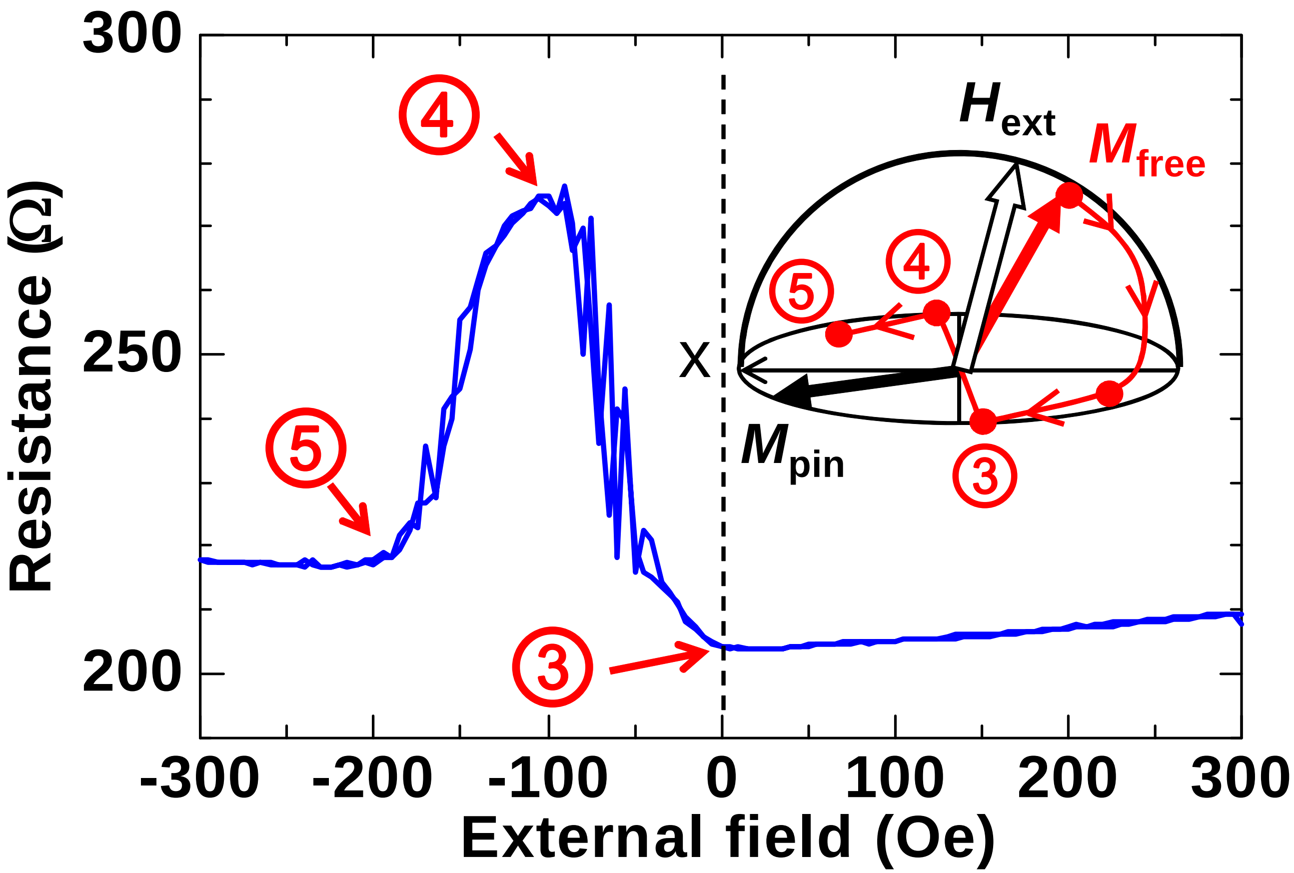
$$\frac{\delta V_{dc}(\text{Non - linear FMR})}{\delta V_{dc}(\text{Homodyne detection})} = \frac{I_{dc}}{I_{rf}}$$

Field II experiment

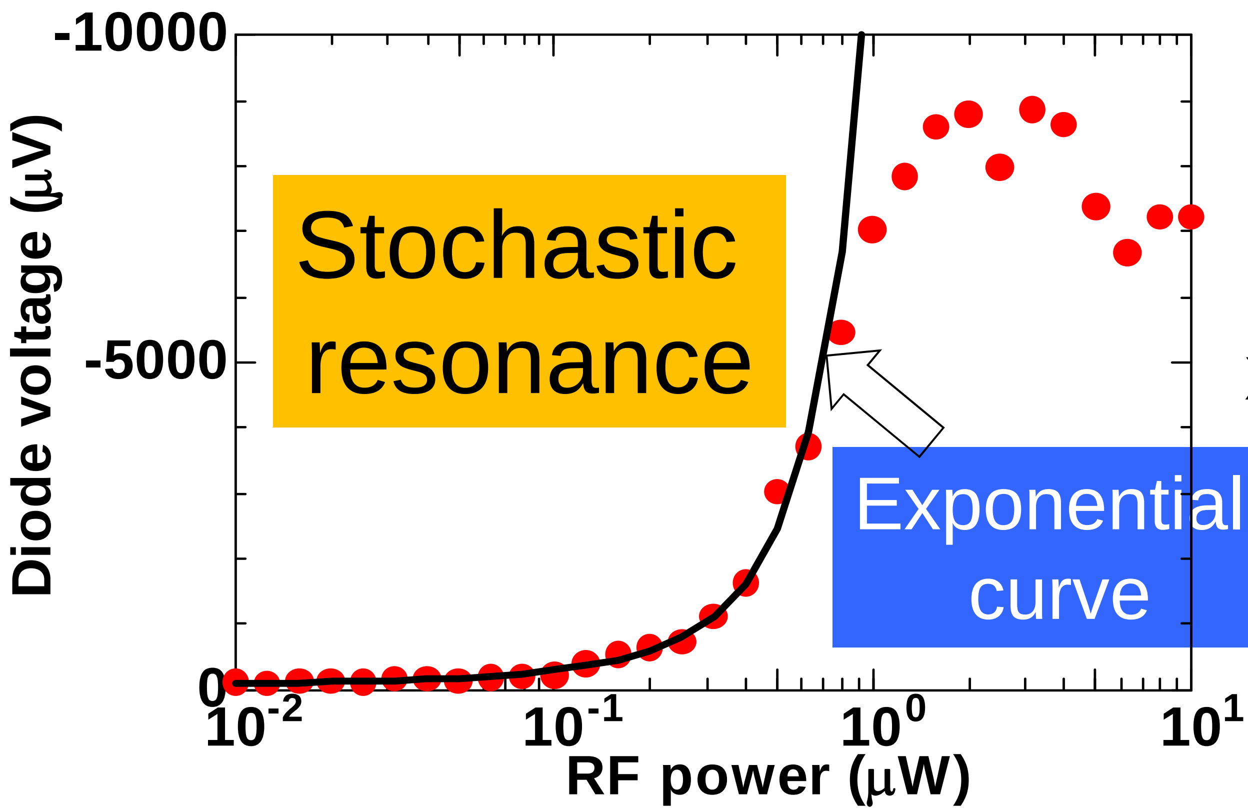


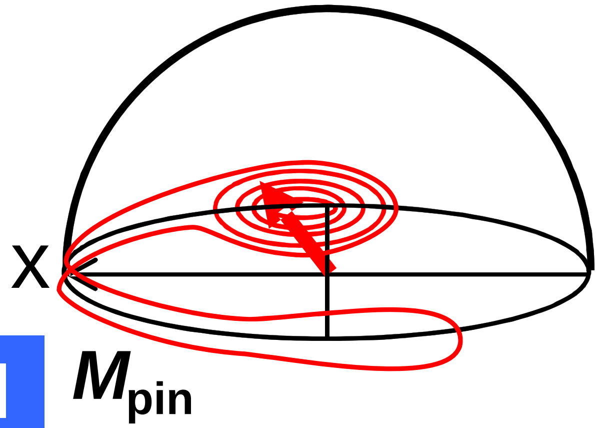
Field II experiment

④ is stabilized by a current



Field II experiment





Exponential pumping of a global orbit (Incoherent)

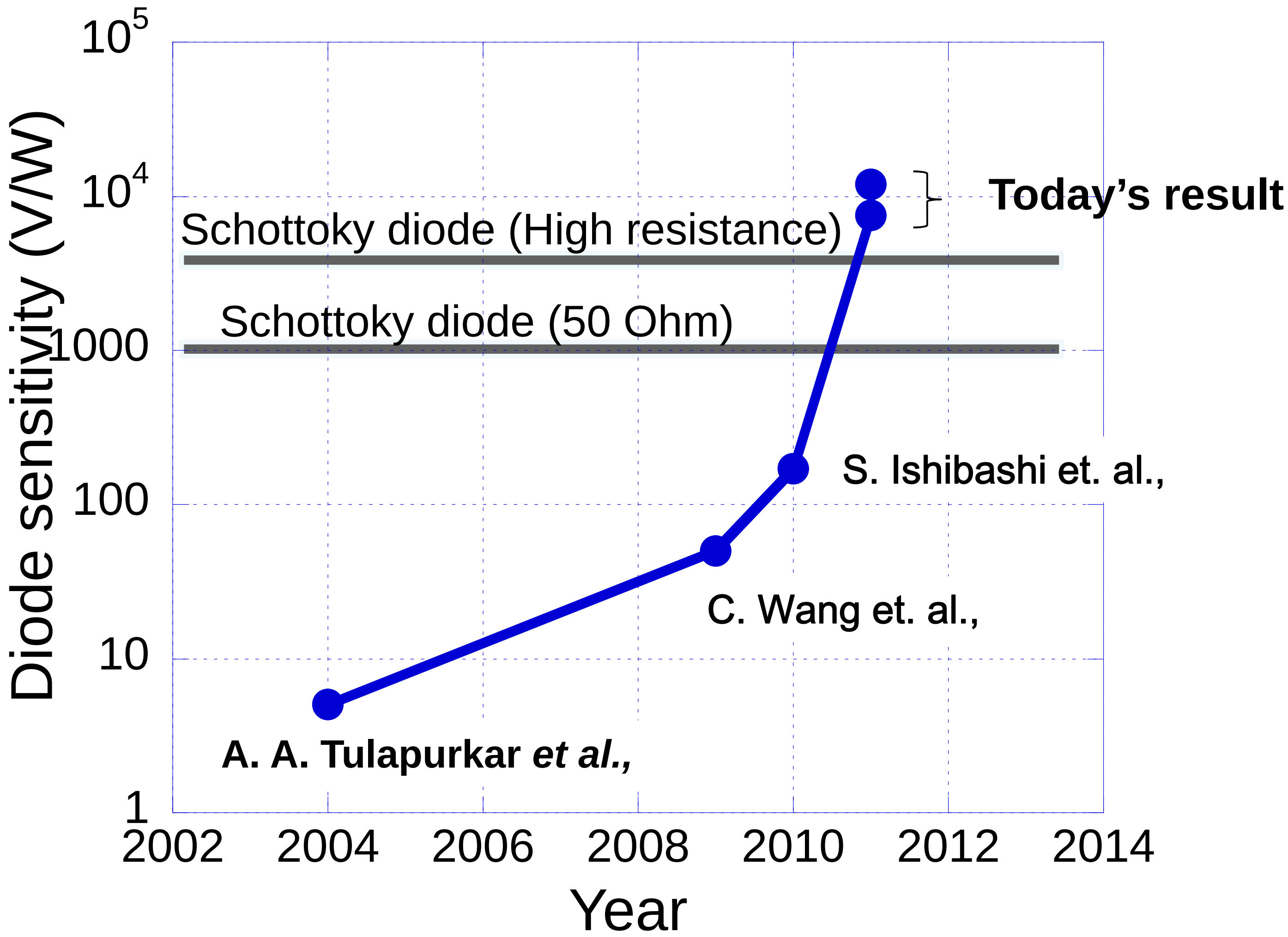
Power detection

$$R = R_0 + \delta R(\omega) + \delta R_{dc}(P_{rf})$$

$$\delta V_{dc} = I_{dc} \times \delta R_{dc}(P_{rf})$$

Maximum sensitivity = 7000 V/W at 1 μW
(Larger than that of *p-n* junction !)

Summary



Using Nonlinear FMR and Stochastic resonance, the Diode sensitivity can be larger than that of semiconductor diode