



*Comprehensive report on achievements of  
the JST PRESTO Project*

“Materials and Processes for Next-  
Generation Innovative Devices”

Katsuaki Sato

Japan Science and Technology Agency (JST)

# Objectives

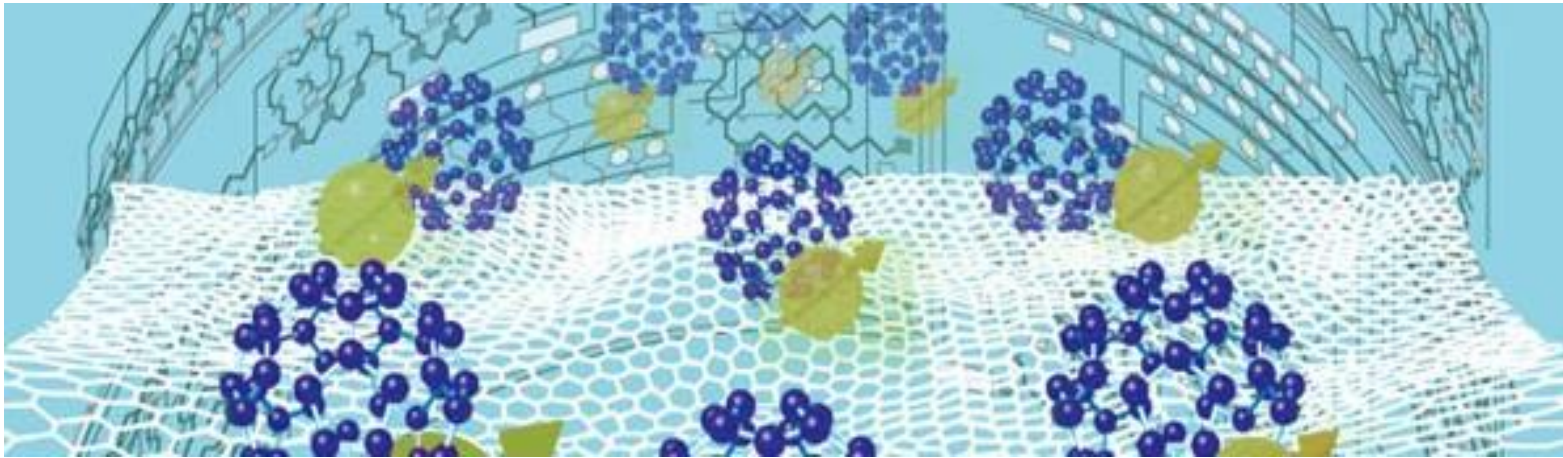
This presentation is a report on the achievements of the JST-PRESTO project “Materials and Processes for Next Generation Innovative Devices”, which started on October 2007 and ended on March 2013.

*I dedicated myself as a Research Supervisor of this Project.*

# Contents

1. How the Project was designed?
2. Scientific and technical achievements
  1. Semiconductor nanoelectronics
  2. Wide-gap semiconductors
  3. Spintronics devices and materials
  4. Molecular and organic electronics
  5. Other achievements
3. Outcomes
4. How has been the project managed?
5. Summary





## Introduction

How the Project was designed?



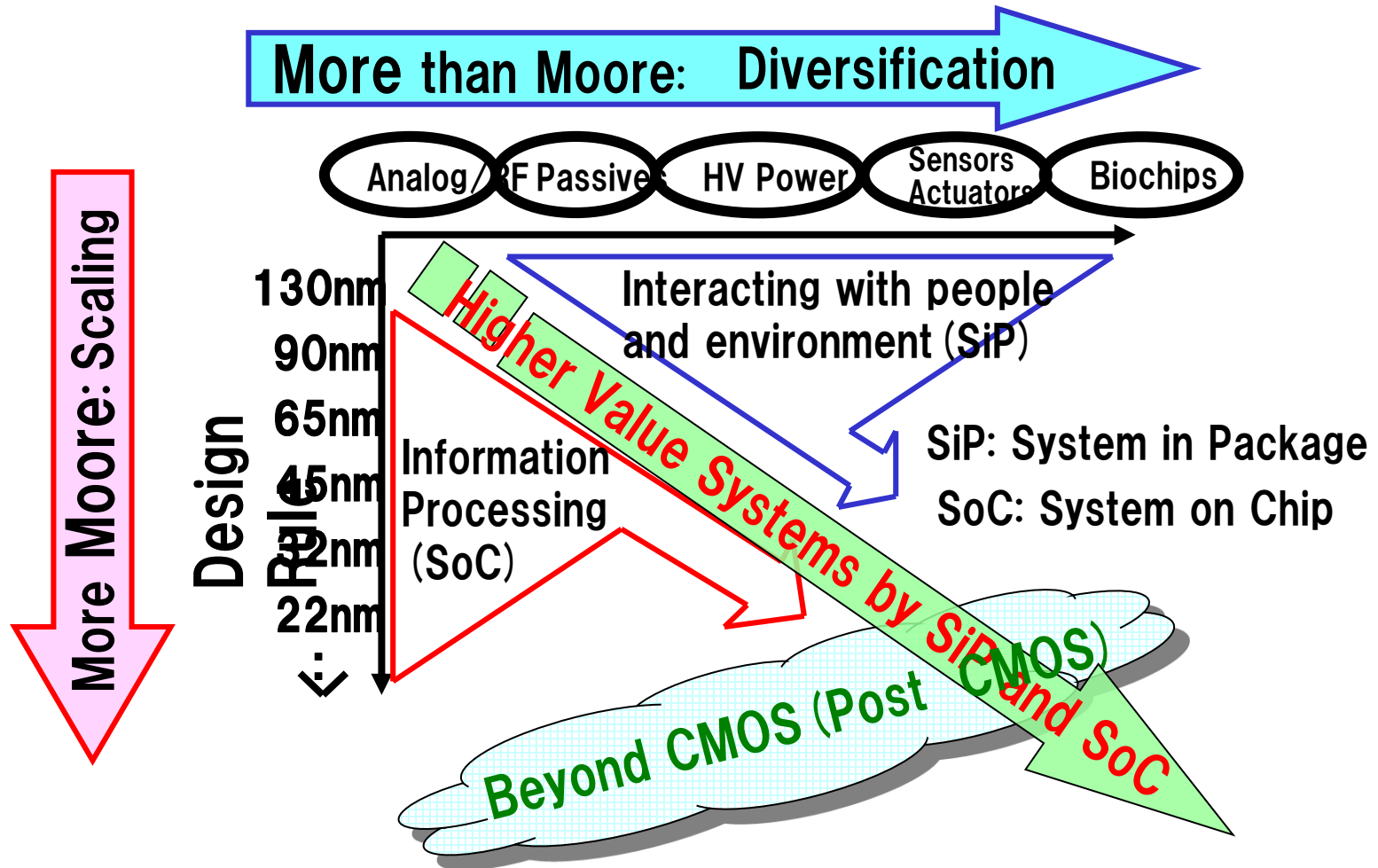
## Background of the Project

- Silicon crystals used for semiconductor integrated circuits represented by CMOS are regarded as the most basic material supporting today's living.
- Semiconductor manufacturing technologies are indivisibly related to nanotechnology, since they become more and more sophisticated as exemplified by the fact that the manufacturing accuracy of the CMOS micro-processing plunges into the nanometer range.
- Consequently the limit of 22 nm half pitch is approaching, which in turn requires device development based on new concepts and/or new principles beyond conventional silicon CMOS technologies.

## Three ways to overcome the limit

- ITRS (International Technology Roadmap for Semiconductors) published a roadmap to overcome the limit (2005)
  - **More Moore: extension of the limit by invention of novel technologies**
  - **More than Moore: addition of higher functionalities by integration of different technologies**
  - **Beyond CMOS: development of devices based on new concept**

# ITRS roadmap 2005



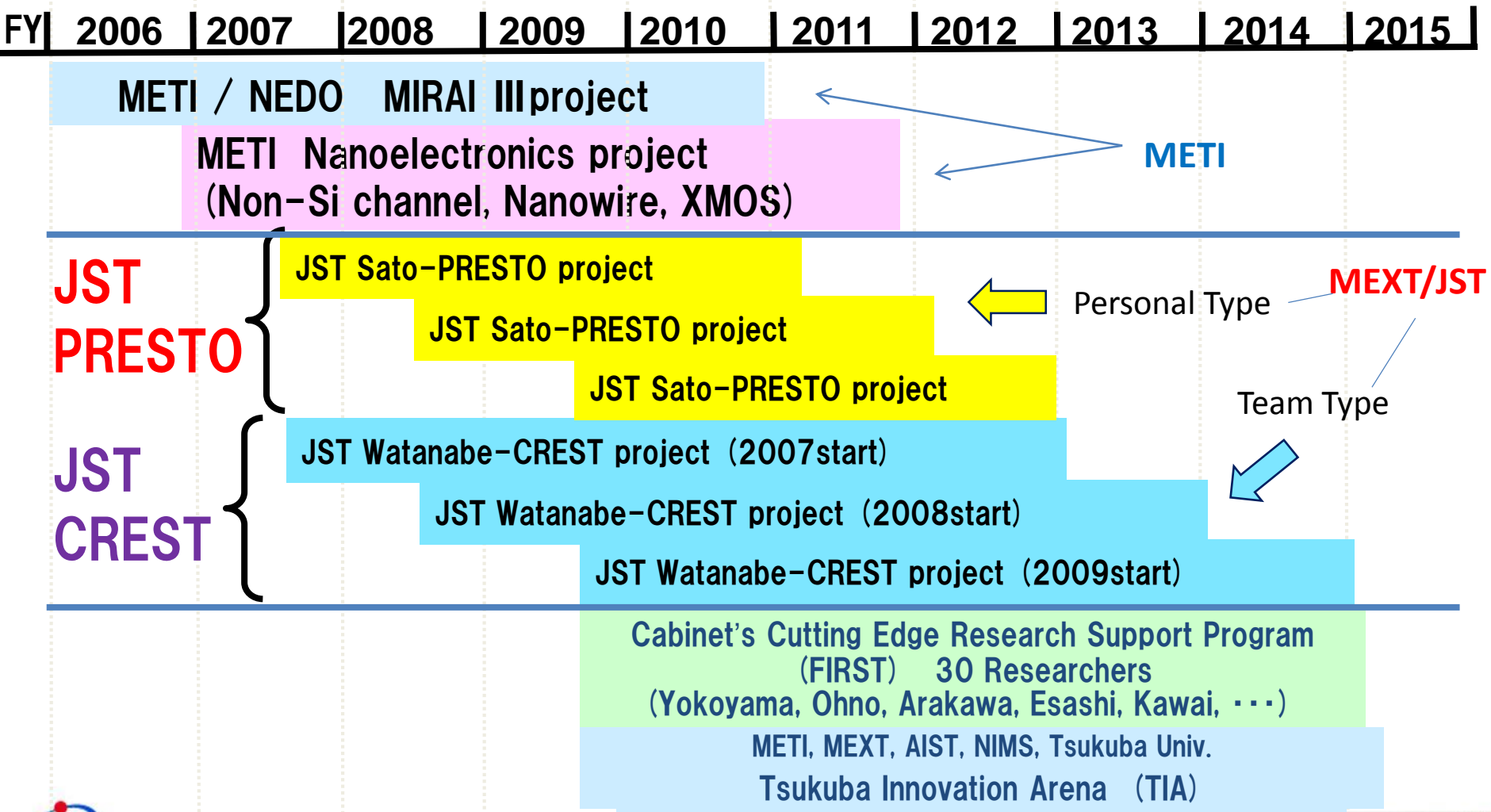
ITRS International Technology Roadmap for Semiconductors 2005



## *Strategic Sector* (Target of Research) from MEXT for Next-Generation Devices

- “Research and development of materials and nano-processes to realize devices with novel concept, novel functionality and novel structure”
- It lists following fields as important targets
  1. Development of **non silicon materials** for beyond-CMOS
  2. Pioneering materials for novel concept-devices by using **combined functionalities of photon, electron and spin**
  3. Development of novel devices based on **nano-scale fabrication**
  4. Development of thin **flexible resilient materials**

# Japan's National Projects for Next Generation Nanoelectronics Devices



## Sato-PRESTO Project

- The PRESTO\* project “**Materials and Processes for Next Generation Innovative Devices**” started in 2007 FY
- The scope of this project involves
  - Semiconductor nano-electronics
  - Wide-gap semiconductors
  - Spintronics devices and materials
  - Molecular and organic electronics

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\* *Precursory Research for Embryonic Science and Technology (Sakigake)*



# Organization



**Supervisor**



**Office**

**Research Manager  
Administrative Manager**

**JST Staffs**



Yuji Awano



Hiroshi Okamoto



Shunri Oda



Kazuhiro Kudo



Akiko Gomyo

**Advisors**



Kazuhiro Komori



Koki Takanashi



Katsumi Tanigaki



Yasushi Nonishi



Akira Fujimaki



Mutsuko Hatano

**33 Researchers**

**phase (1): 11, phase (2): 10, phase (3): 12**

## Two stage screening; (1) papers (2) interview

- The Research Supervisor conducts two-stage screening of the application together with advisors from the research area.
- **Screening by Papers:** Research Supervisor select candidates for interview by examining submitted application papers with a help of area advisors  
EX: *25 interviewees from nearly 100 applicants*
- **Screening by Interview:** Research Supervisor select candidates by interview consulting with advisors  
EX: *10 from 25 interviewees*
- *Based on the selection, JST determines individual rese research themes*



## Duration and Budgets

- Duration: 3.5 years
- Budget: 40MYen (~400KEuros) per person
- Members: 33 (Total 1.4BYen~14MEuro)
- Average age at adoption: 34.5 years old
- Affiliation: Universities: 25, Government Agencies: 8

For Comparison: Case of Watanabe-CREST

Duration Max 5.5 years

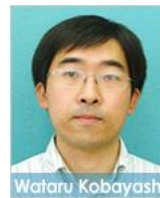
Budget 150-500 M Yen (1.5-5 M Euro) per team

Teams: 18



# Fields

## Heat



## Charge



## Light



# Materials

## Oxides



Wataru Kobayashi



Eiji Saitoh



Norikazu Mizuuchi



Masataka Higashiwaki



Yasushi Takahashi



Naoki Fukata



Yoshihiro Kangawa



Ryuji Katayama



Katsuhiko Tomioka



Tomoteru Fukumura



Tomofumi Susaki

## Dielctrics



Hiroyuki Nakamura



Seiya Kasai



Toshihiro Nakaoka



Kohei Hamaya



Mitsuru Takenaka



Hiroshi Kumigashira

## Organics



Takeshi Yasuda



Hiroshi Yamamoto



Masashi Shiraishi



Katsunori Wakabayashi



Jiro Nishinaga



Shuichi Murakami



Hideo Kaiju



Akinobu Yamaguchi



Tomoyasu Taniyama

## Nano Carbon



Koji Nakano



Yutaka Noguchi



Tomoki Machida



Suguru Noda



Iwao Kawayama



Arita Tsukamoto

## Superconductors

## Metals



Y.K. Takahashi



## Research Themes

(1<sup>st</sup> phase 2007 start) 11 themes

Researchers	Research Themes
S. Kasai	Research on <b>stochastic resonance nanodevices and their integration</b> for novel noise-robust information processing systems
E. Saitoh	Spintronics based on <b>spin currents and spin-photon coupling in dielectrics</b>
S. Shiraishi	<b>Spin current</b> control in <b>molecules</b>
Y. Takahashi	Development of <b>half-metal at RT</b> for spintronics devices
T. Taniyama	Control of spin polarization and its application to <b>tunable spin sources</b>
A. Tsukamoto	Ultrafast manipulation and measurement of <b>spin dynamics</b> by <b>femtosecond laser pulse</b>
N. Fukata	Development of semiconductor nanowires for the realization of <b>vertical three-dimensional</b> semiconductor devices
S. Murakami	Unified <b>theory</b> of <b>spin and heat currents</b> and its applications
T. Yasuda	High-performance <b>organic field-effect transistors</b> using intrachain carrier transport along uniaxially aligned p-conjugated polymers
A. Yamaguchi	Study in novel electromagnetic properties of modulated and/or <b>periodic magnetic structure</b> composed of <b>nanoscale magnets</b>
K. Wakabayashi	Design and physical properties forecast of <b>nano-carbon electronic devices</b> based on computational methods

## (2<sup>nd</sup> phase: 2008 start) 10 themes

Researchers	Research Themes
R. Katayama	Novel optical function using photonic nano-structure of <b>polar wide-gap semiconductors</b>
I. Kawayama	Creation of an optically-generated-flux-quantum nano-device with <b>superconducting nanobridges</b>
Y. Kangawa	Fabrication of <b>III-nitride substrate for optoelectronic integrated circuit</b> and control of its heat transfer
W. Kobayashi	Development of materials for <b>thermoelectronics</b>
T. Susaki	New functionalities at <b>the interfaces of wide-gap oxides</b>
M. Takenaka	<b>Ge Nano Electro-Optic LSI</b> for intrachip optical interconnects
T. Nakaoka	Charge/spin/photon <b>hybrid single-electron device based on quantum dot</b>
K. Hamaya	Development of <b>single-electron spin transistors</b> with <b>silicon-based</b> nanostructures
T. Fukumura	<b>Wide-gap ferromagnetic semiconductor</b> devices
N. Mizuochi	Quantum information devices <b>by single paramagnetic color center in wide-bandgap semiconductor</b>

spintronics

wide-gap

semiconductor

molecules/organics

others

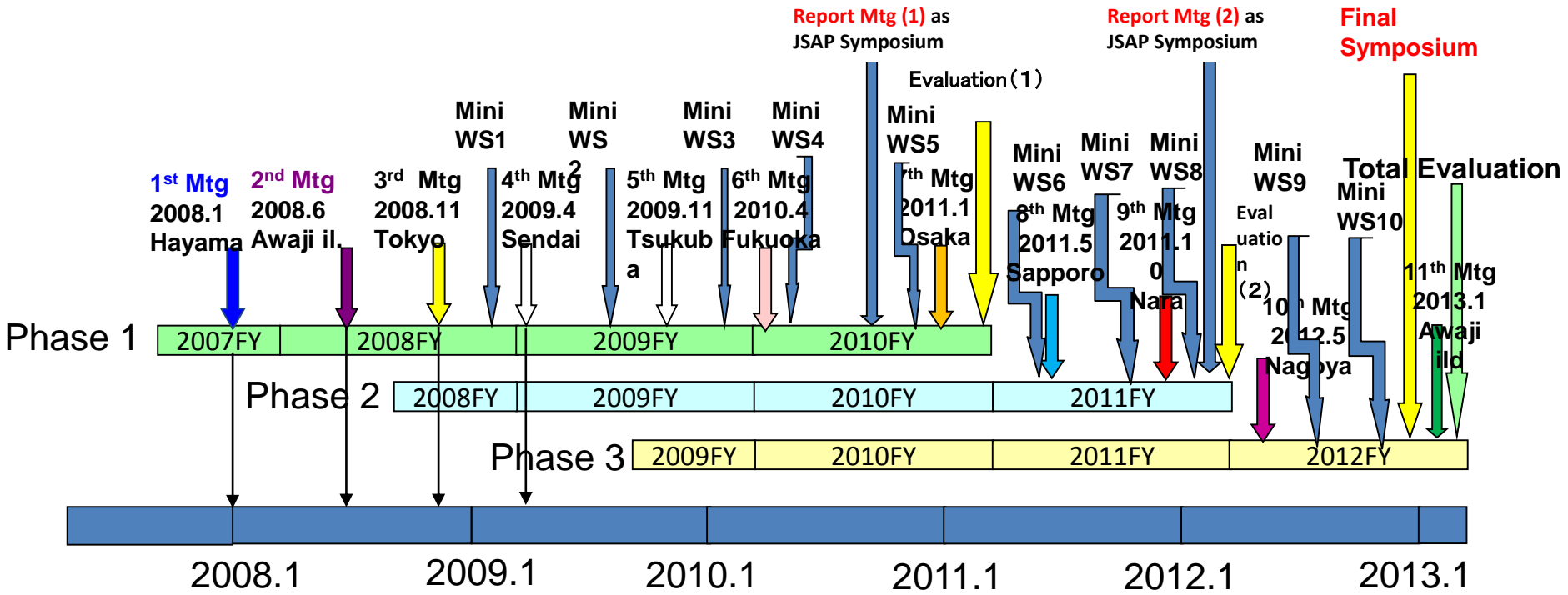


## (3<sup>rd</sup> phase: 2009 start) 12 themes

Researchers	Research Themes
H. Kaiju	Creation of novel high-performance <b>non-volatile memory using spin quantum cross devices</b>
H. Kumigashira	Development of memory with low environmental stress using <b>nano-capasitor structure</b>
Y. Takahashi	Silicon Raman <b>laser</b> using <b>photonic crystal nanocavity</b>
K. Tomioka	Control of Si/III-V super-heterointerface and development of <b>nanowire-based tunneling FETs</b>
K. Nakano	Development of high-performance <b>organic field-effect transistors</b> through the control of molecular arrangement
H. Nakano	Spin manipulation in <b>dielectric-channel transistors</b>
J. Nishinaga	New devices using <b>fullerene / III-V compound</b> semiconductor heterostructures
H. Noguchi	Development of <b>organic single-electron transistors</b> controlled by photo-induced gate signal
S. Noda	Facile implementation of <b>nanocarbons with selectable higher-order structures</b>
M. Higashiwaki	Interface control and device application of <b>III-oxide/nitride semiconductor composite structures</b>
T. Machida	Physics and application of <b>quantum dot devices based on graphene</b>
H. Yamamoto	Development of novel <b>organic devices</b> based on <b>electronic correlation</b>

# Project Flow

- The phase I group: October 2007 → March 2011
- The phase II group: October 2008 → March 2012
- The phase III group: October 2009 → March 2013





Products of the Research Project

# Scientific and technical achievements

# Total Number of Publications and Patents

	Papers		Conferences		Books		Invited Talks		Total (w/o Patents)	Patents	
	Int'l	Domestic	Int'l	Domestic	Int'l	Domestic	Int'l	Domestic		Domestic	International
1st Phase 2007-2011	194	8	159	234	1	37	107	75	815	26	5
2nd Phase 2008-2012	77	5	97	159	0	6	42	23	409	10	2
3rd Phase 2009-2013	68	10	95	176	6	7	46	24	432	16	9
<b>Total</b>	<b>339</b>	<b>23</b>	<b>351</b>	<b>569</b>	<b>7</b>	<b>50</b>	<b>195</b>	<b>122</b>	<b>1656</b>	<b>52</b>	<b>16</b>



# Publications and Patents

	Papers		Conference		Books		Invited		Total (w/o Patents)	Patents	
	Int'l	Dome stic	Int'l	Dome stic	Int'l	Dome stic	Int'l	Dome stic		Dom	Intrn'l
07FY 2 <sup>nd</sup> half	28	1	9	26	0	5	11	5	85	4	1
08FY 1 <sup>st</sup> half	18	3	14	29	0	4	7	10	85	6	1
08 2 <sup>nd</sup> half	26	0	27	36	1	5	16	11	122	5	0
09FY 1 <sup>st</sup> half	30	1	51	66	0	2	16	14	180	4	2
09 2 <sup>nd</sup> half	45	1	52	100	1	10	19	22	250	5	1
10FY 1 <sup>st</sup> half	47	3	49	92	0	7	34	22	254	5	2
10 2 <sup>nd</sup> half	51	6	39	68	0	10	20	16	210	3	0
11FY 1 <sup>st</sup> half	41	1	51	35	1	2	16	1	148	13	1
11 2 <sup>nd</sup> half	32	4	24	66	1	5	20	4	156	5	1
12FY 1 <sup>st</sup> half	19	2	24	38	2	0	18	13	116	2	7
12 2 <sup>nd</sup> half	2	1	9	13	1	0	14	4	44	0	0
13FY 1 <sup>st</sup> half	0	0	2	0	0	0	4	0	6		
<b>Total</b>	<b>339</b>	<b>23</b>	<b>351</b>	<b>569</b>	<b>7</b>	<b>50</b>	<b>195</b>	<b>122</b>	<b>1656</b>	<b>52</b>	<b>16</b>

# Patents

## International

Researcher	Application Number	Date of Application	Title of Invention	Inventors
S. Kasai	PCT/JP2008/065758	2008/09/02	Signal reproducing device	S. Kasai
E. Saitoh	PCT/JP2009/060225	2009/06/04	Spintronic device and information transmitting method	S.Saitoh, K.Naito, Y. Kajiwara, K. Ando
E. Saitoh	PCT/JP2009/060317	2009/06/05	Thermoelectric conversion device	K.Uchida, Y.Kajiwara; Yosuke, H.Nakayama, E.Saitoh
S. Noda	PCT/JP2012/054810	2012/2/27	Method for producing graphene, graphene produced on substrate, and graphene on substrate	S.Noda, S.Takano
K. Tomioka	PCT/JP2010/005862	2011/04/25	Tunnel field effect transistor and method for manufacturing same	K.Tomioka.T.Fukui, T.Tanaka
K. Tomioka	PCT/JP2010/003762	2010/6/4	Light emitting element and method for manufacturing same	K.Tomioka.T.Fukui

Semiconductor nanoelectronics  
Wide-gap semiconductors  
Spintronics devices and materials  
Molecular and organic electronics

## Achievements



## Achievements

# Semiconductor Nanoelectronics



# Semiconductor nanoelectronics

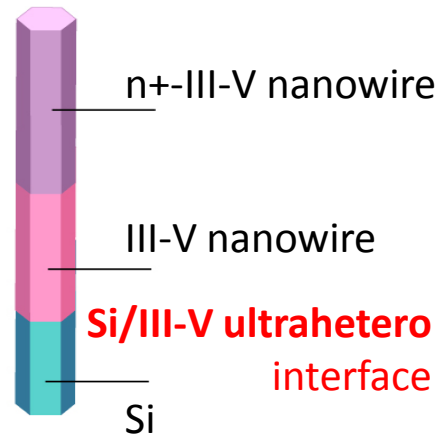
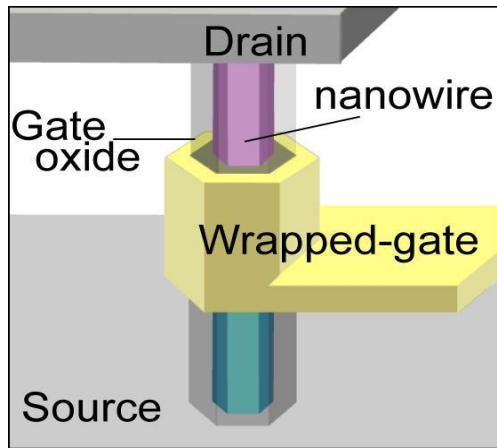
1. K.Tomioka successfully fabricated *InAs nanowire/Si tunnel-FET* with record SS (subthreshold slope) of **21mV/dec** much smaller than theoretical limit of 60
2. N.Fukata succeeded in characterization of *small amount of dopant in nanowire* Si using EPR and Raman spectroscopy
3. M.Takenaka developed high performance *Ge n-MOS FET* and low noise Ge PD for optical interconnection
4. Y.Takahashi obtained promising experimental evidences for *Si-Raman laser* in Si photonic crystals
5. S.Kasai realized a novel signal processing technology under the concept of *Stochastic Resonance*



Katsuhiro Tomioka

# Control of Si/III-V super-heterointerface and development of nanowire-based tunneling FETs

The goal of this project to fabricate steep-slope nanowire-based FET by controlling Si/III-V heterojunctions without misfit dislocations, which can be achieved with nano-heteroepitaxial methods.



## Katsuhiro Tomioka (Hokkaido Univ/JST)

### Papers

Appl.Phys.Lett., **98**, 083114 (2011)  
Nature **488**, 189 (2012)  
IEEE VLSI Technol. 2012 Tech. Dig. 47 (2012)

### Award

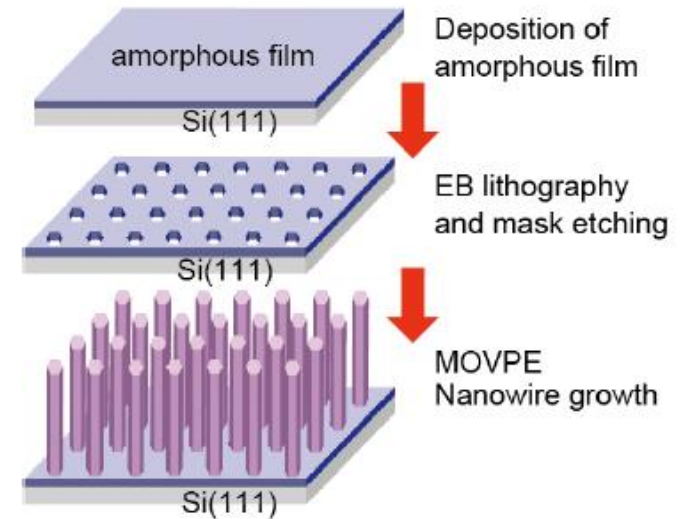
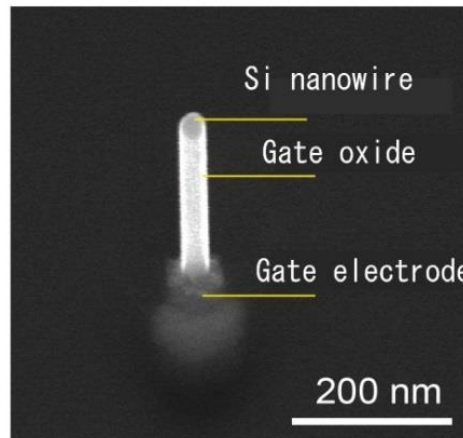
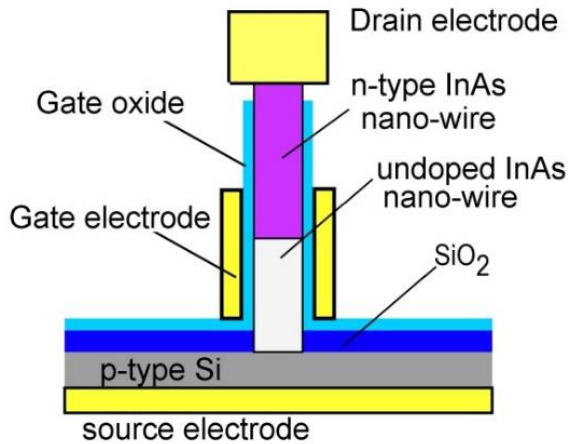
JSAP Presentation Award

### Outreach

Press Lecture, JST News, Science News

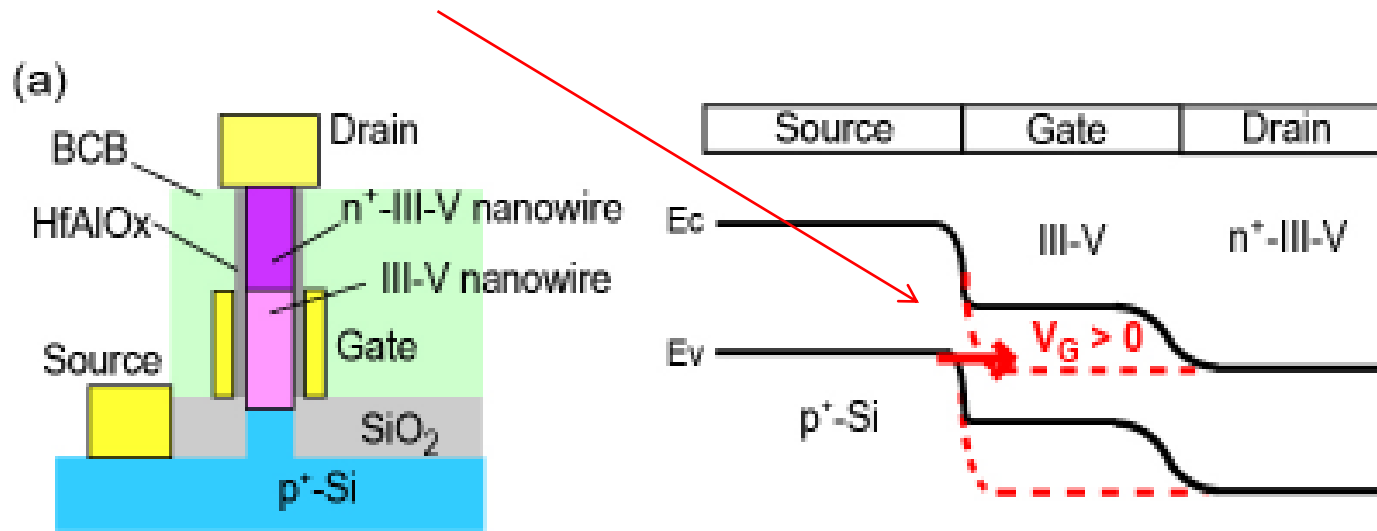
# InAs nanowire Tunnel FET

- Tomioka succeeded in fabricating a Tunnel FET using InAs nanowire on Si substrate by MOVPE through holes fabricated on SiO<sub>2</sub> insulator by electron beam lithography.



# How the InAs nanowire TFET works

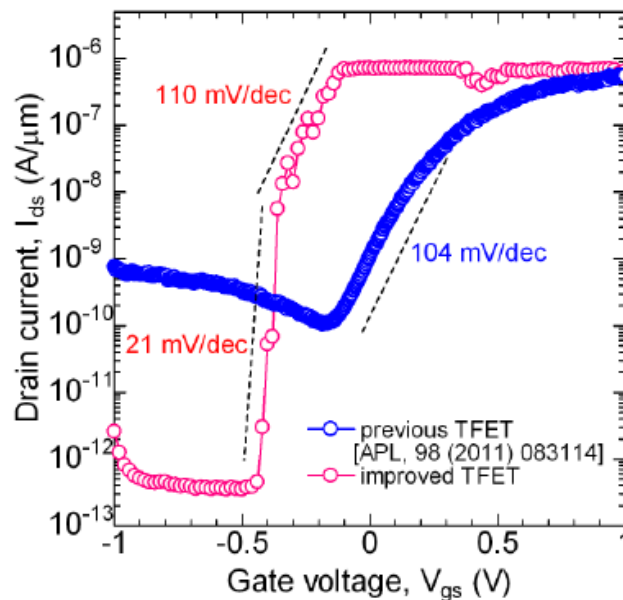
- Figure illustrates TFET using III-V NWs/Si heterojunctions. Each TFETs are composed of a combination of III-Vs and Si in order to utilize Zener tunnel mechanism working at a band discontinuities across the III-V and Si junctions.



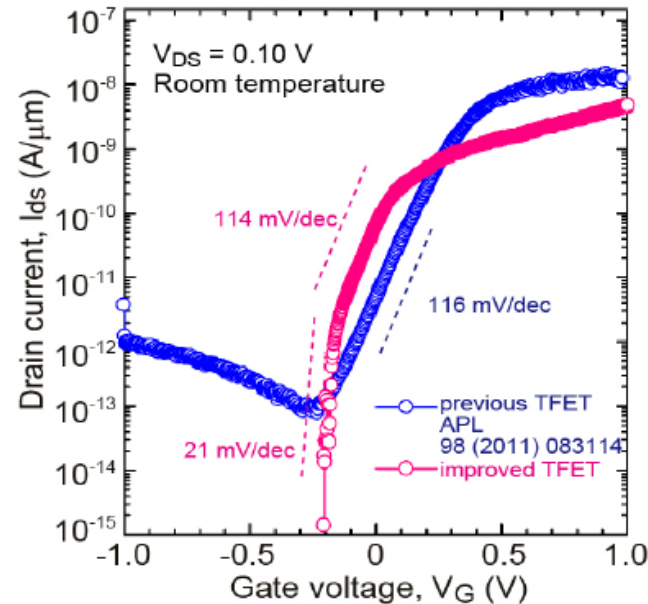


# InAs nanowire Tunnel FET

- He attained subthreshold slope of  $SS=21\text{mV/dec}$  far below the theoretical limit of  $60\text{mV/dec}$  of ordinary FET



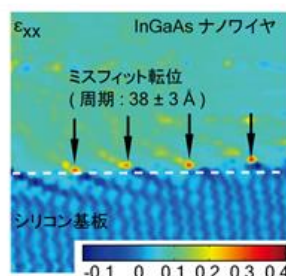
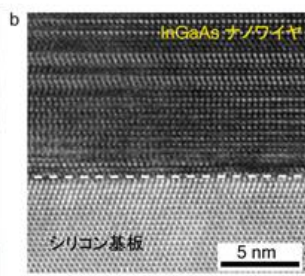
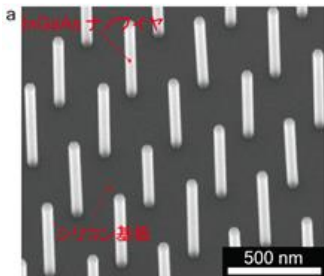
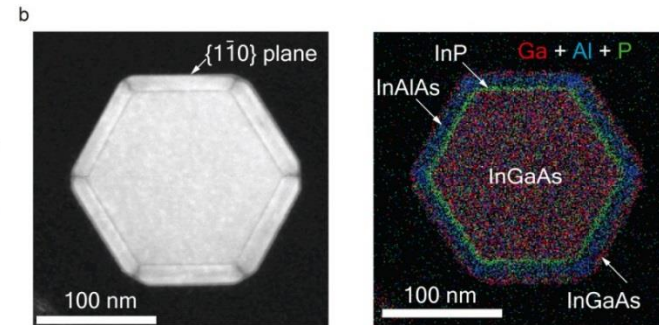
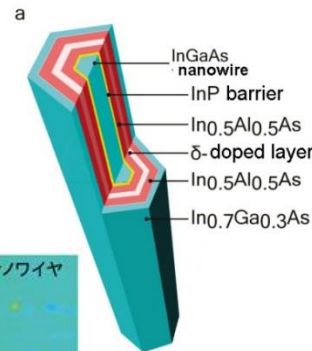
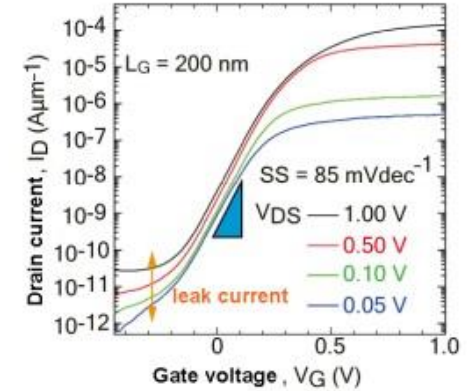
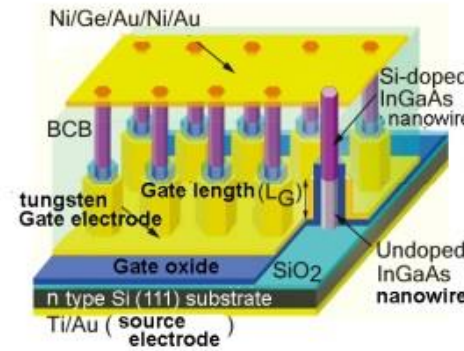
**Fig. 9** Experimental transfer characteristics of optimized TFET with a NW-diameter of 30 nm (red curve)  $V_{DS} = 1.00$  V.



**Fig. 10** Experimental transfer characteristics of optimized TFET with a NW-diameter of 30 nm (red curve)  $V_{DS} = 0.10$  V.

# Nanowire FET with core-shell HEMT structure

- Tomioka fabricated high performance FET using InAs nanowire with core-shell HEMT structure.



# Development of semiconductor nanowires for the realization of vertical three-dimensional semiconductor devices



- To overcome the limiting factors in planar MOSFETs, vertical structural arrangements called surrounding gate transistors (SGT) have been suggested as the basis for next-generation semiconductor devices.
- Fukada studies one dimensional Si and Ge semiconductor nanowires which are expected for the components in SGT.

## Naoki Fukata (NIMS)

### Papers

Adv. Mater. **21**, 2829 (2009).  
Nano Lett. **11**, 651 (2011).  
ACS NANO **6**, 8887 (2012).

### Award

MRS Poster Award

### Comment

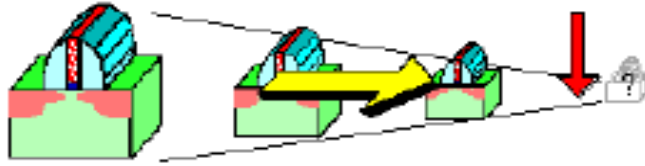
Adopted as FIRST Program

N. Fukata, M. Mitome, Y. Bando, M. Seoka, S. Matsushita, K. Murakami, J. Chen, and T. Sekiguchi: Appl. Phys. Lett. 93 (2008) 203106.

# Vertical type MOSFET using semiconductor nanowires

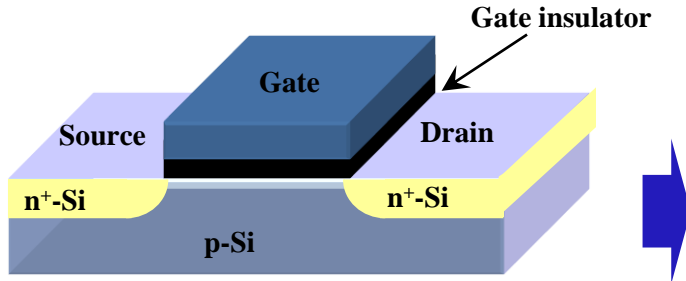
Transistor size scaling

**Limit of scaling ?**

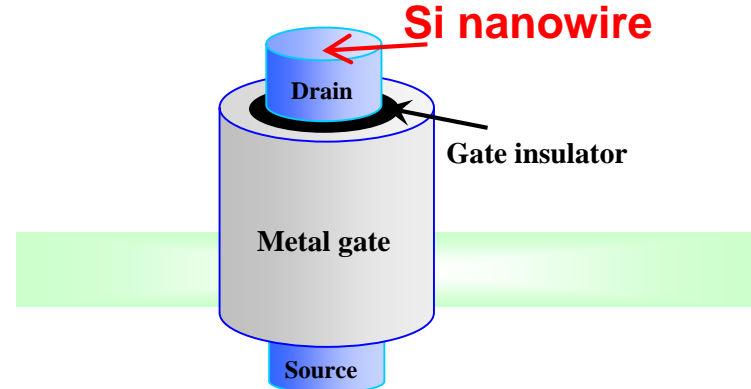


**2-orders of magnitude reduction in  
transistor size in 30 years.**

Present: Planar type



Next generation: Vertical type



**Miniaturization of FET**

**Increase in power consumption &  
leak current**

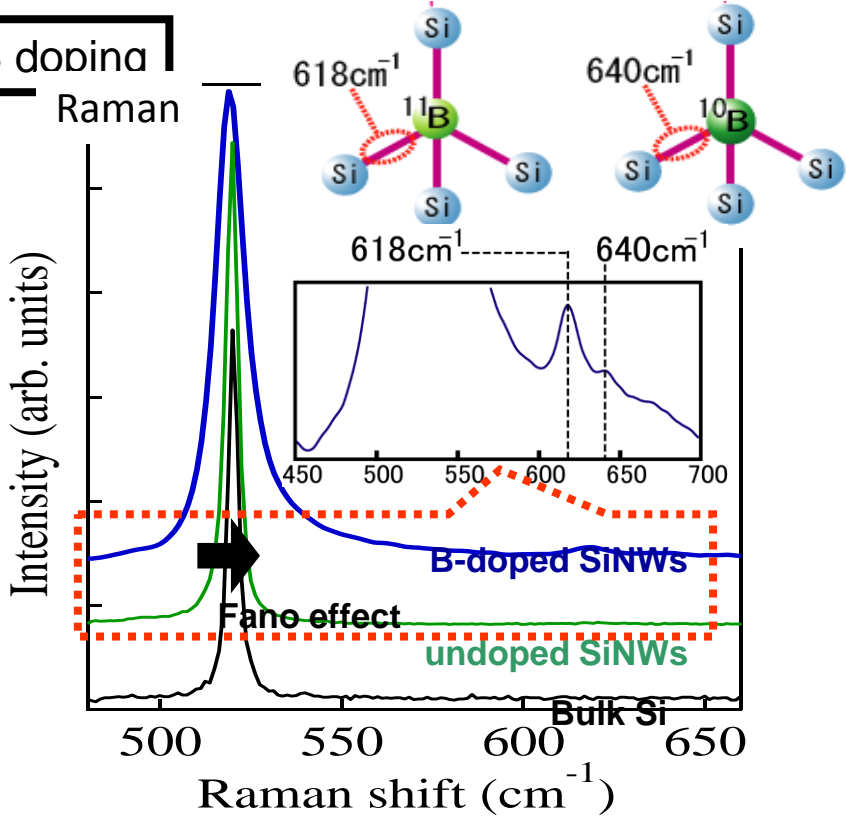
**Enhancement of the heating**

**Vertical-type MOSFET using Si  
nanowires !**



# Synthesis & Impurity doping in Si nanowires

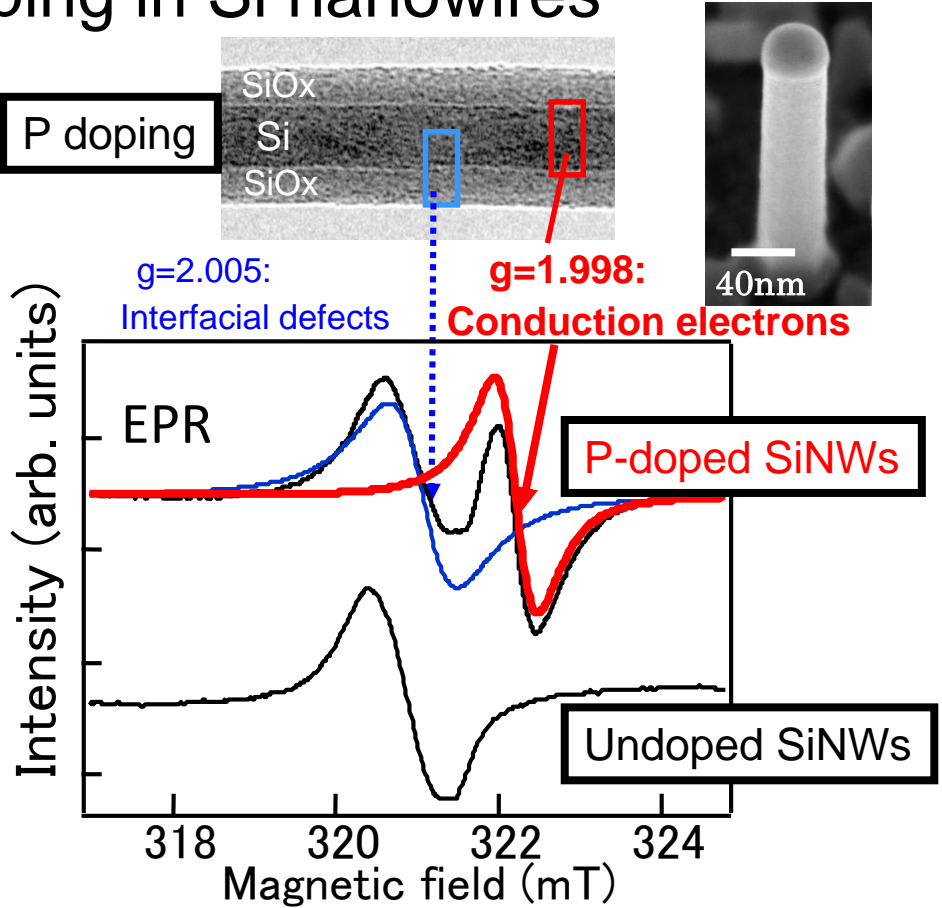
**B dopina**



First observation of B local vibrational peak and Fano effect in B-doped SiNWs

Formation of p-type SiNWs

**P doping**

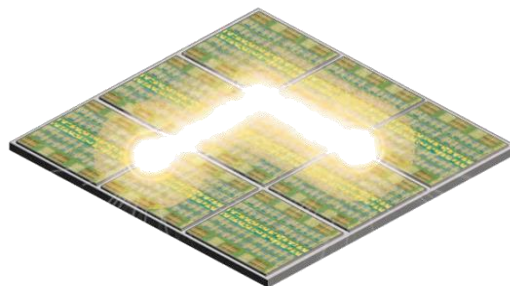
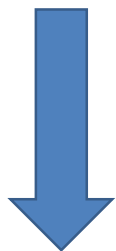


First observation of conduction electron signals in P-doped SiNWs

Formation of n-type SiNWs

# Ge Nano Electro-Optic LSI for intrachip optical interconnects

The target of this research is monolithical integration of Ge MOSFETs and Ge photodetectors on a Si substrate for ultrahigh performance LSI.



Fundamental technologies for one-chip super computers and photonic router chips will be established through this research.

## Mitsuru Takenaka (Univ Tokyo)



### Representative papers

IEEE Electron. Dev. Lett. **21**,1092 (2010).

Jpn. J. Appl. Phys. **50**, 010105 (2011).

Optics Exp. Lett. **20**, 8718 (2012)

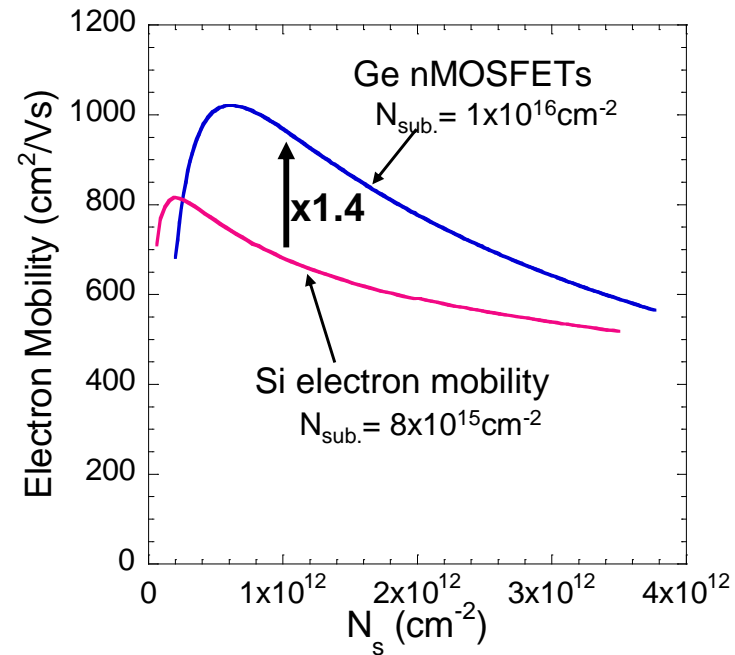
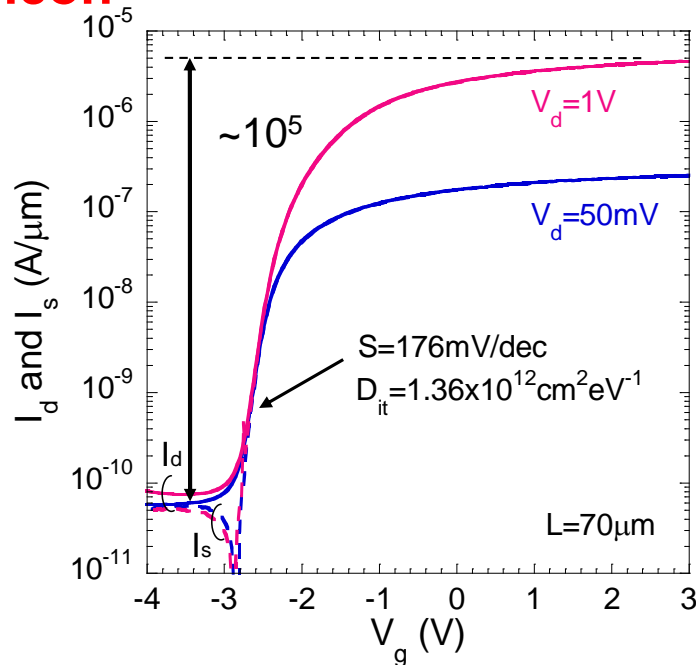
### Award

Silicon Technology Division Paper Award  
of JSAP

] M. Takenaka, S. Tanabe, S. Dissanayake,  
S. Sugahara, S. Takagi: 21st Annual  
Meeting of the IEEE Laser & Electro-  
Optics Society, Newport Beach, US  
(2008) Paper MN2.

# Toward Realization of Ge CMOS

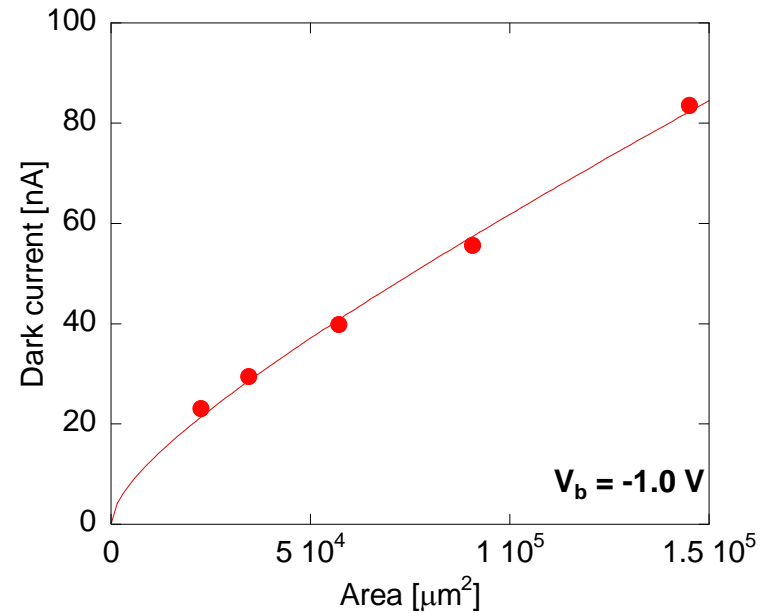
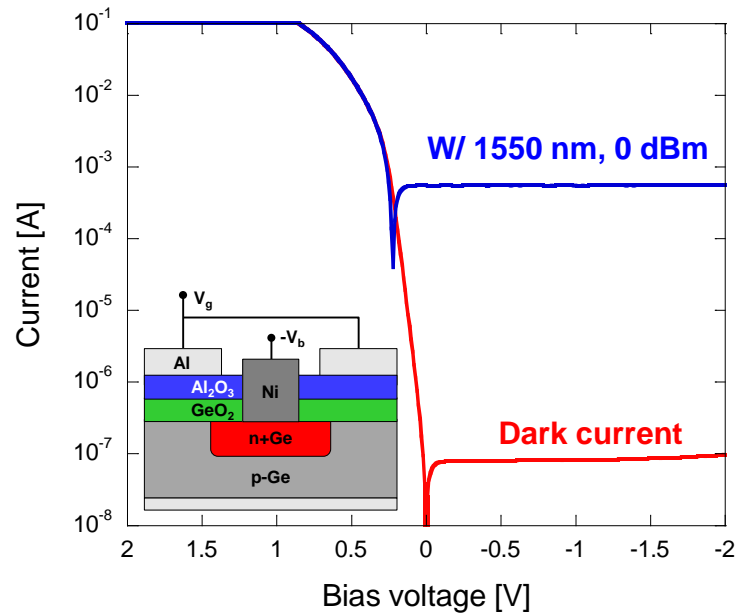
- Achievement of World Record on/off Value of  $10^5$
- First Verification of Record Effective Mobility higher than Silicon



**Electrical Characteristics and Effective Mobility in Ge n-MOS FET grown by vapor deposition technique**

# Ge Photodetector

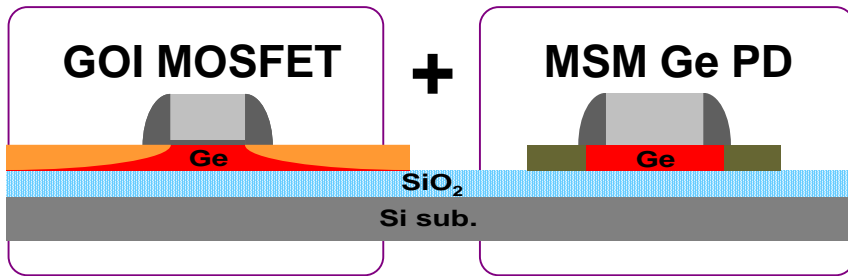
- Thermally oxidized  $\text{GeO}_2$  (Surface Passivation of Ge)
  - Vapor-phase doping (reduction of Junction leakage by 2 order of magnitude compared with ion-implantation)
- ↓
- First experimental demonstration that dark current of Ge PD can be reduced to less than 1 nA



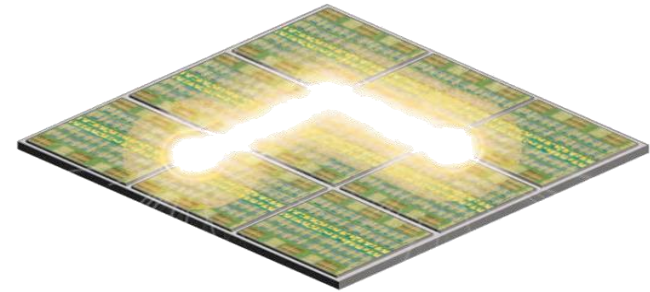


# Ge-based LSI with on-chip optical interconnects

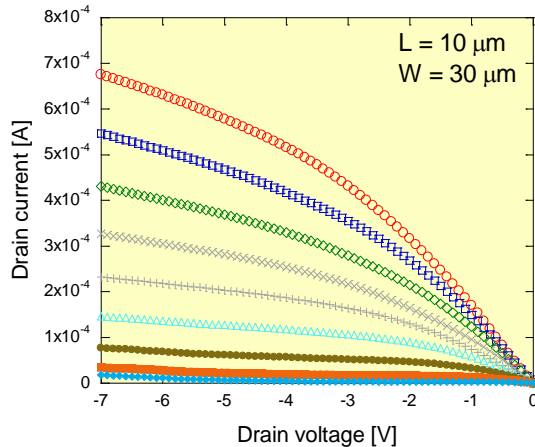
## Monolithic integration:



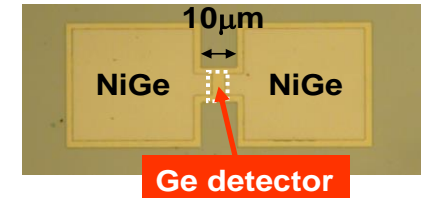
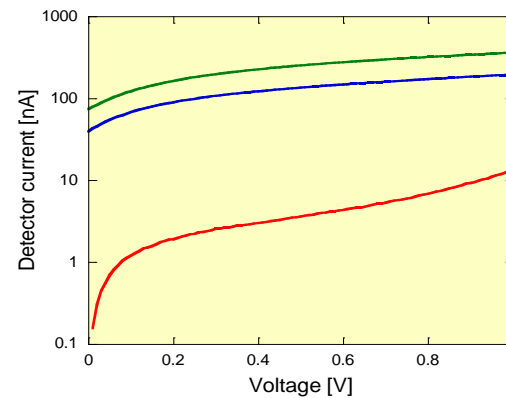
## Ge based LSI with on-chip optical interconnects



### GOI MOSFET



### Ge PD



# Silicon Raman Laser using Photonic Crystal Nanocavity

Nanocavities in two-dimensional photonic crystal slabs have high quality factors and small modal volumes approaching one cubic wavelength.

They can enhance the light-matter interactions including nonlinear optical effects. Using the nanocavities, silicon Raman lasers with small sizes and low thresholds may be realized, which have many advantages

such as the low energy consumption, dense integration, CMOS compatibility, and operation at telecom wavelengths.



**Yasushi Takahashi**  
**(Osaka Pref Univ)**

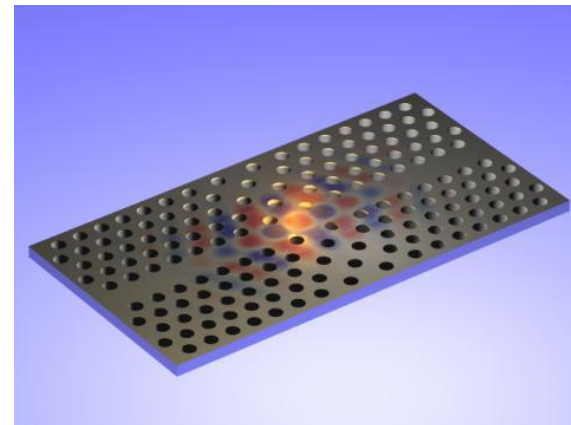
## Papers

Opt. Exp. **19**, 11916(2011)

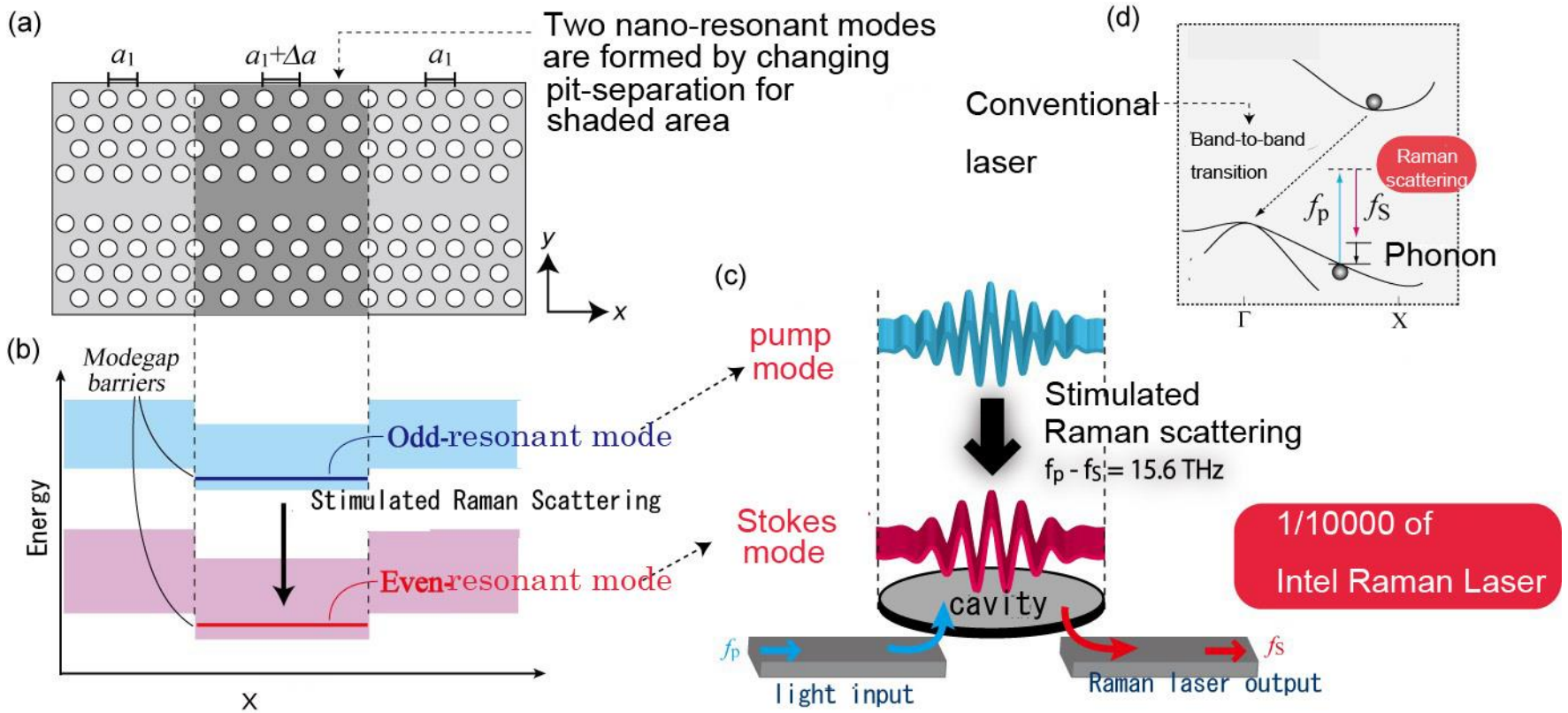
Nature Photonics **6**, 56 (2012)

Optics Express **20**, 22743 (2012)

Nature (2013) in press



# Explanation of Silicon Raman Laser



## Measurement

Fig(c) shows a Raman scattering spectrum observed when odd-resonant mode is excited by 1mW input power,

Excitation-power dependence clearly shows nonlinear enhancement of the resonant Raman peak, indicating symptom of stimulated Raman emission,

**Nature in press**

(a),(b) are spectra of odd and even resonant modes, (c) Raman spectrum by exciting odd nano resonant mode



# Research on **stochastic resonance** nanodevices and their integration for novel noise-robust information processing systems

Novel semiconductor nanodevices  
utilizing "stochastic resonance" and their  
integration are investigated to realize  
state-of-the-art electronics hardware  
for noise-robust information processing.



Seiya Kasai

## Seiya Kasai (Hokkaido U)

### Paper

Appl.Phys.Lett. **96**,194102 (2010)

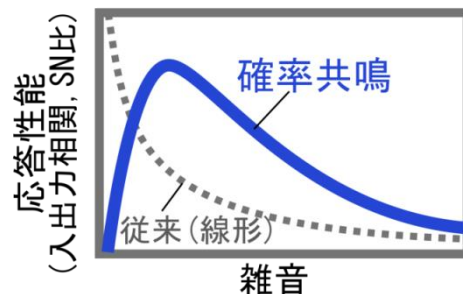
### Award

MNC2007 Outstanding  
Paper Award

MNC2010 Outstanding  
Paper Award

### アウトリーチ

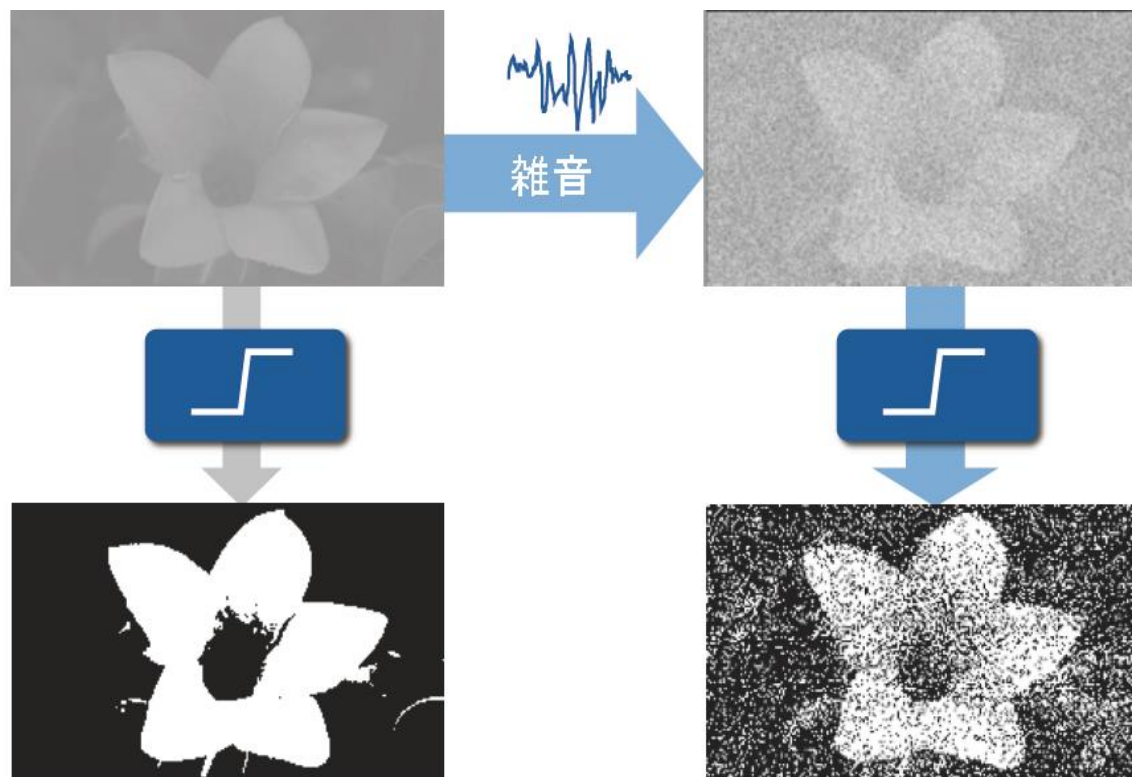
Science News



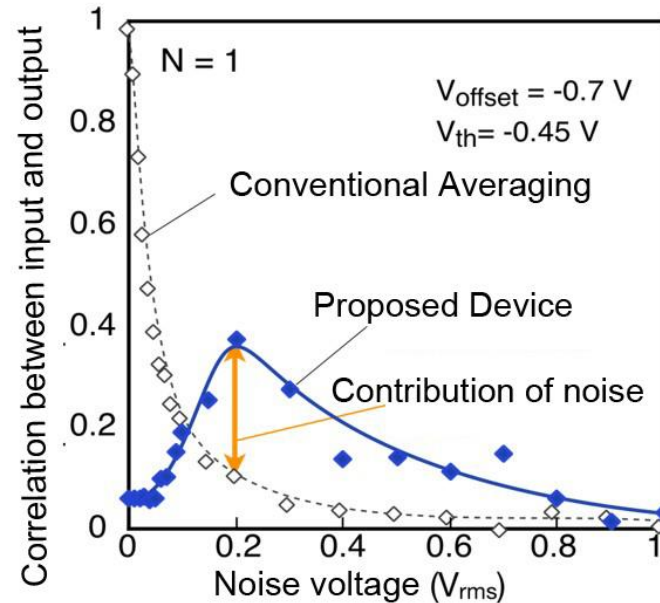
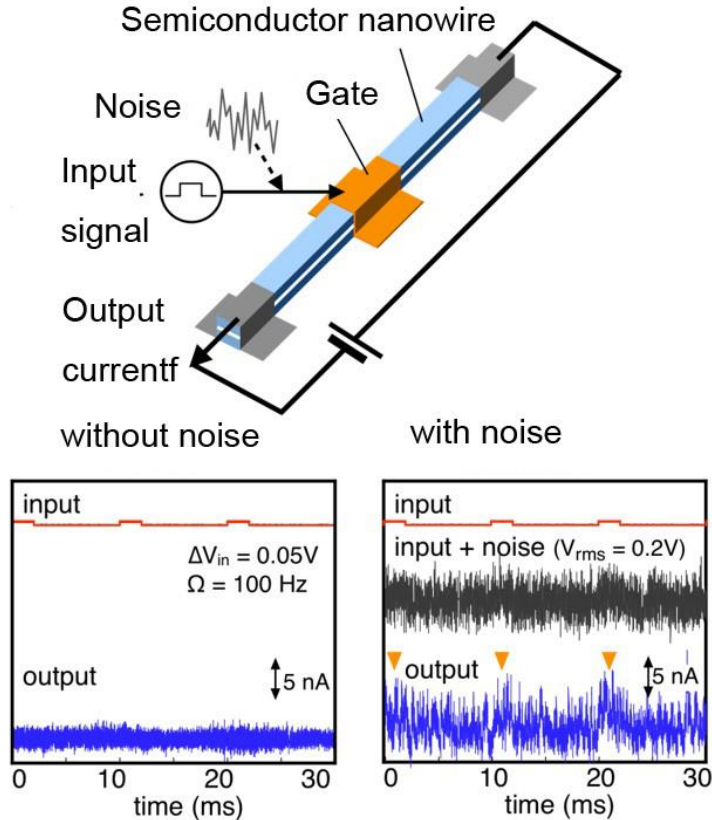
## Characteristic Feature of “Stochastic Resonance”

Middle level  
information is lost if  
simple filter is used.

Grey information is  
reproduced when  
stochastic resonance  
is applied.



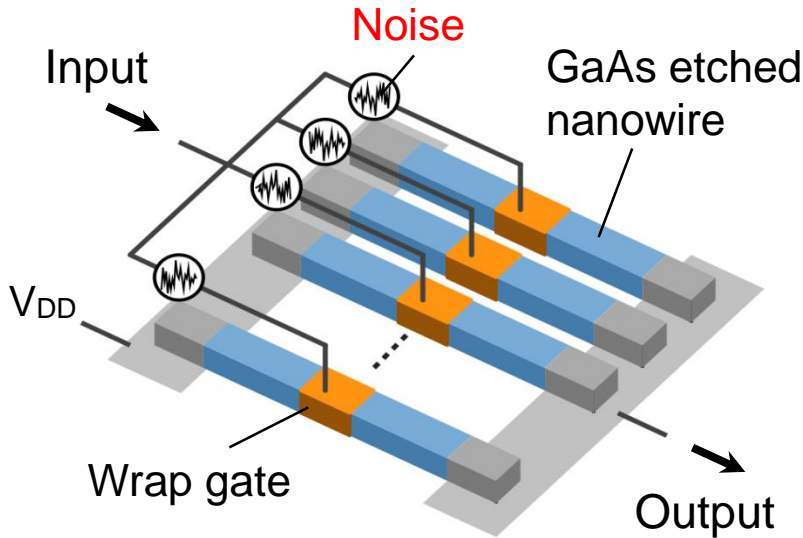
# Electronic introduction of stochastic resonance by using a nanowire transistor



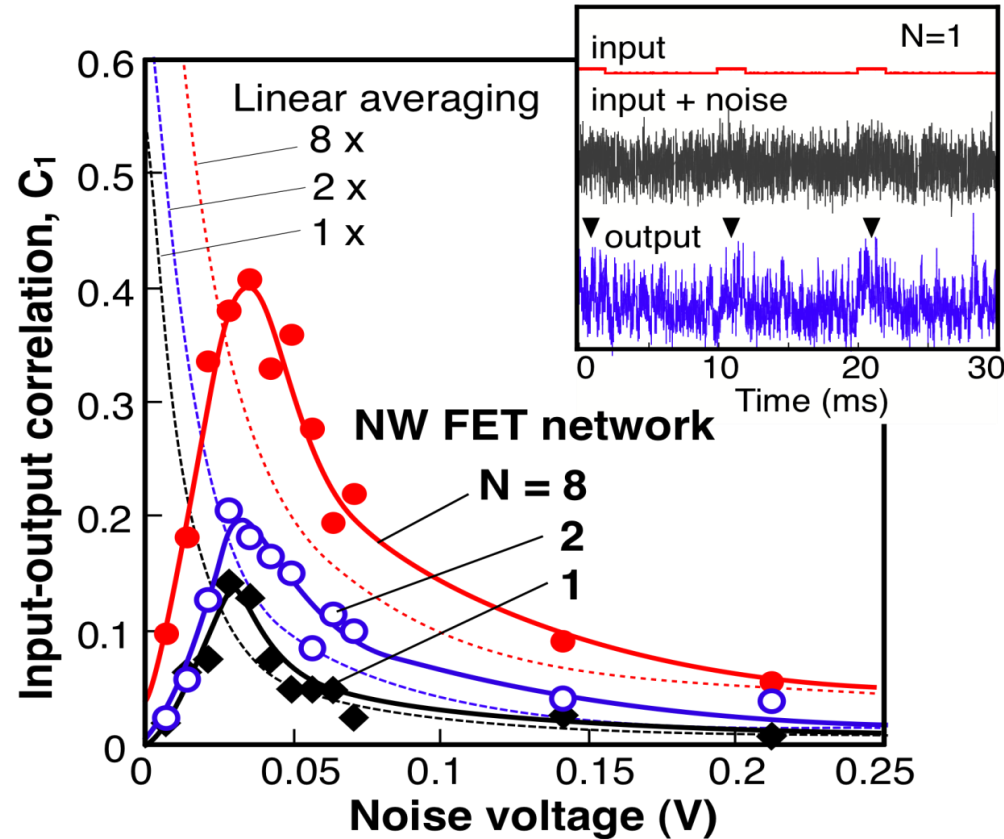
Parallel adder network of nanowire FETs proved enhancement of stochastic resonance



# Stochastic Resonance in Nanowire FET Network



S.Kasai et al., Appl. Phys. Express 1, 083001 (2008)

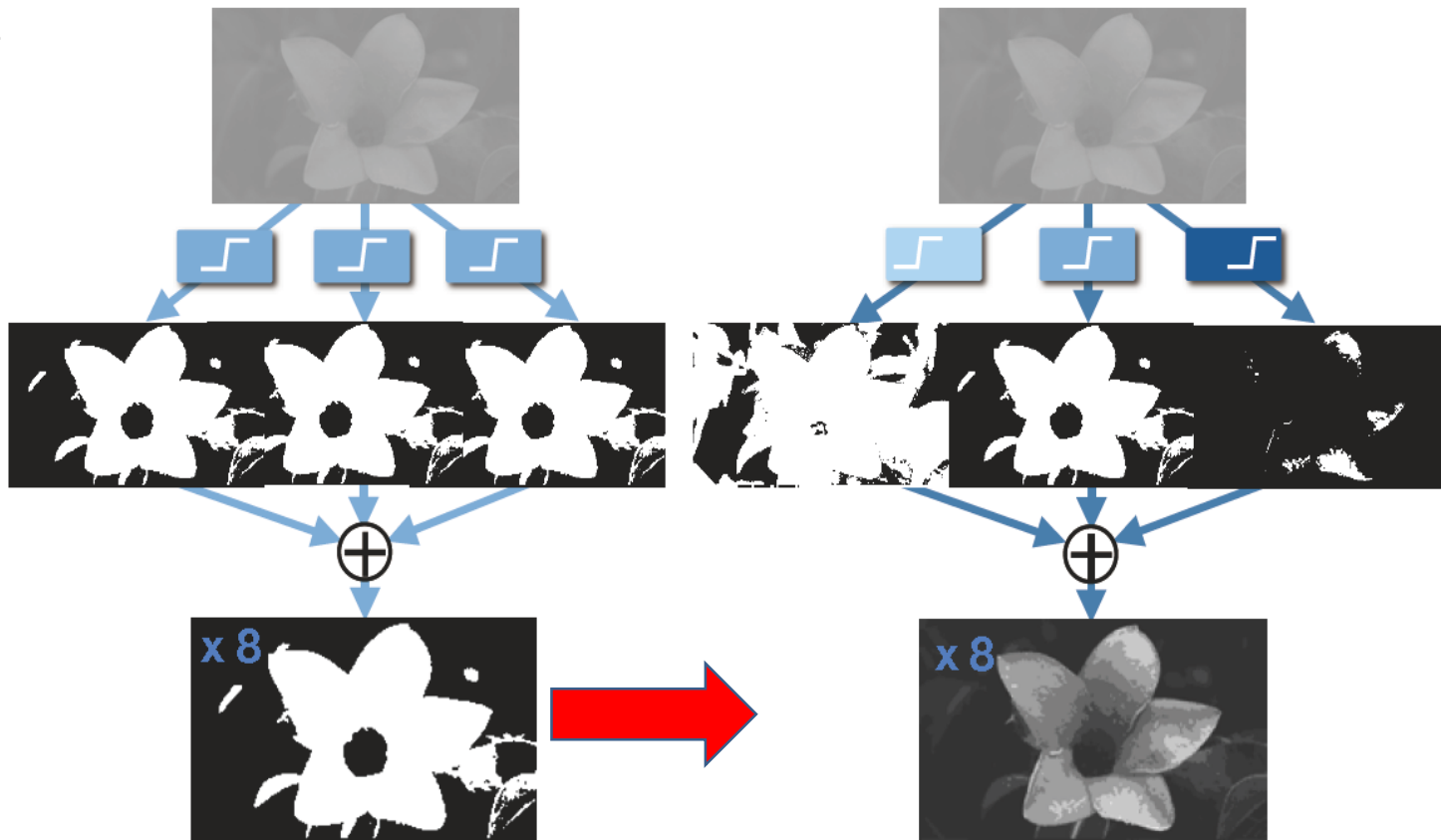


Stochastic resonance (SR) is a phenomenon that many bio-systems use to enhance their response in noisy environment.

The SR was realized in GaAs nanowire FET networks and enhanced weak-signal detection was successfully demonstrated.



# Scatter of thres

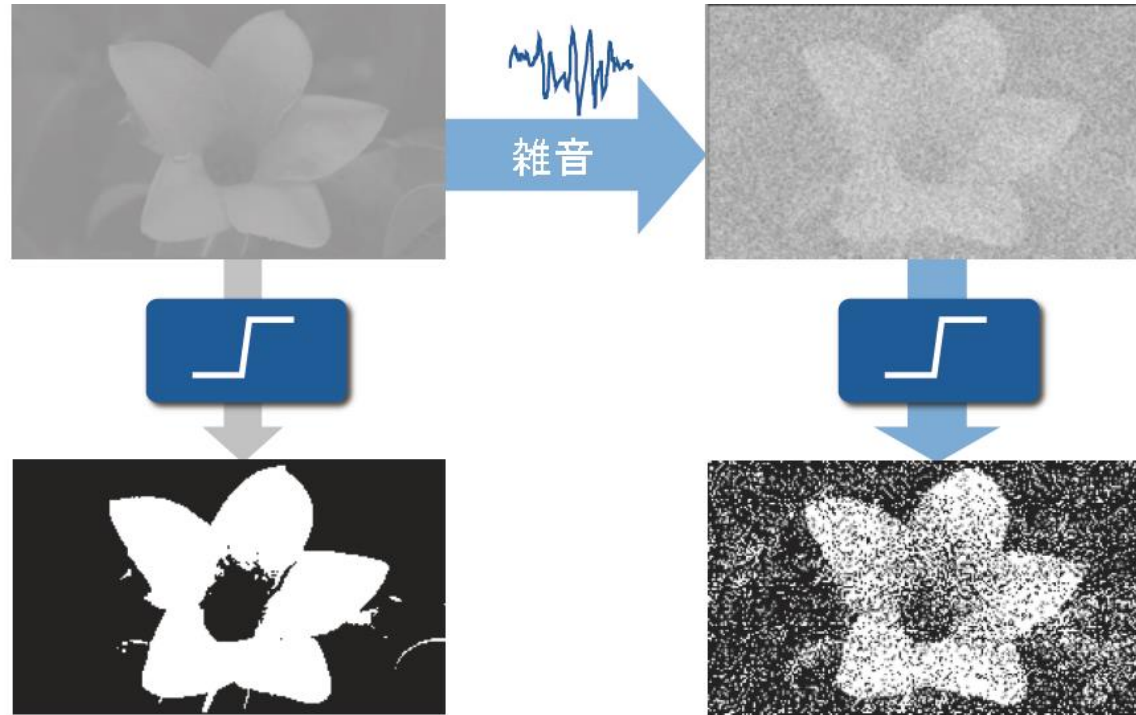


しきい値のばらつきは入力信号の中心が大きくずれても  
応答曲線が変わらず、入力信号の変化に追従できる。

先端集積回路の同一設計でのばらつきも利用できる。

# Improvement of SNR by using noise

- Stochastic resonance improve grey scale reproduction



High contrast but  
lose grey scale

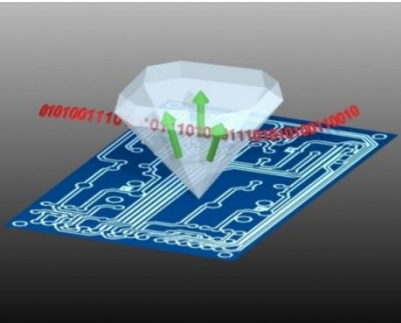
recover grey scale by  
addition of noise

# Wide Gap Semiconductors

# Wide-gap semiconductors

1. N.Mizuochi succeeded in **room temperature** operation of quantum information processing solid state device and current-induced **single photon source** by using *NV center in diamond p-i-n junction*
2. Y.Kangawa succeeded in *LPE growth of AlN single crystal* for III-N substrate using solid state nitrogen source (LiN)
3. R. Katayama fabricated GaN thin film *with periodic modulation of polarity* for nonlinear optics
4. M.Higashiwaki succeeded in fabricating *Ga<sub>2</sub>O<sub>3</sub>-based device* for power electronics

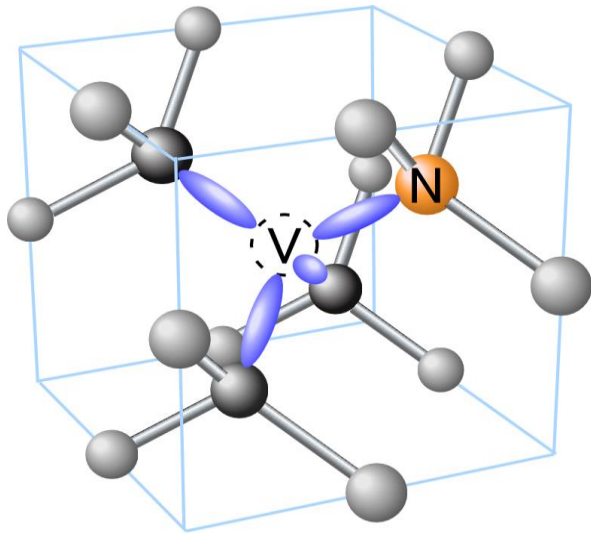




## Single NV center in diamond



Norikazu Mizuochi



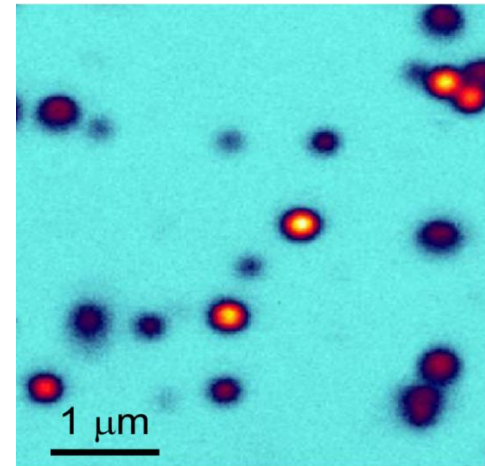
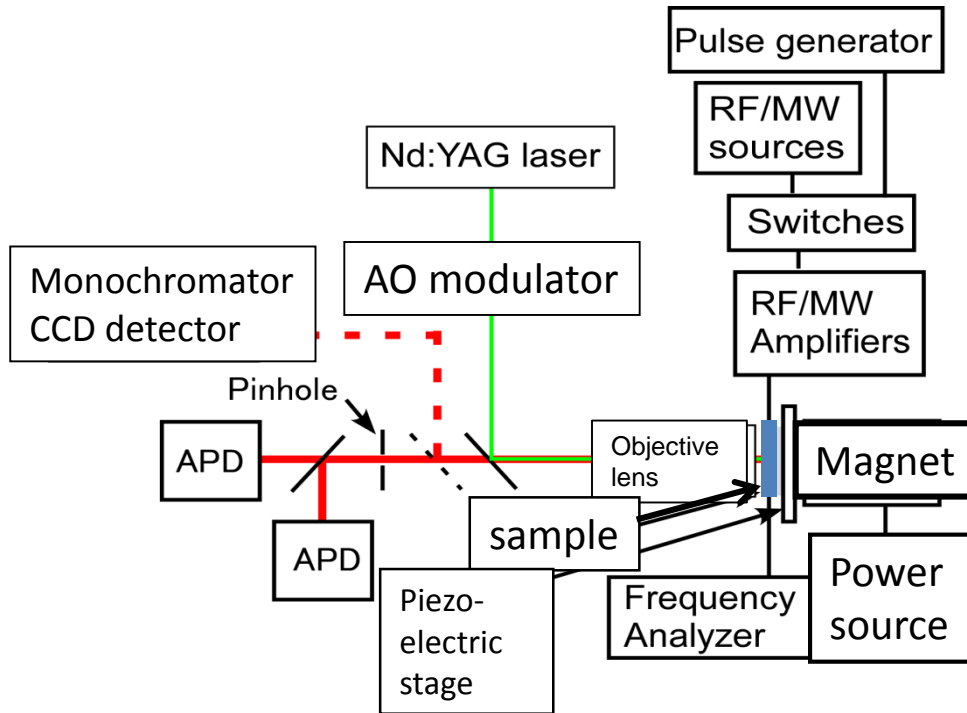
NV center: ( $NV^-$ , 6 electrons,  $C_{3v}$ )

- Ground state: spin triplet (electron spin  $S=1$ )
- Long coherence length.
- Observation of single NV center and single spin manipulation is possible
- Initialization of electron spin states by light irradiation is possible

Quantum information processing solid state device for  
**room temperature** operation

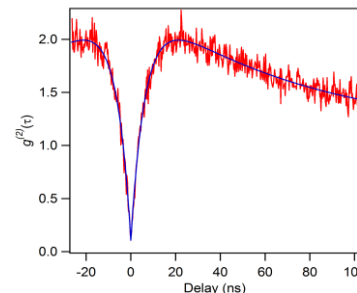
(Quantum register, Quantum repeater, single photon emitter ...)

# Measurement Instruments for single NV center



Fluorescent image of single  
NV center by confocal laser  
microscope

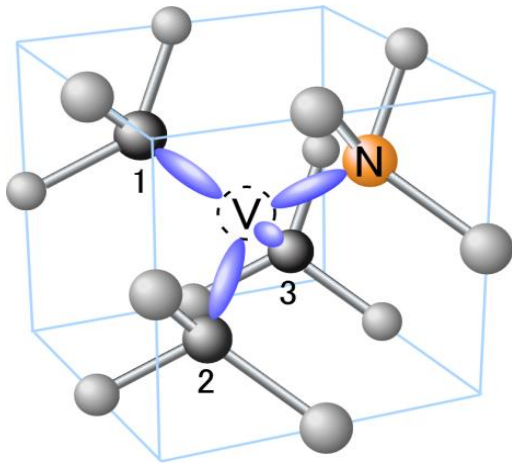
Anti-bunching measurement using  
Hanbury-Brown Twiss  
interferometer



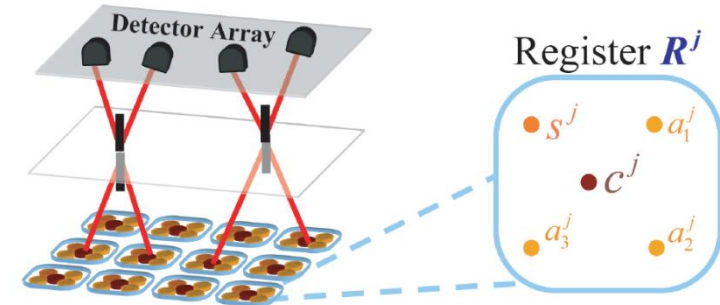
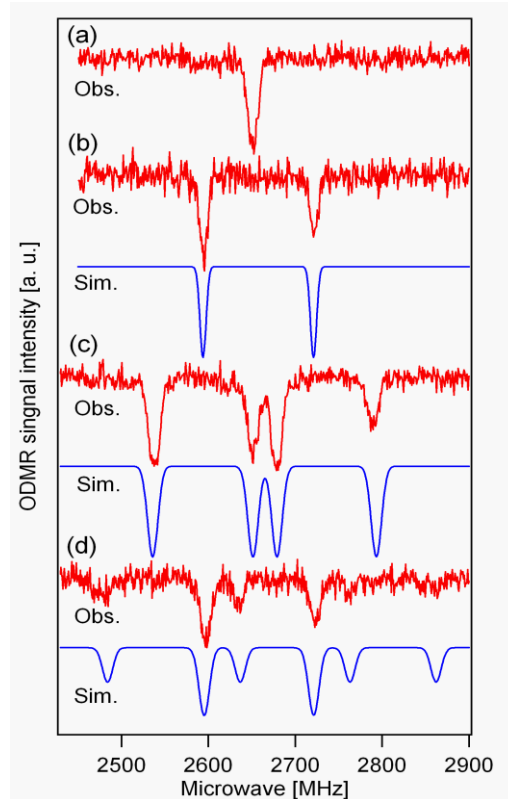
## Multiple quantum bit

Quantum register: multiple q-bits of single NV-center

### $^{13}\text{C}$ -doped system



N: nitrogen. V: Vacancy (V).  
Carbon atoms labeled at 1-3 are  
called as nearest-neighbor  
carbon atom from vacancy.



Jiang et al., PRA 76, 062323 (2007)

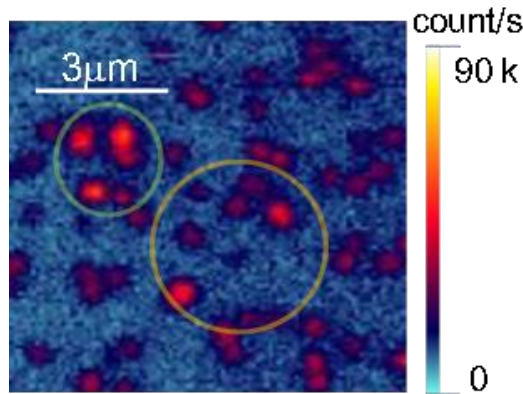
Experimental and simulated  
ODMR spectra of nearest  
neighbor carbon atoms  
assigned as consisting of (a)0,  
(b)1, (c)2, (d)3  $^{13}\text{C}$ -center(s)

G. Balasubramanian, P. Neumann, D. Twitchen, M. Markham, R. Kolesov, N. Mizuochi, J. Isoya, J. Achard, J. Beck, J. Tissler, V. Jacques, F. Jelezko, J. Wrachtrup, "Ultralong spin coherence time in isotopically engineered diamond", **Nature materials**, v. 8, p. 383-387 (2009)

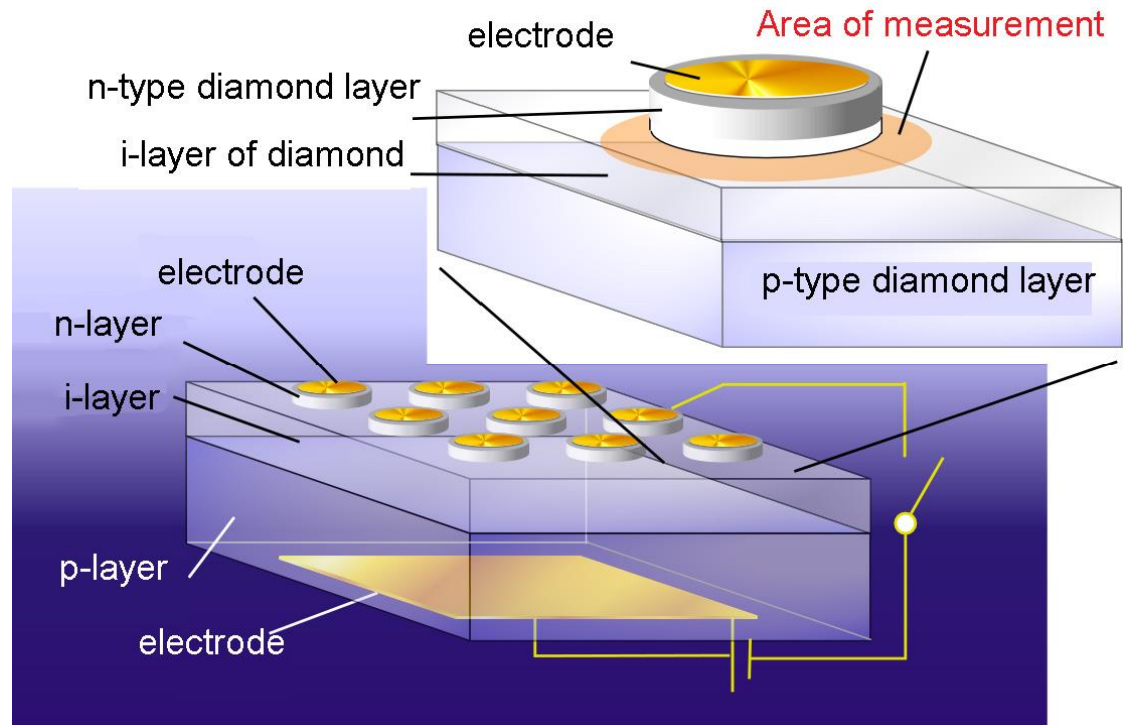


# Room temperature single photon emission from NV<sup>0</sup> center in diamond LED

- Mizuochi succeeded in observing single photon emission from p-i-n light emitting diode of diamond.



EL image of single NV center



N. Mizuochi, T. Makino, H. Kato, D. Takeuchi, M. Ogura, H. Okushi, M. Nothaft, P. Neumann, A. Gali, F. Jelezko, J. Wrachtrup, S. Yamasaki, "Electrically driven single photon source at room temperature in diamond", **Nature Photonics**, 6, 299-303 (2012).



## Achievements



# Spintronics devices and materials

# Spintronics devices and materials

1. E. Saitoh succeeded in transferring DC signal through *insulator* by using spin current. He discovered *Spin Seebeck* effect by using thermal spin current
2. S. Murakami proposed unified theory of spin and heat and predicted high thermoelectric performance in *topological insulators*
3. S. Shiraishi succeeded in spin injection to single sheet of *graphene*
4. K. Hamaya succeeded in spin injection to *nondegenerate silicon* leading to gate voltage control of spin injection
5. T. Fukumura succeeded in controlling magnetic properties by gate-voltage in *room temperature ferromagnetic semiconductor*  $\text{TiO}_2:\text{Co}$
6. Y. Takahashi developed *Heusler alloy*  $\text{Co}_2\text{Mn}(\text{Ga},\text{Ge})$  with the highest degree of spin polarization

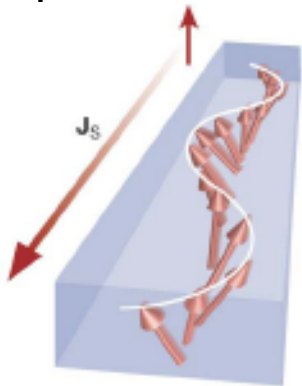
# Spintronics based on spin currents and spin-photon coupling in dielectrics



By utilizing the strong interaction between a spin current and an electric field in **dielectric materials**, the spin-wave spin currents will realize the coherent and **low-loss information transmission** which can be controlled in terms of light and/or an electric field



Realization of **Ultimate Spintronics** using pure Spin Current detached from electric current



Spin current is a wave of magnetization in ferromagnet, which is capable of transferring Spin Current (Flow of Spin Angular Moment)

## Eiji Saitoh (Tohoku Univ)

### Representative Papers

Nature **464**, 262-266 (2010).

Nature materials **9**, 894-897 (2010).

Nature materials **10**, 655 -659 (2011).

### Awards

Sir Martin Wood Prize

JSPS Award

Japan Academy Prize

Japan IBM Science Prize

### Promotion

Lecturer Keio U → Prof Tohoku U

### Special Comment

Editor of a Book "Spintronics for Next-Generation Innovative Devices" (John Wiley)

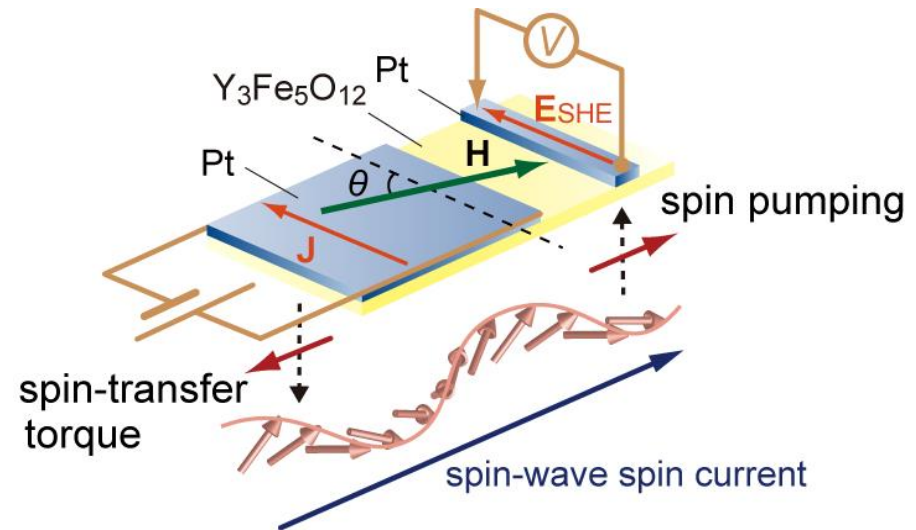
### Outreach

Press Lecture, JST News

Contribution to Scientific Progress

# A magnetic insulator transmits electrical signals via spin waves

- Saito succeeded in transmitting electric signals through YIG using spin waves (pure spin current) in the insulator.
- The spin Hall effect, which converts the charge current to a spin current, and its inverse forms the basis for a proof of principle. (cited in *Physic Today*)

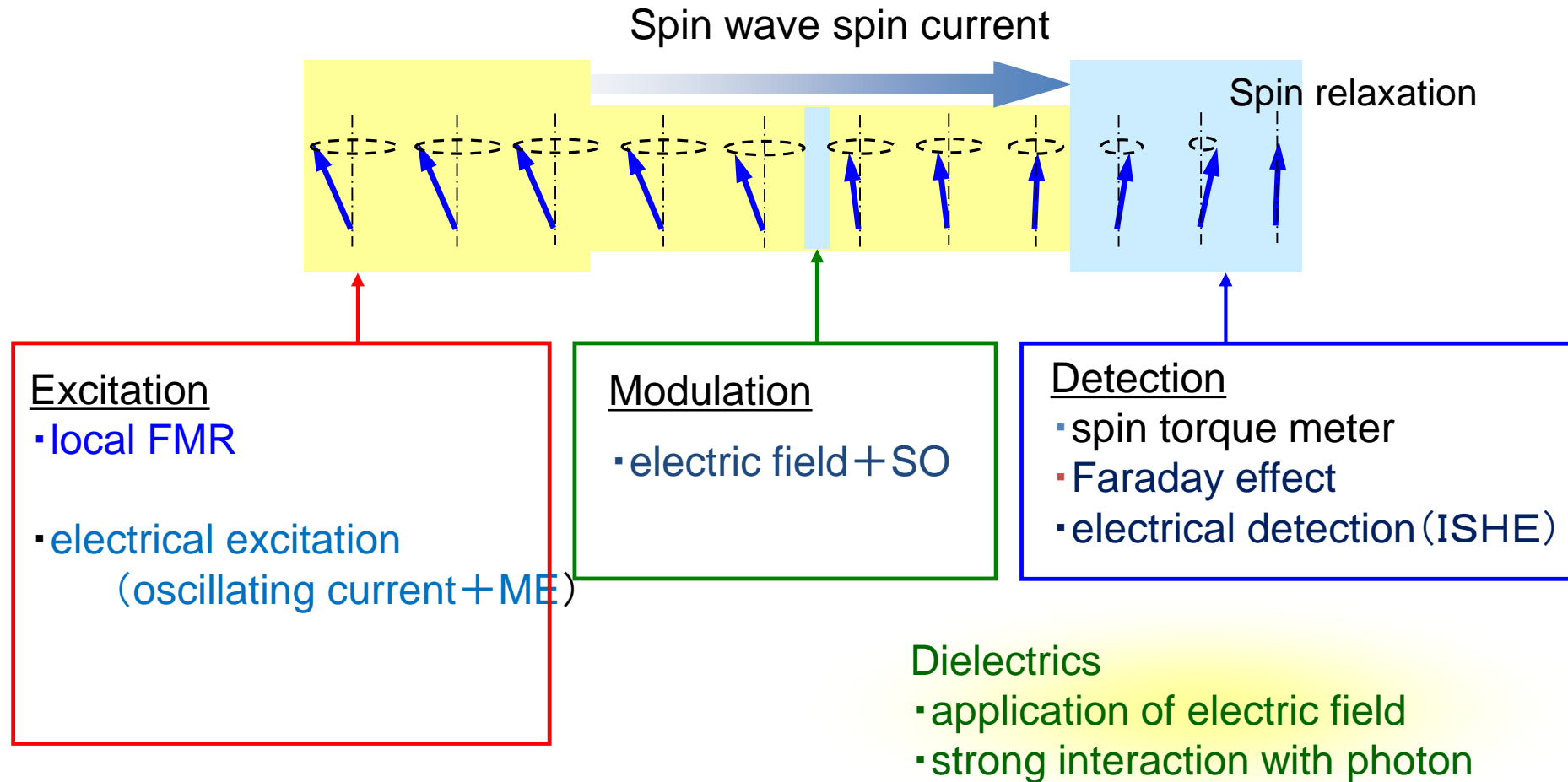


Y. Kajiwara, K. Harii, S. Takahashi, J. Ohe, K. Uchida, M. Mizuguchi, H. Umezawa, H. Kawai, K. Ando, K. Takanashi, S. Maekawa & E. Saitoh, *Nature* **464** 262 (2010)



Contribution to Scientific Progress

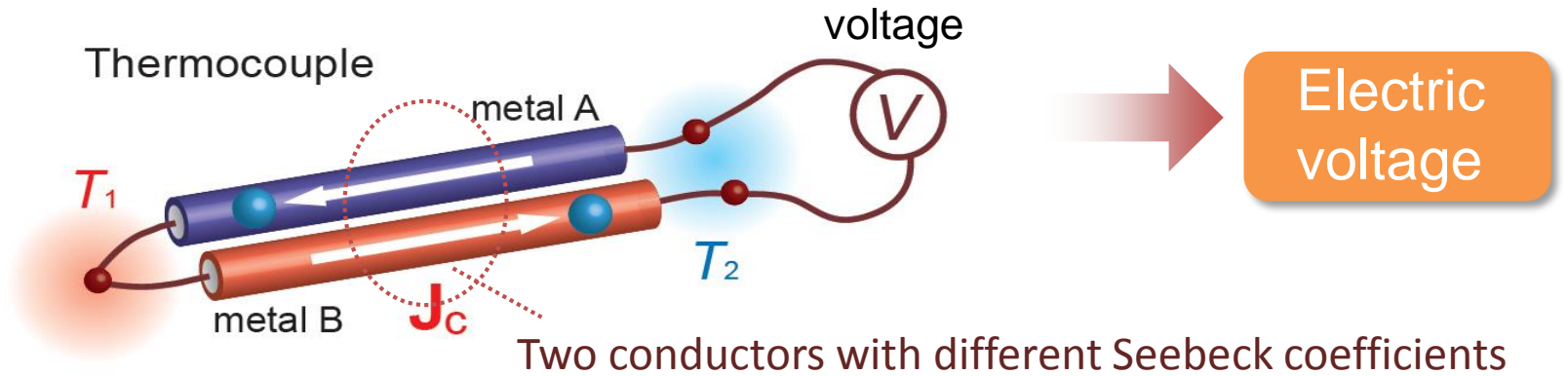
*Excitation, modulation and detection of spin wave spin current*



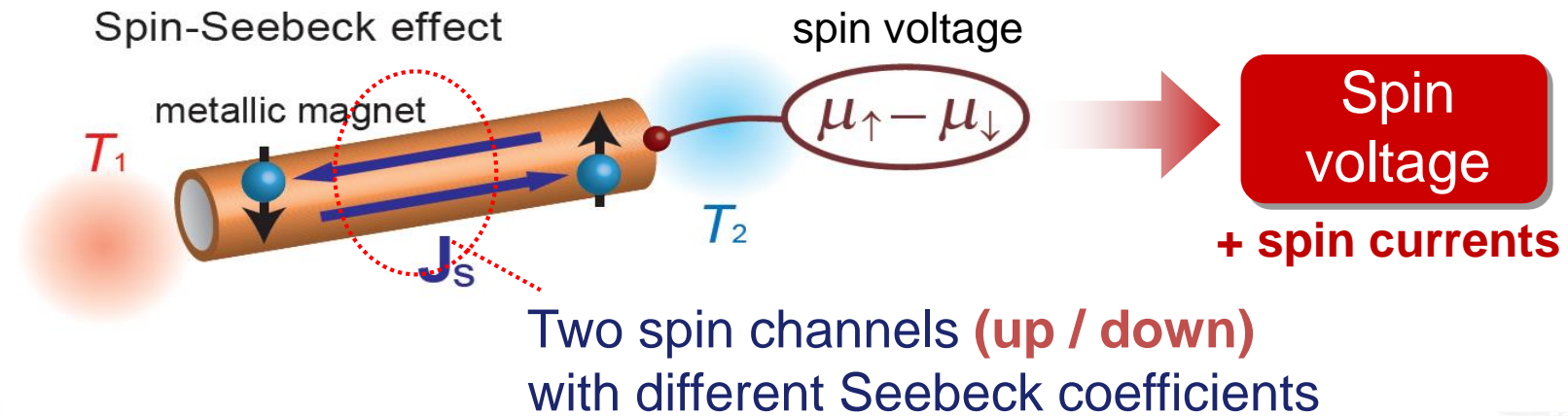
Contribution to Scientific Progress

Promising challenging technology

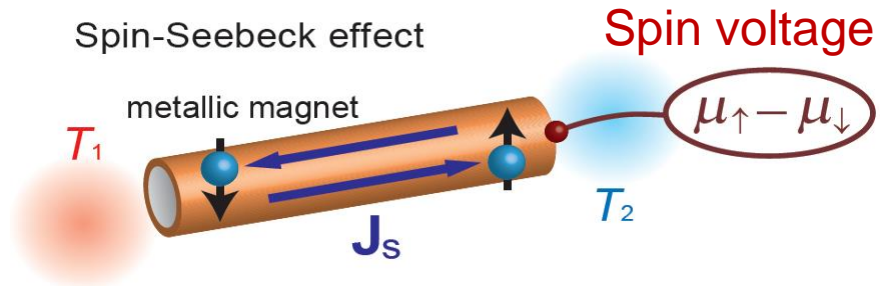
## Seebeck and "spin-Seebeck" effects



depending on the density of electrons

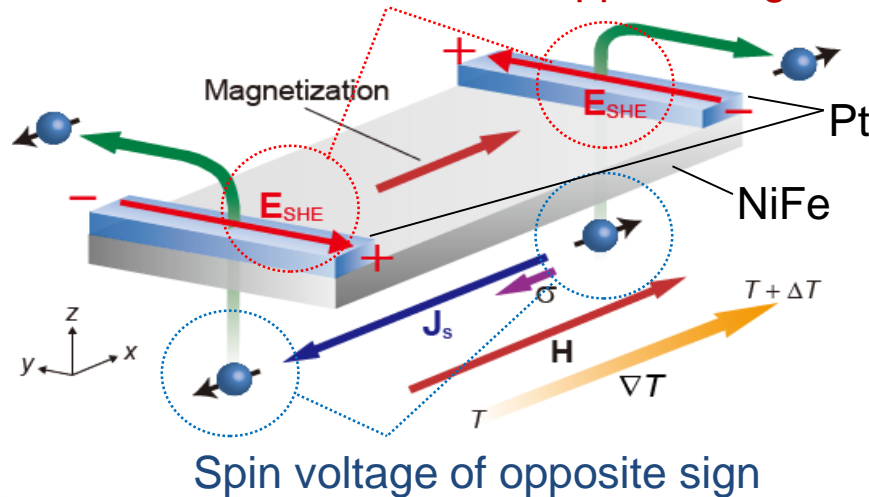


# Observation of spin-Seebeck effect

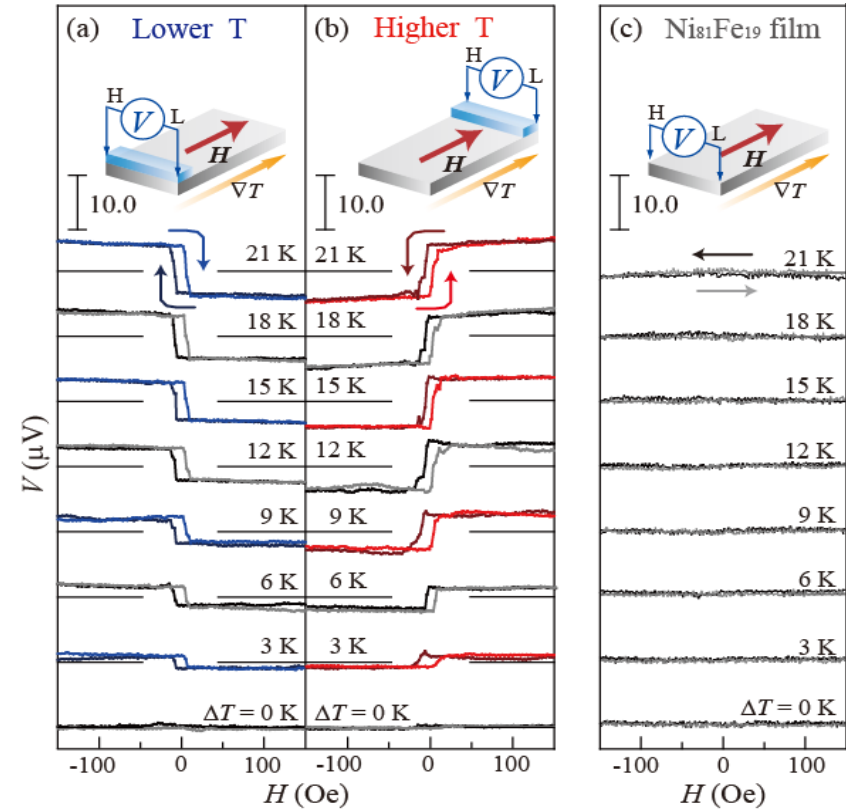


using the inverse spin-Hall effect (ISHE)

electromotive force of opposite signs



Magnetic field dependence of  $V$



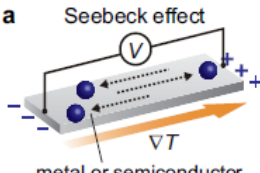
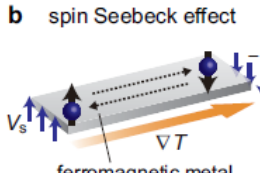
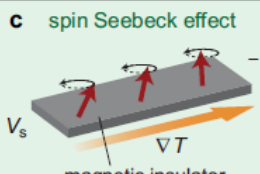
ISHE voltage induced by  
the spin-Seebeck effect

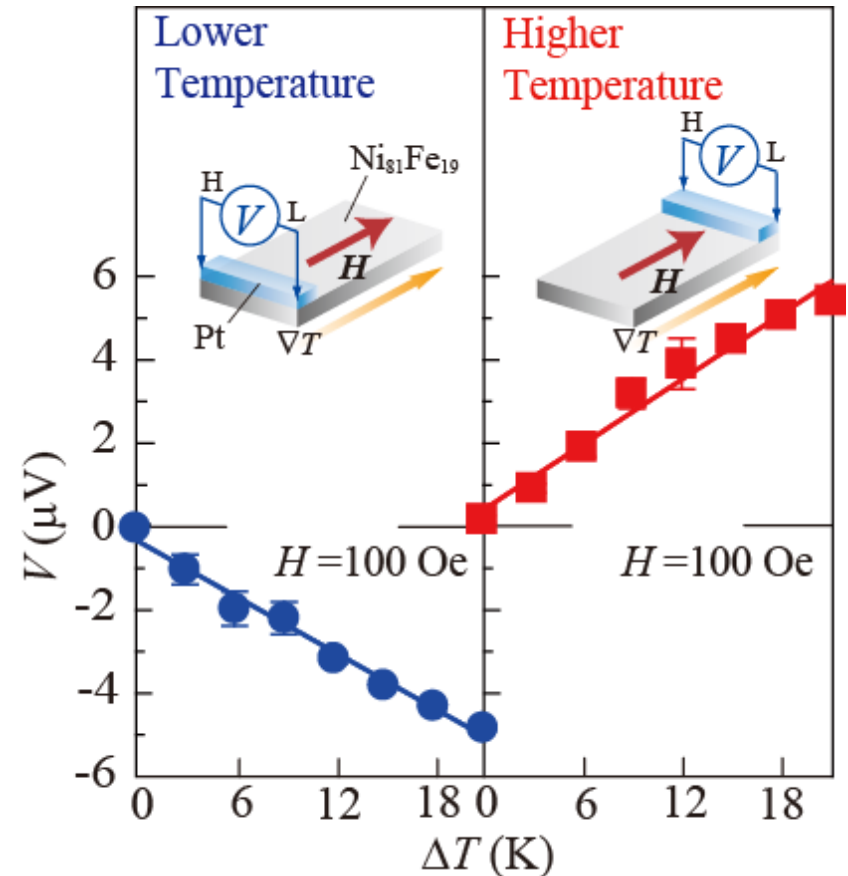
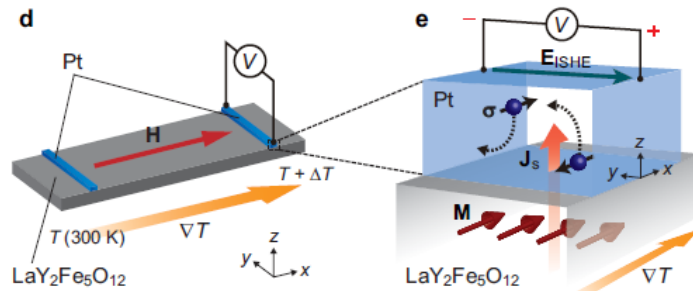
Contribution to Scientific Progress

Promising challenging technology (Energy Harvesting)

# Spin Seebeck insulator

- Saito succeeded in observing spin Seebeck effect in **insulating  $\text{LaY}_2\text{Fe}_5\text{O}_{12}$**

output	Electricity	Magnetism
Material		
Conductor	<b>a</b> Seebeck effect  metal or semiconductor	<b>b</b> spin Seebeck effect  ferromagnetic metal
Insulator	✗	<b>c</b> spin Seebeck effect  magnetic insulator



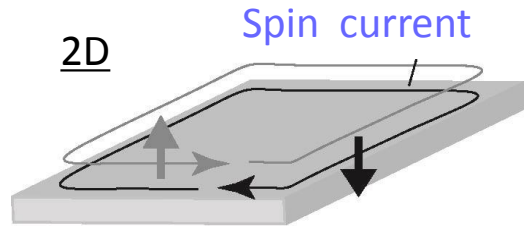
K. Uchida, E. Saitoh et al.:  
Nature Mat. (online Sept 27, 2010)



# Theory of spin current and heat current



- 1) Bismuth ultrathin films as quantum spin Hall phases
- 2) Universal Phase Diagrams for 2D and 3D quantum spin Hall phases
- 3) Quantum spin Hall systems as candidates for **efficient thermoelectrics**



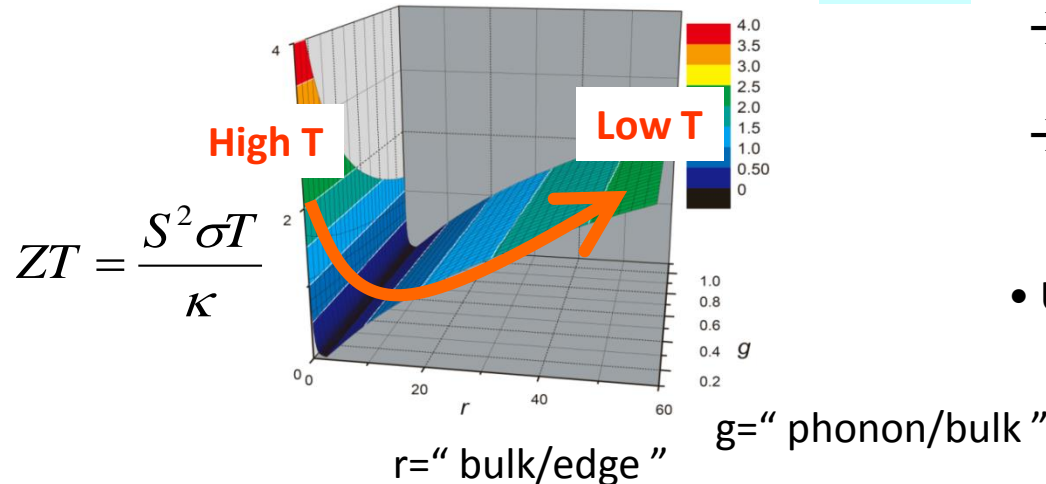
**Expectation** : QSH systems can be good thermoelectric.

- \* suppress phonon conduction, keeping electron conduction
- \* Low-dimensional states (edge states, surface states)
- \* Similar materials involved ( $\text{Bi}_{1-x}\text{Sb}_x$ ,  $\text{Bi}_2\text{Se}_3$  etc.)

**Result**

- Lower temp.
  - longer inelastic scattering length for edge states
  - edge states become dominant
- **bulk-to-edge crossover of thermoelectric transport**
- Ultrathin & narrow ribbon (of QSH system)
  - crossover occurs at around 10K

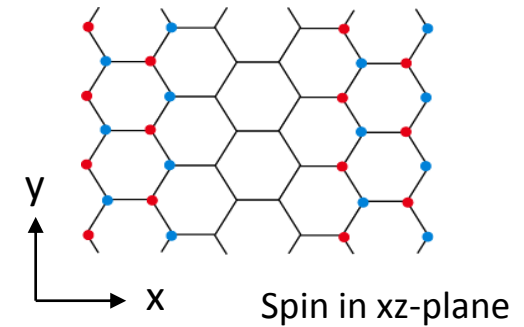
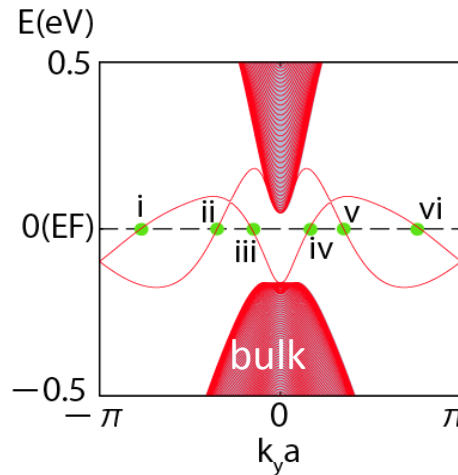
**Quantum spin Hall systems can be good thermoelectrics at low temp.**



Zigzag edge

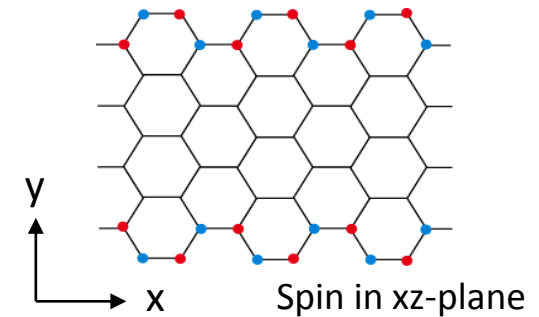
	$S_x$	$S_y$	$S_z$
i-U	0.822	-0.000	-0.229
i-L	-0.822	0.000	0.229
ii-U	-0.680	0.000	-0.217
ii-L	0.680	-0.000	0.217
iii-U	0.141	0.000	-0.095
iii-L	-0.141	-0.000	0.095
iv-U	-0.141	-0.000	0.095
iv-L	0.141	0.000	-0.095
v-U	0.680	-0.000	0.217
v-L	-0.680	0.000	-0.217
vi-U	-0.822	0.000	0.229
vi-L	0.822	-0.000	-0.229

(a) (111) 1-bilayer: spin polarization on edges



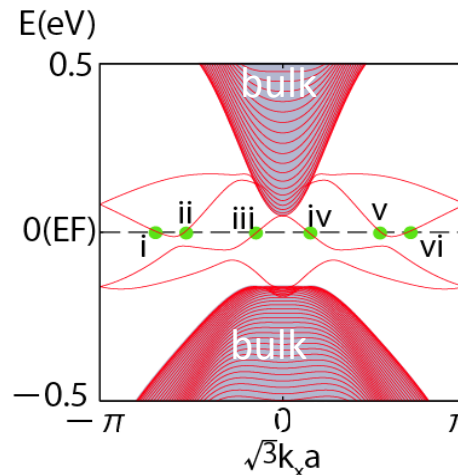
Odd number of Kramers pairs  
of edge states

Quantum spin Hall state



Armchair edge

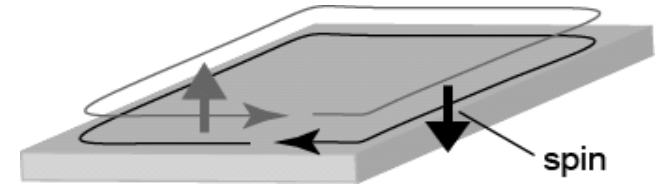
	$S_x$	$S_y$	$S_z$
i-U	0.763	0.000	-0.010
i-L	-0.763	-0.000	0.010
ii-U	0.395	0.000	-0.237
ii-L	-0.395	-0.000	0.237
iii-U	0.250	-0.000	-0.395
iii-L	-0.250	0.000	0.395
iv-U	-0.250	0.000	0.395
iv-L	0.250	-0.000	-0.395
v-U	-0.395	-0.000	0.237
v-L	0.395	0.000	-0.237
vi-U	-0.763	-0.000	0.010
vi-L	0.763	0.000	-0.010



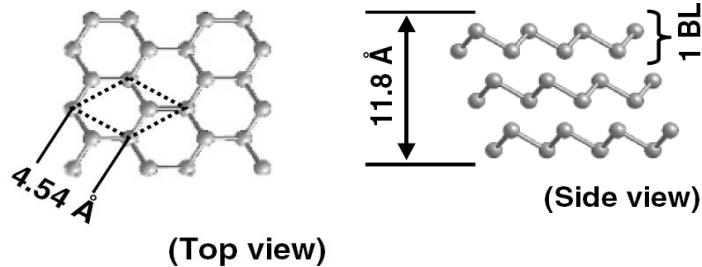
## Theoretical Approach

### Quantum Spin Hall Effect in Bismuth

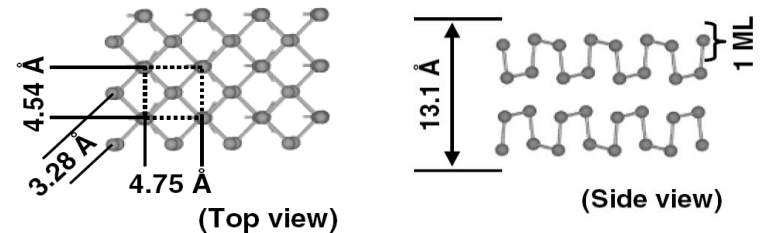
- Bulk Bi show no gap, while edge is gapless.
- Bi ultra thin film (*topological insulator*)



(111) 1-bilayer = quantum spin Hall phase



{012} 2-monolayer = insulating phase



- Thermoelectric figure of merit

$$ZT = \frac{S^2 \sigma T}{\kappa}$$

Idealized model (perfect conductor on the edge)

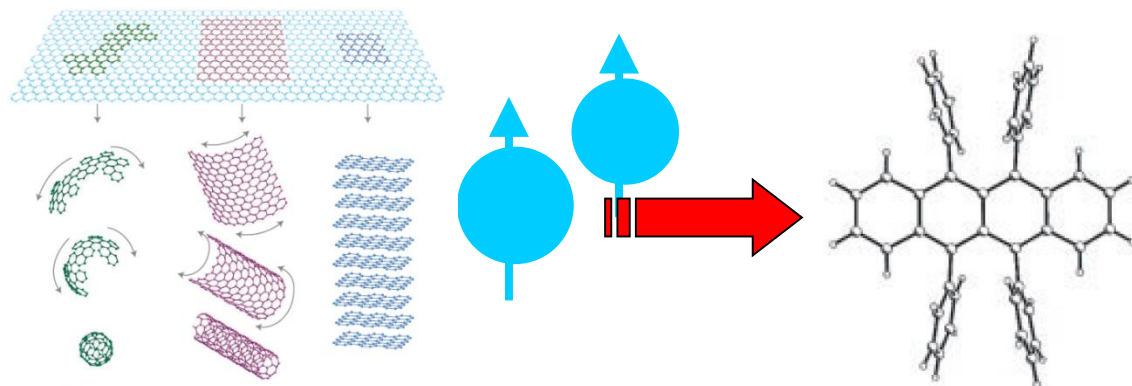
- In the quantum spin Hall phase, figure of merit  $ZT$  of thermoelectric conversion is determined by the balance between the edge and the bulk.
- $ZT$  is large if the chemical potential is close to the band edge.
- $ZT$  is large if the length of system is long. ← edge states dominantly determine  $ZT$ .
- $ZT$  increases with temperature. ← Higher energy carriers contribute to  $ZT$ .

Wada, Murakami: "Well-localized edge states in two-dimensional topological insulator: bismuth film", APS March Meeting 2010(2010), Oregon, USA (2010/3/15).

# Spin current control in molecules

The purpose of this project is establishing and driving molecular spintronics, which is regarded to be one of the most potential research field, by observation of spin injection and control of spin current in molecules.

Objectives: Molecular semiconductors including nanocarbons such as graphene and fullerene, single crystalline organic semiconductor such as rubrene



**Masashi Shiraishi**  
**(Osaka Univ)**



## Representative Papers

Adv. Func.Mat. **22**,3845(2012).

Appl.Phys.Lett. **99**,043505 (2011).

## Award

JSAP Paper Award

## Promotion

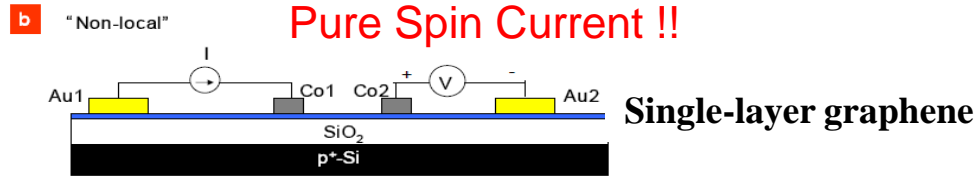
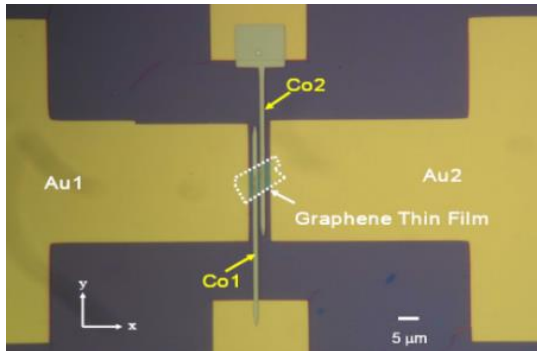
Associate Prof→Prof

## Outreach

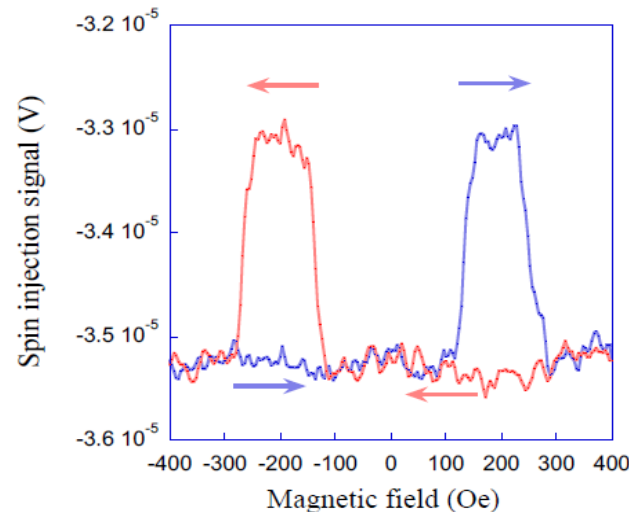
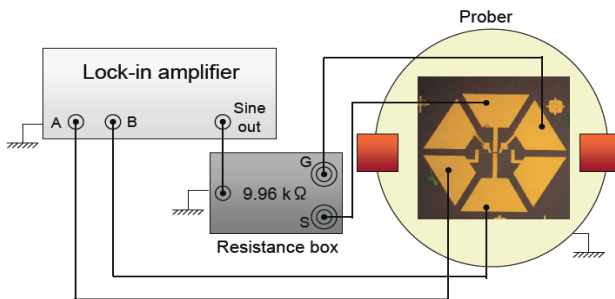
JST News



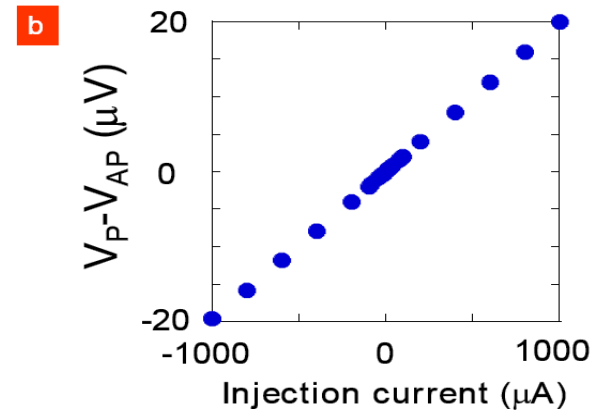
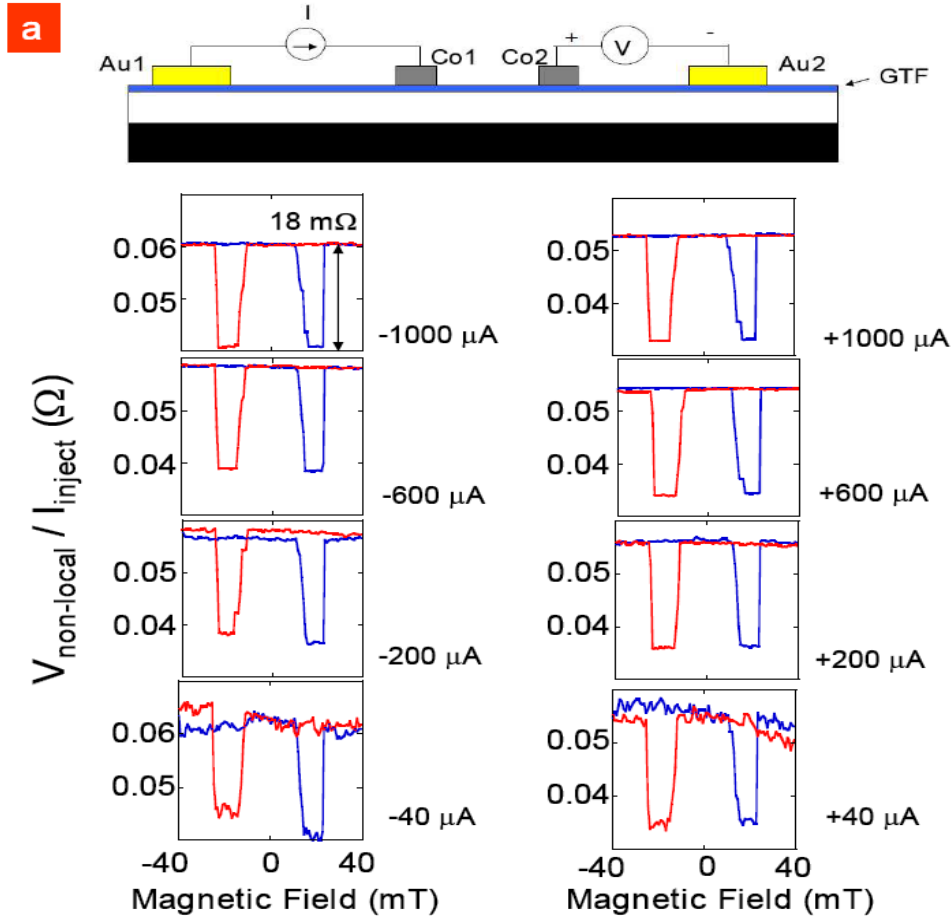
# Graphene Spintronics



Non-local measurement  
(Experimental setup)

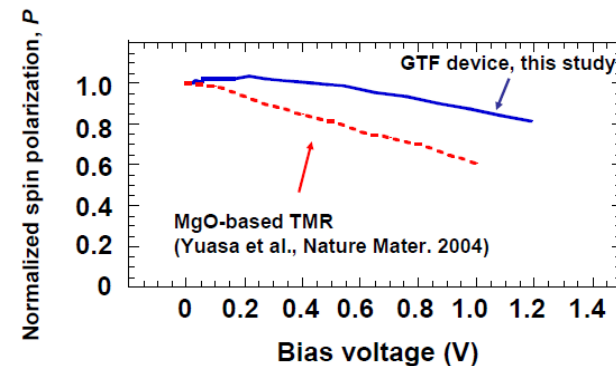


# Graphene Spintronics



$$\Delta V_{\text{non-local}} = \frac{2P^2}{(1-P^2)^2} \left( \frac{R_F}{R_N} \right) R_F \cdot \left[ \sinh\left(\frac{L}{\lambda_{sf}}\right) \right]^{-1} \cdot I_{\text{inject}},$$

Spin polarization is CONSTANT.

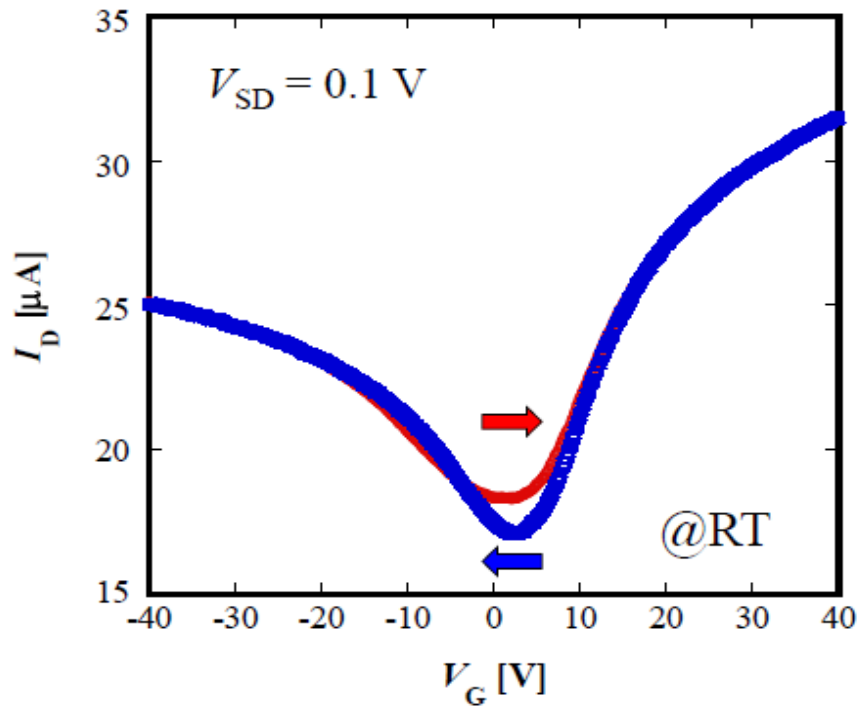


*Better  
robustness  
than that in  
MgO-TMR*

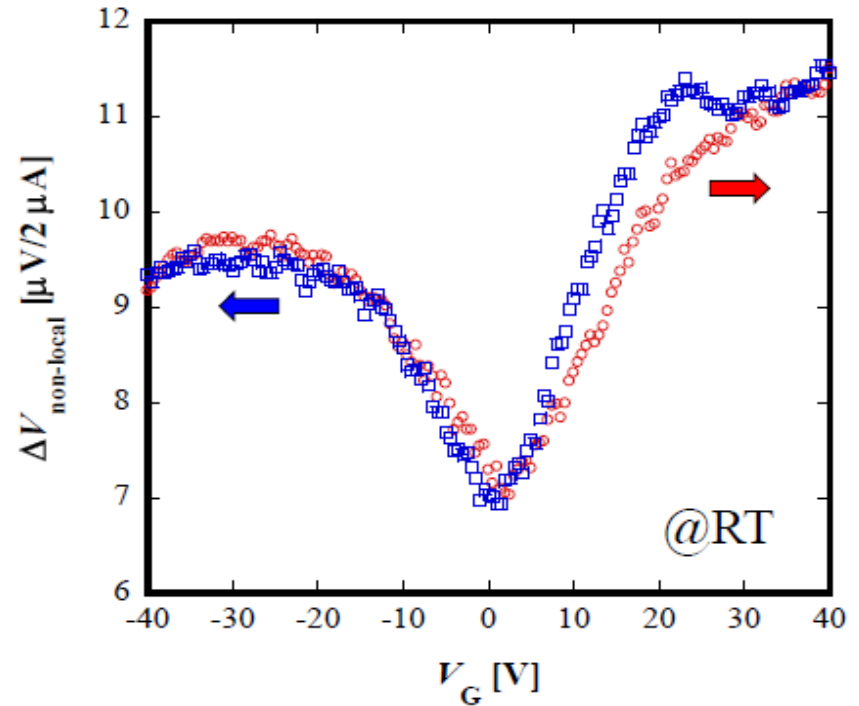
# Gate Voltage Control of Spin Current in Graphene

(Transistor with a Single Layer Graphene)

FET characteristics between Co electrodes



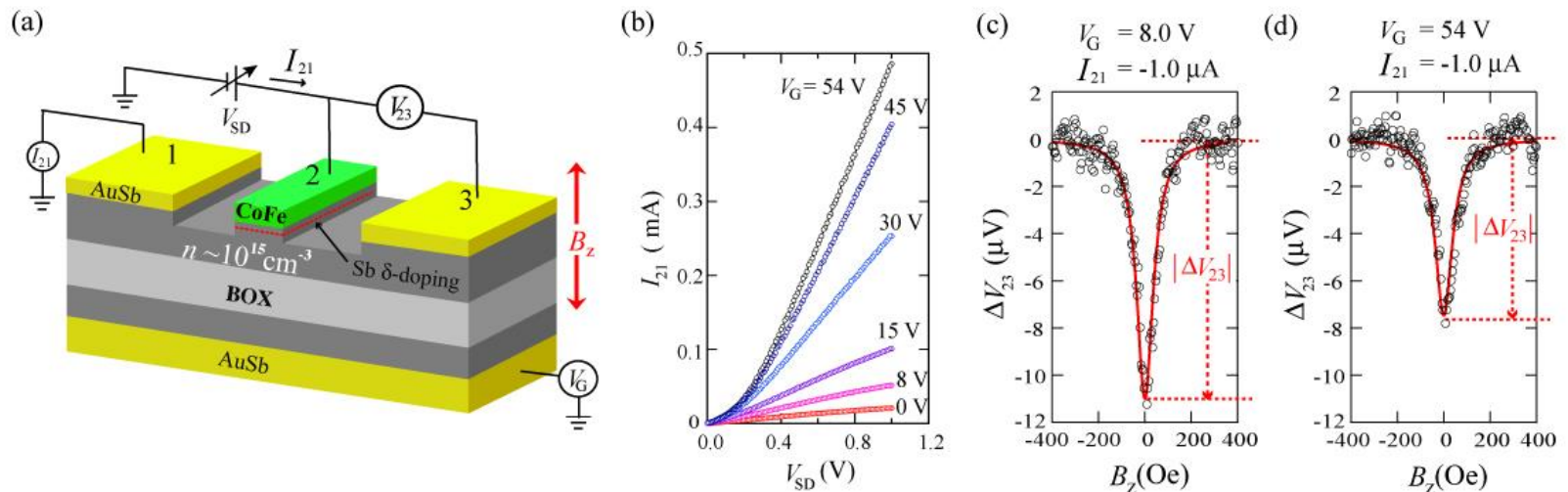
A gate voltage dependence of the spin signal





# Silicon Spintronics

- For application of spintronics, combination with Si technology is very important.
- Previous studies of Si spintronics used only highly doped metallic Si, which is not suited for gate-control devices.
- Hamaya successfully utilized low-doped Si for spintronics application.



M. Ishikawa, H. Sugiyama, T. Inokuchi, K. Hamaya, Y. Saito,  
"Effect of the interface resistance of CoFe/MgO contacts on spin  
accumulation in silicon", Appl. Phys. Lett. 100, 252404 (2012).



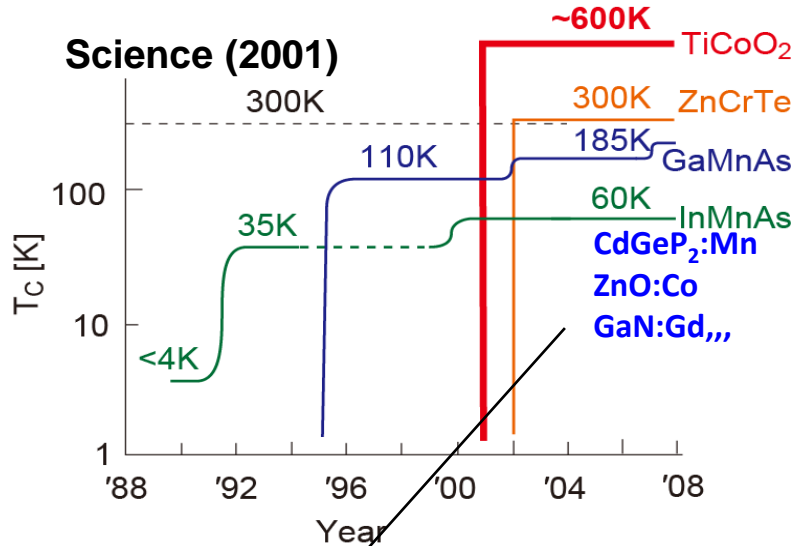


Tomoteru Fukumura

Contribution to Scientific Progress

# High $T_C$ FM semiconductor: Co-doped $TiO_2$

Extraordinary high  $T_C$



**$TiO_2:Co$  Room temperature FM semiconductor**

**Giant MO effect at RT**

T. Fukumura, Jpn. J. Appl. Phys. (2003)

H. Toyosaki, Appl. Phys. Lett. (2005)

**Anomalous Hall effect at RT**

H. Toyosaki, Nature Mater. (2004)

T. Fukumura, Jpn. J. Appl. Phys. (2007)

**Tunneling Magnetoresistance**

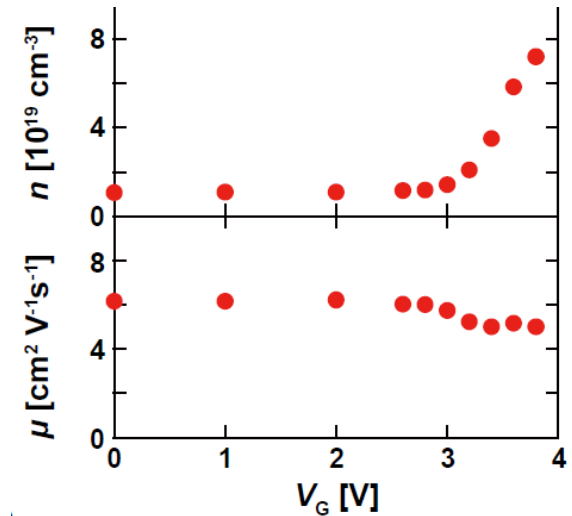
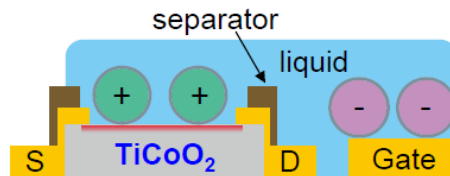
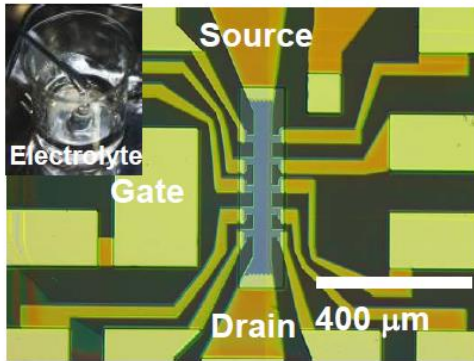
H. Toyosaki, Jpn. J. Appl. Phys. (2005)

G.A. Medvedkin, T. Ishibashi,  
T. Nishi, K. Hayata, Y.  
Hasegawa and K. Sato: Jpn.  
J. Appl. Phys. 39 Part 2  
[10A] (2000) L949-L951

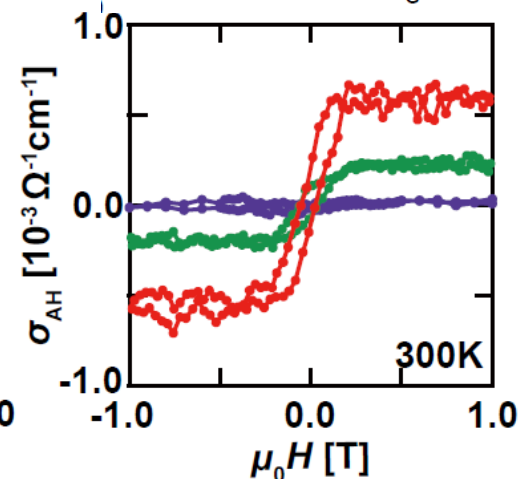
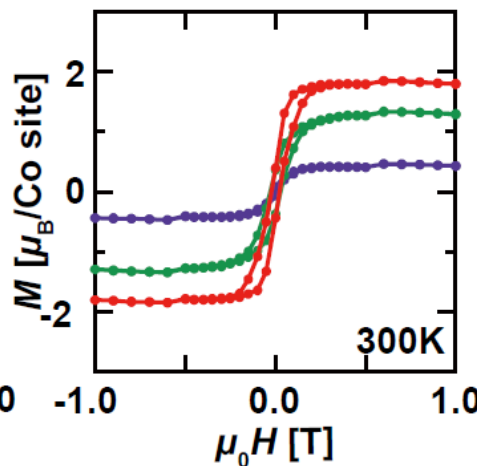
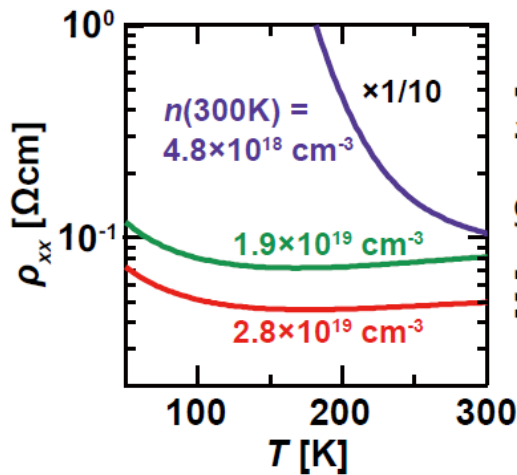
$Zn_{1-x}TM_xO$  combinatorial library

IIIB		IVB		VB		VIB		VIIB		VIIIB		IB		IIB	
21	2	22	2	23	2	24	2	25	2	26	2	27	2	28	2
Sc	8	Ti	8	V	8	Cr	8	Mn	8	Fe	8	Co	8	Ni	8
Scandium	10	Titanium	11	Vanadium	12	Chromium	13	Manganese	14	Iron	15	Cobalt	16	Nickel	18
44.955910	47.867	50.9415	51.9961	54.938049	55.8457	58.933200	58.6934	63.546	65.39						

# Carrier control of magnetism in $\text{TiO}_2:\text{Co}$ by gate voltage



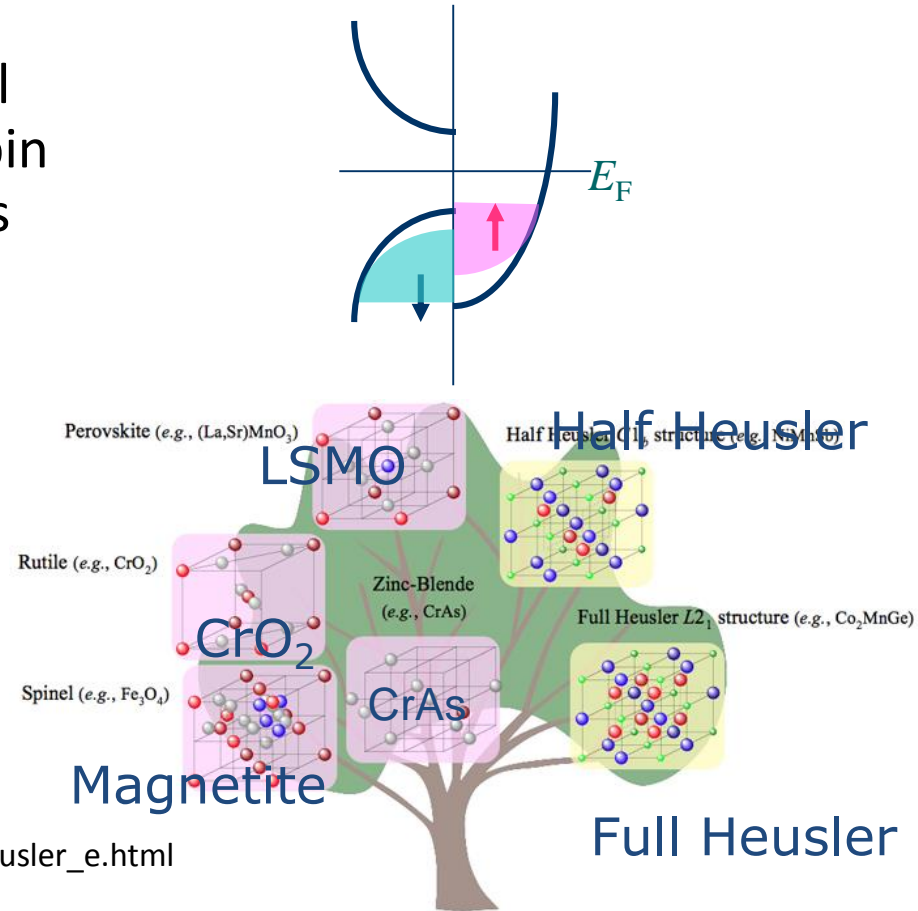
PM insulator  $\rightarrow$  FM metal



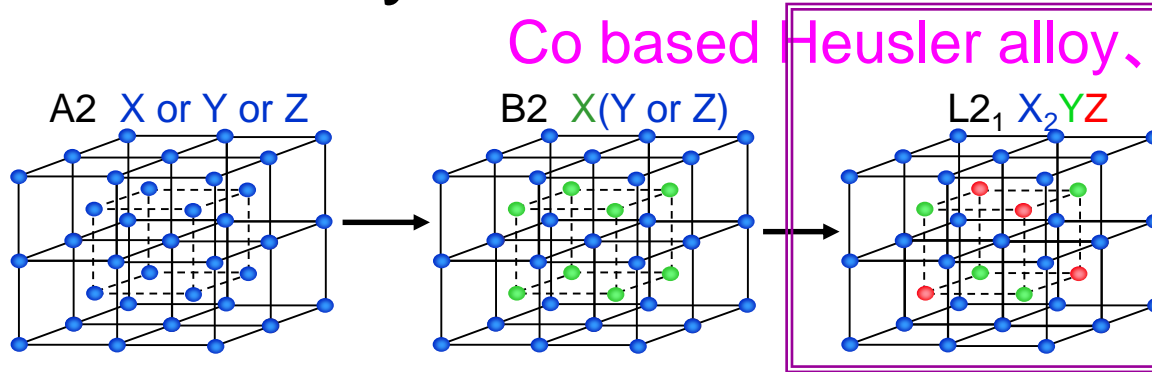
# Half metal electrodes for MTJ

- Half metal is a magnetic material in which electronic state for  $\uparrow$  spin is metallic while that for  $\downarrow$  spin is semiconducting.
- Therefore the electronic state at the Fermi level is fully spin-polarized in half metals.
- Heusler compounds, LSMO ( $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ ), magnetite ( $\text{Fe}_3\text{O}_4$ ), chromium oxide ( $\text{CrO}_2$ ) are candidates of half metals.

[http://www.riken.go.jp/lab-www/nanomag/research/heusler\\_e.html](http://www.riken.go.jp/lab-www/nanomag/research/heusler_e.html)

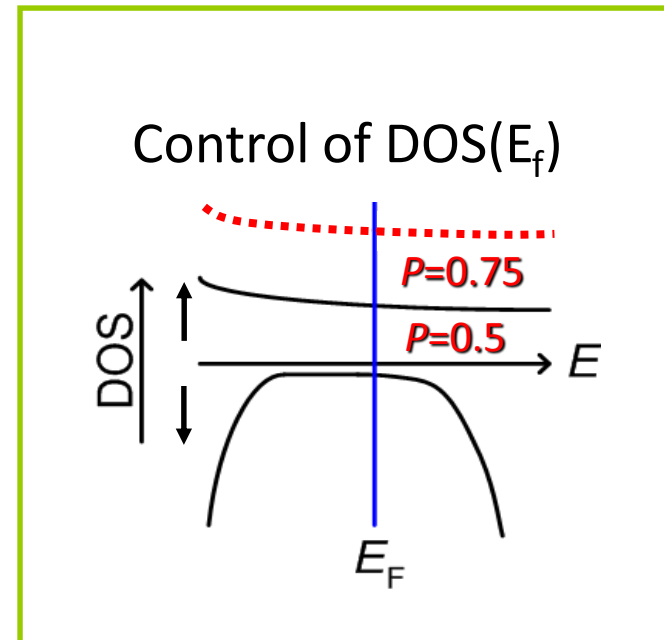
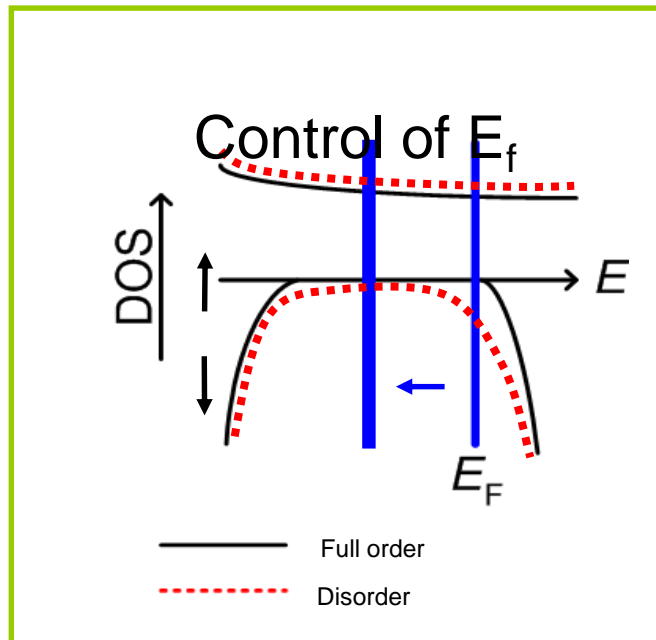


# Alloy search for RT half-metal



Co based Heusler alloy, X<sub>2</sub>YZ

High T<sub>c</sub>  
Theoretical P=1  
However,  
Experimental P is low





## Search of high spin-polarization half metals using PCARS

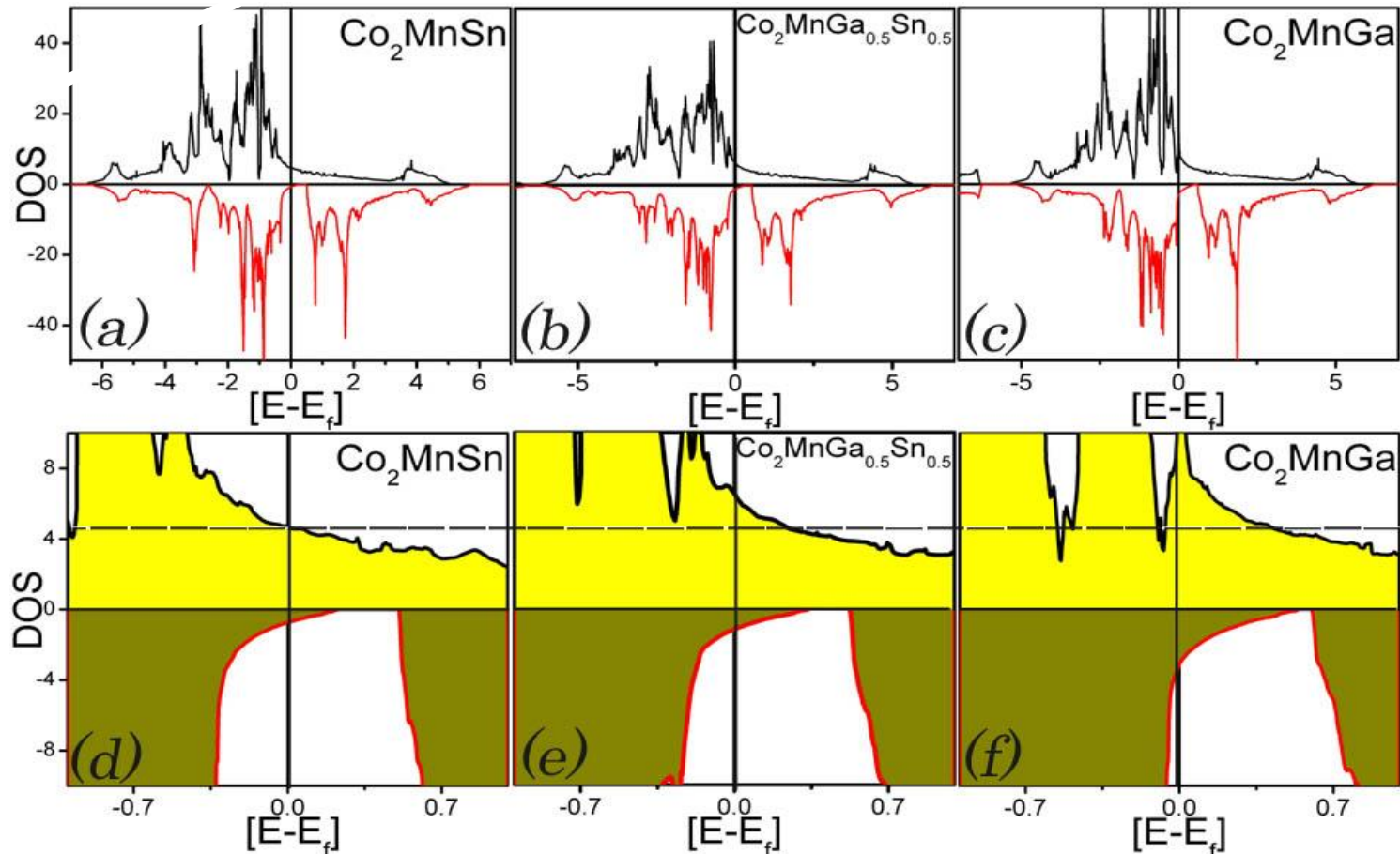
- Aiming at high performance GMR devices Takahashi has investigated as many as 32 full Heusler alloys and found 74% spin polarization in CoMnGeGa alloy.

Metals and binary	P	Ref.
Fe	46	
Co	45	
FeCo	50	
Co <sub>75</sub> Fe <sub>25</sub>	58	
B2-FeCo	60	
[Co/Pd] <sub>n</sub>	60	

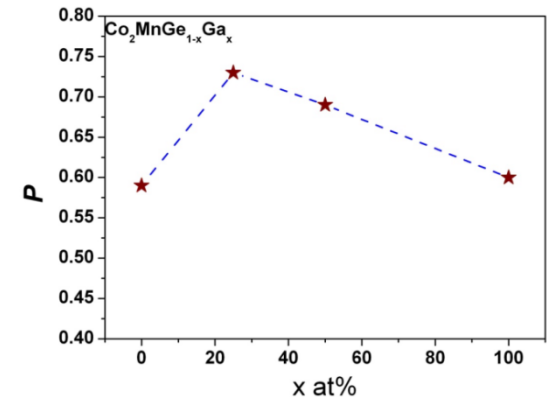
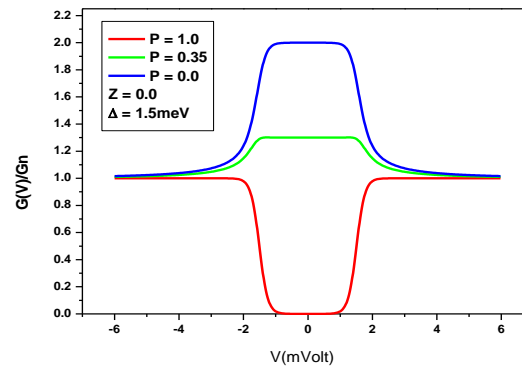
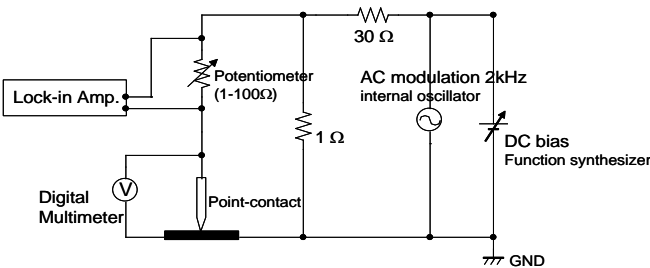
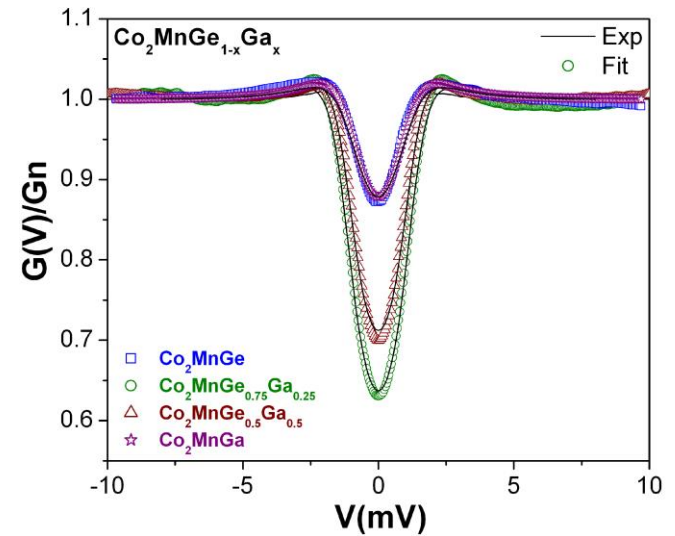
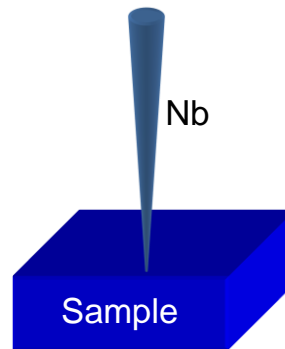
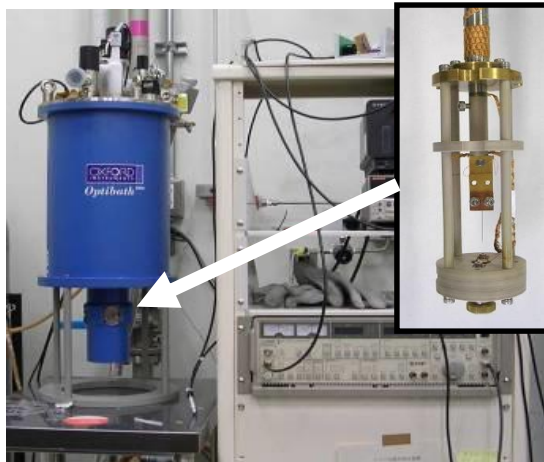
Ternary alloys	P	Ref.
Co <sub>2</sub> MnSi	56	
Co <sub>2</sub> MnGe	58	
Co <sub>2</sub> MnSn	60	
Co <sub>2</sub> MnAl	60	
Co <sub>2</sub> MnGa	60	
Co <sub>2</sub> CrAl	62	
Co <sub>2</sub> FeAl	59	
Co <sub>2</sub> FeSi	60	
Co <sub>2</sub> FeGa	58	
Co <sub>2</sub> CrGa	61	
Co <sub>2</sub> TiSn	57	
Co <sub>2</sub> VAI	48	
Fe <sub>2</sub> VAI	56	

Quaternary alloys	P	Ref.
Co <sub>2</sub> Mn(Ge <sub>0.75</sub> Ga <sub>0.25</sub> )	74	
Co <sub>2</sub> Mn(Ga <sub>0.5</sub> Sn <sub>0.5</sub> )	72	
Co <sub>2</sub> Fe(Si <sub>0.75</sub> Ge <sub>0.25</sub> )	70	
Co <sub>2</sub> FeGa <sub>0.5</sub> Ge <sub>0.5</sub>	68	
Co <sub>2</sub> (Cr <sub>0.02</sub> Fe <sub>0.98</sub> )Ga	67	
Co <sub>2</sub> MnGeSn	67	
Co <sub>2</sub> (Mn <sub>0.95</sub> Fe <sub>0.05</sub> )Sn	65	
(CoFe) <sub>2</sub> MnGe	65	
Co <sub>2</sub> (Mn <sub>0.5</sub> Fe <sub>0.5</sub> )Ga	65	
Co <sub>2</sub> (Cr <sub>0.02</sub> Fe <sub>0.98</sub> )Si	65	
Co <sub>2</sub> MnTiSn	64	
Co <sub>2</sub> MnAl <sub>0.5</sub> Sn <sub>0.5</sub>	63	
Co <sub>2</sub> MnGa <sub>x</sub> Si <sub>1-x</sub>	63	
Co <sub>2</sub> FeAlGa	63	
Co <sub>2</sub> MnSiGe	63	
Co <sub>2</sub> (Mn <sub>0.5</sub> Fe <sub>0.5</sub> )Si	61	
Co <sub>2</sub> Mn(Al <sub>0.5</sub> Si <sub>0.5</sub> )	60	
Co <sub>2</sub> FeGa <sub>0.5</sub> Si <sub>0.5</sub>	60	
Co <sub>2</sub> Fe(Al <sub>0.5</sub> Si <sub>0.5</sub> )	60	

## Search of Heusler alloys following band calculation



# Point contact Andreev reflection (PCAR)



**Co<sub>2</sub>MnGe<sub>0.75</sub>Ga<sub>0.25</sub> shows highest P**

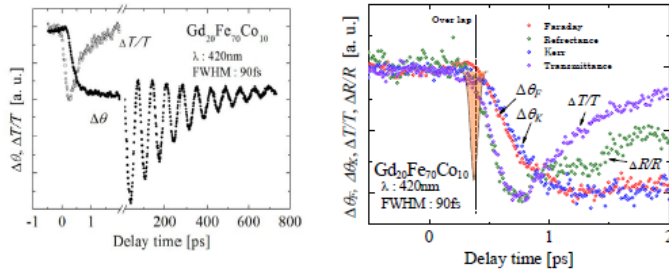


# Light-Induced ultrafast magnetization reversal

- The response time of magnetization reversal is usually limited by the spin dynamics which follow Landau-Lifshitz-Gilbert equation.
- By a collaboration of Nihon Univ. group and Radboud Univ. group, ultrafast magnetization switching (less than ps) was accomplished in the vicinity of the compensation point of MO-recording media.

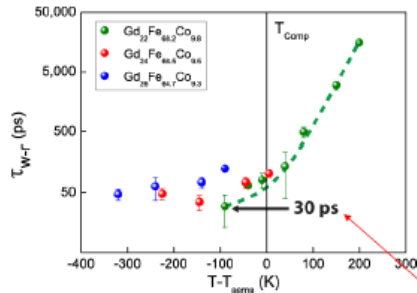


# Analysis of light-induced ultrafast magnetization reversal



The magnetization modified monotonically reaches to a temporal state within 1ps

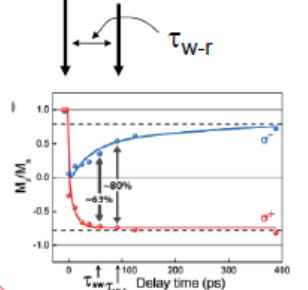
## Composition and temperature dependence of Photo-magnetic switching time



K. Vahaplar et al., Phys. Rev. Lett. 103, 117201 (2009)  
Cooperated work with Radboud Univ. et al.

Fastest write-read event demonstrated for magnetic recording so far.

## Laser irradiation (±σ) Magnetization recovery

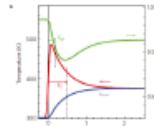


Gd<sub>51</sub>Fe<sub>36.5</sub>Co<sub>9.5</sub> @ room temp.

## Classification of ultrafast dynamics

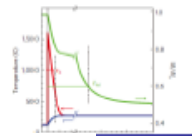
### Type I material

- Strong spin scattering
- Fast demagnetization follows the electron temperature
- Ni, Fe and Co

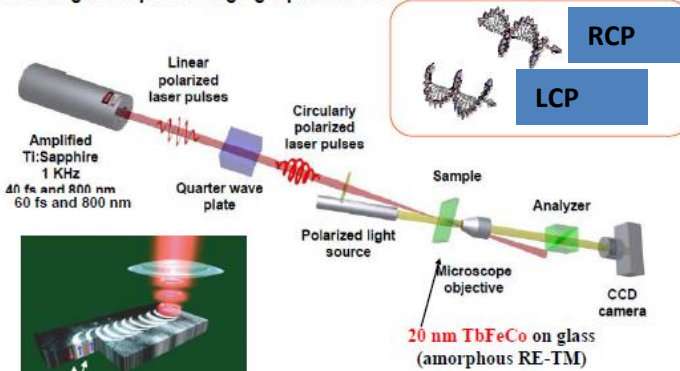


### Type II material

- Weaker magnetic coupling
- 2step demagnetizations very fast (first picosecond) slower demagnetization
- Ga, TbFe



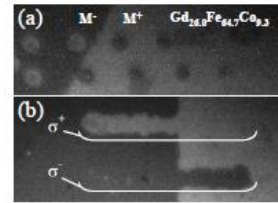
## Static magneto-optical imaging + pulsed laser



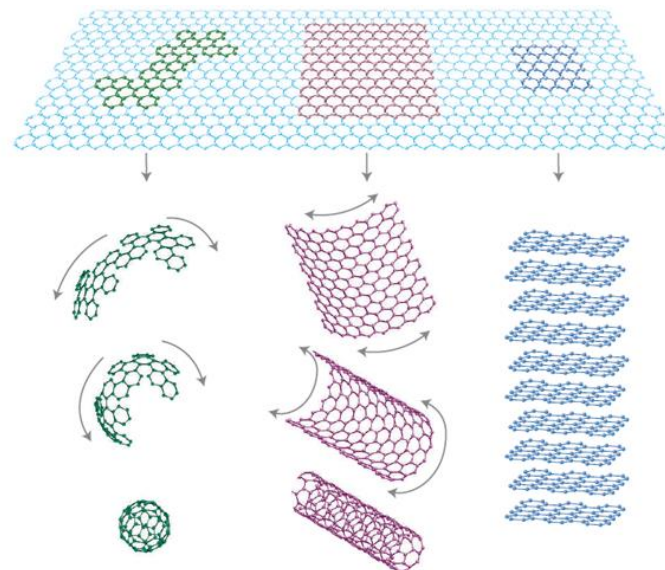
## Magnetization direction

## Origin of photo induced magnetization phenomena

- Spectroscopic measurements Wave length > photon energy
- Pulse width Intensity
- Distinguish thermal, non-thermal contribution
- Control of dynamic motion of spins
  - Angular momentum compensation
  - Linear reversal
  - > Suppress Precessional motion



Light-induced ultrafast magnetic recording



# Molecules and Organics

# Molecules and Organics

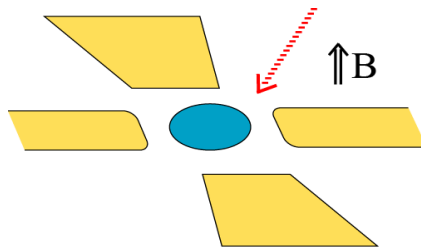
1. K. Machda fabricated nano structured graphene to find single electron and quantum effect
2. H. Yamamoto fabricated organic FET with high field effect mobility using *voltage controlled Mott-transition*. He also succeeded in *electrical control of superconductivity* in organic material
3. S. Noda succeeded in growing single *graphene sheet on insulating substrate* by metal-free process
4. J. Nishinaga succeeded in *delta-doping of C<sub>60</sub> in GaAs* thin film during MBE growth



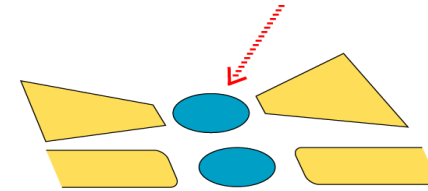
Tomoki Machida

# Graphene Quantum Dot

## Ultra high sensitivity THz detector



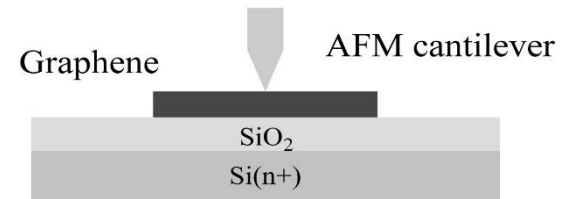
- Single electron transistor + quantum Hall effect



- Parallel double q-dot

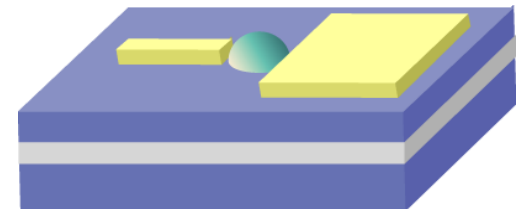
## Room temperature SET

- Local anode oxidation using AFM



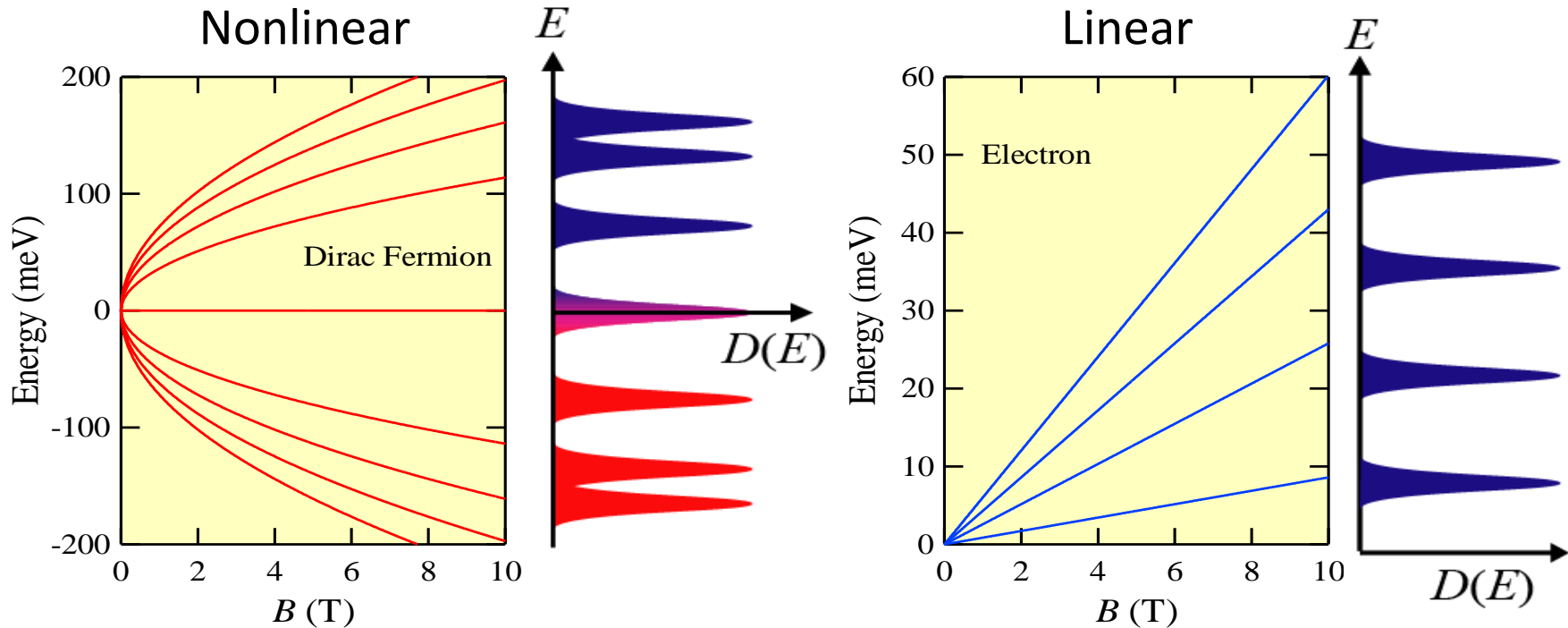
## Q-dot spin valve

- FM electrode + Graphene Q-dot





# Landau quantization: Dirac Fermion v.s. electron



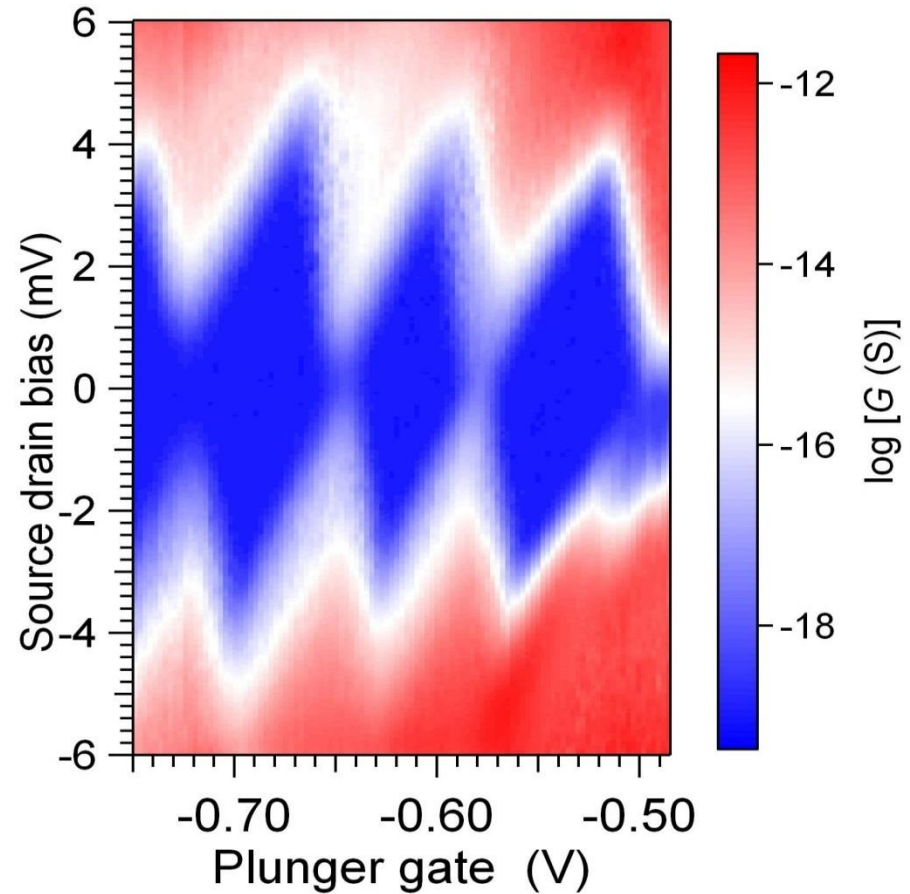
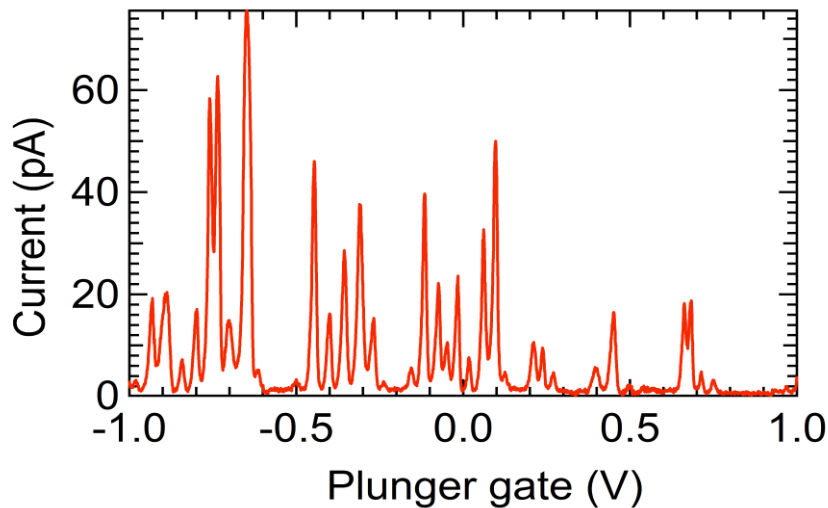
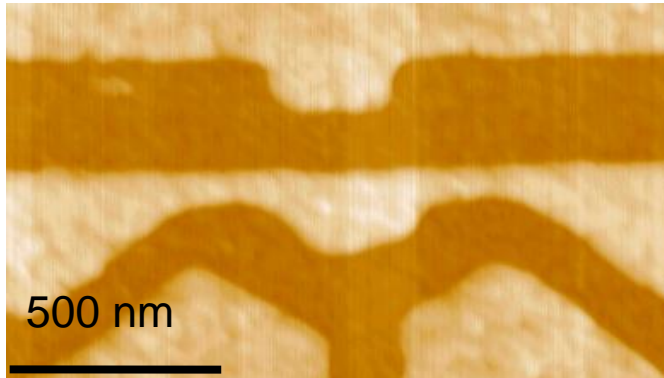
$$E_n = \tilde{c} \sqrt{2|n|\hbar e B} \quad \gg$$

$$\sigma_{xy} = \frac{2e^2}{h} n$$

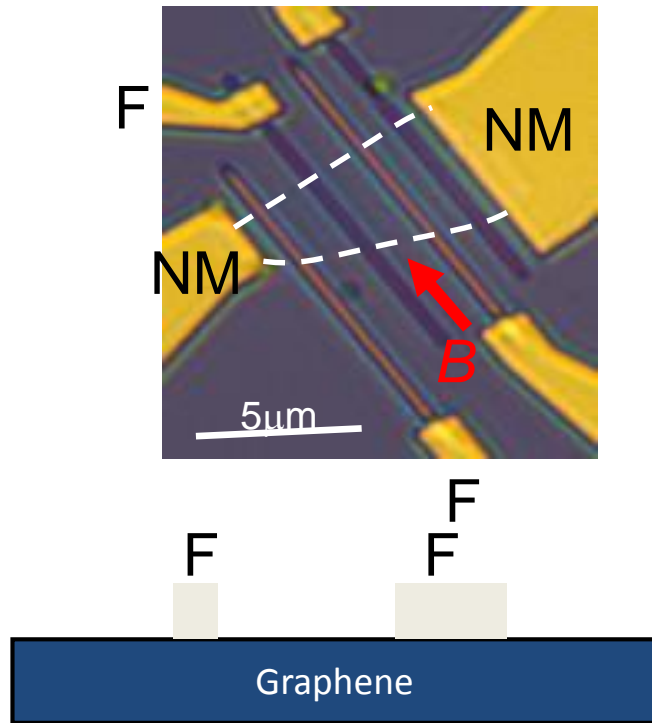
$$E_n = \left( n + \frac{1}{2} \right) \frac{\hbar e}{m^*} B$$

$$\sigma_{xy} = \frac{4e^2}{h} \left( n + \frac{1}{2} \right)$$

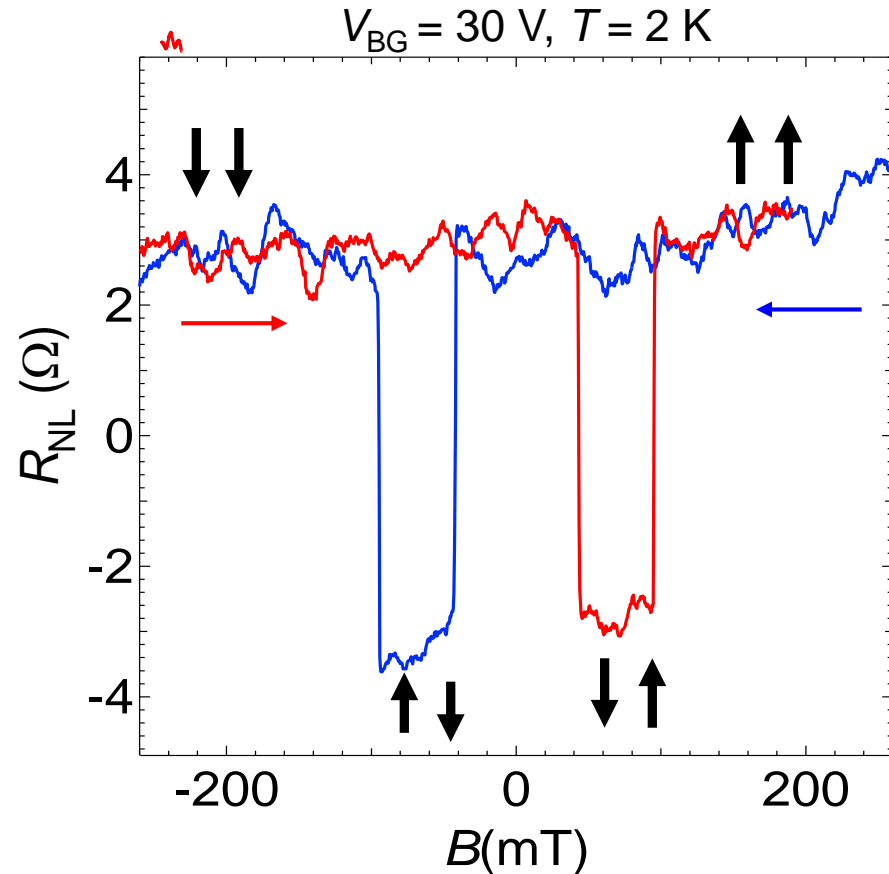
# Graphene single QD



# Nonlocal Magnetoresistance



FM/Graphene/FM  
Spin valve



Without barrier

# Development of novel organic devices based on electronic correlation

Functions peculiar to Strongly correlated material is applied to organic electronics, aiming at high efficiency flexible devices



Realization of two types of “Phase transition transistors using organic materials

- Mott-FET
- Superconducting FET



## Hiroshi Yamamoto (IMR)

### PaperS

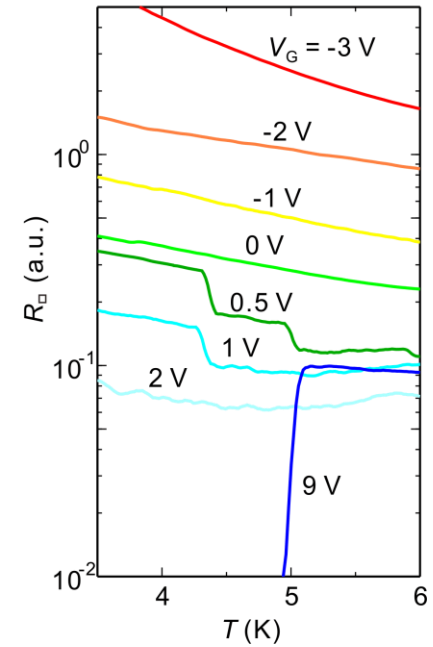
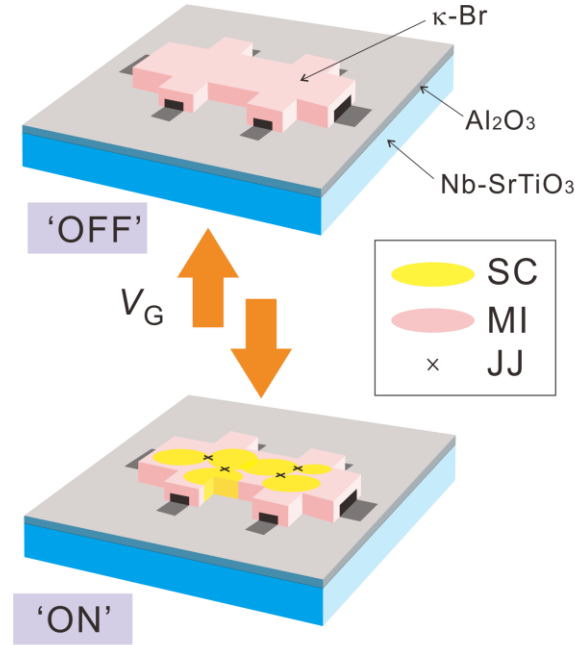
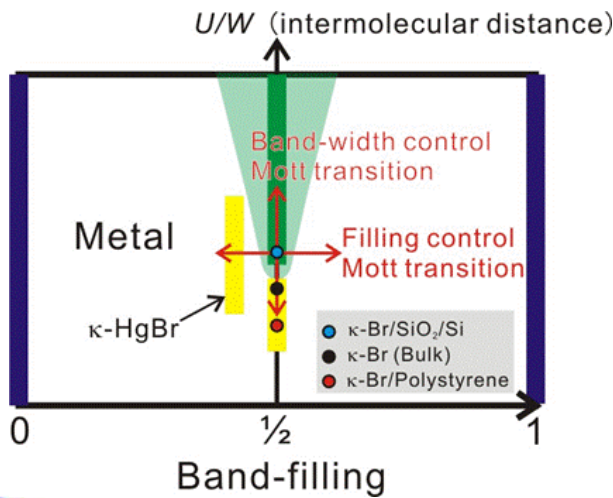
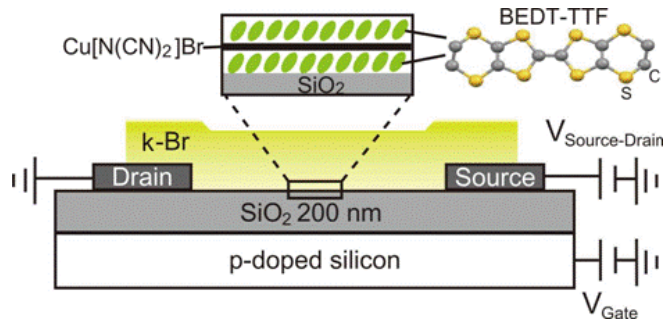
Phys. Rev. **B 84**, 125129 (2011).  
Nature Commun. **3**, 1089 (2012).  
Inorg. Chem. **51**, 11645 (2012).

### Outreach

Review paper for JSAP

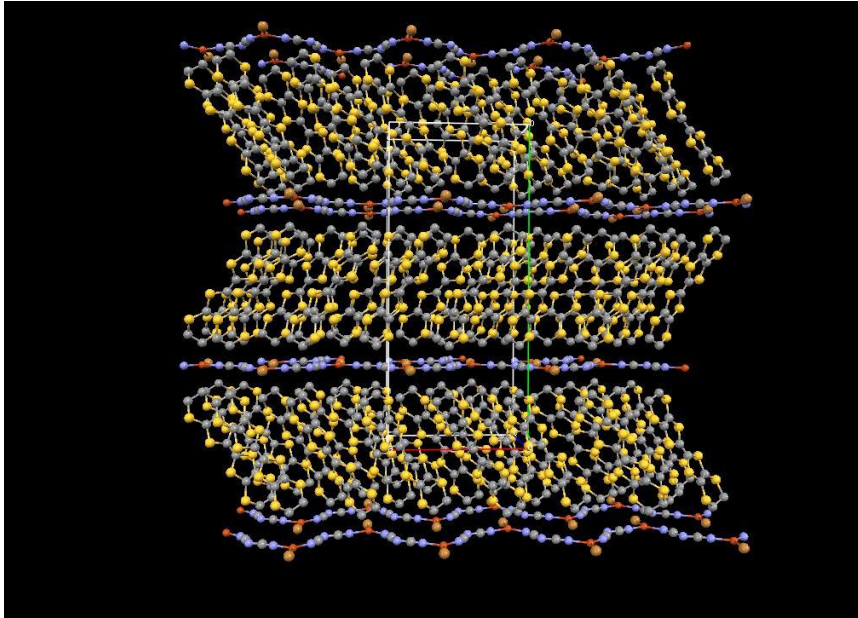


## Dramatic change btw on and off states by gate control

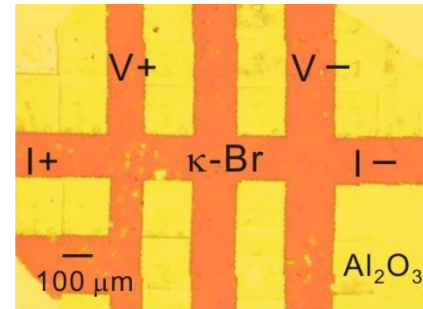
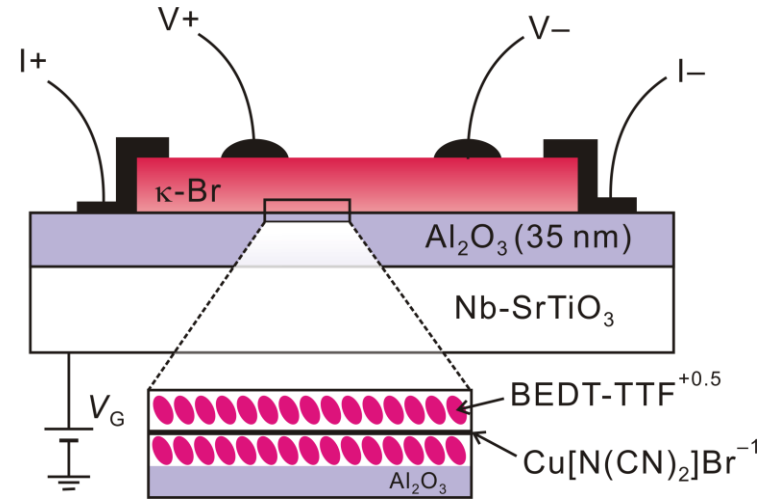


Gate-controlled Josephson junction switching

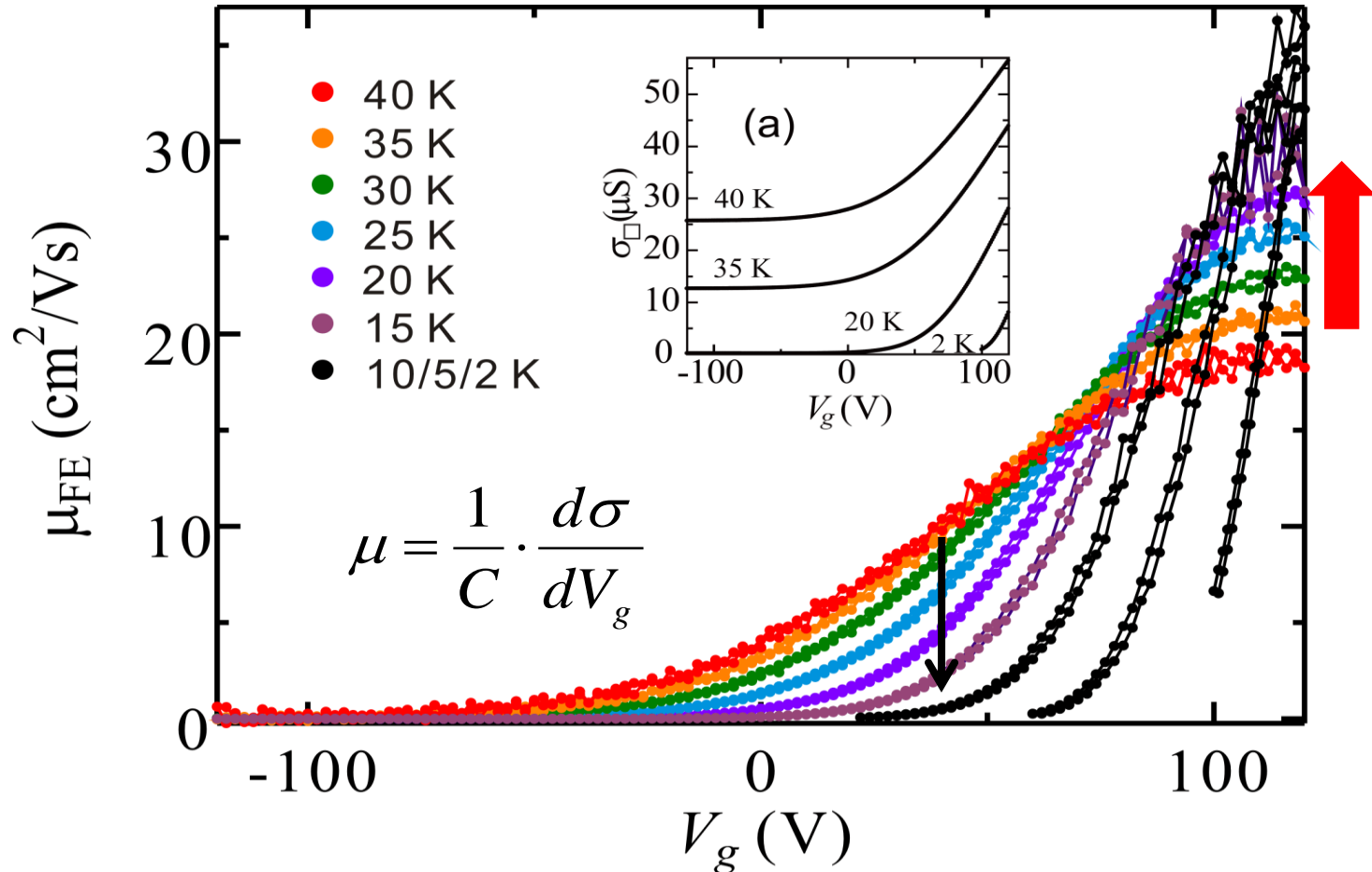
# Organic FET structure



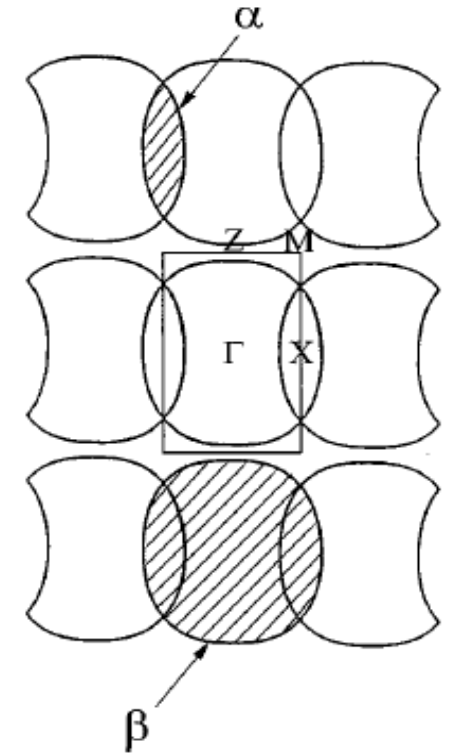
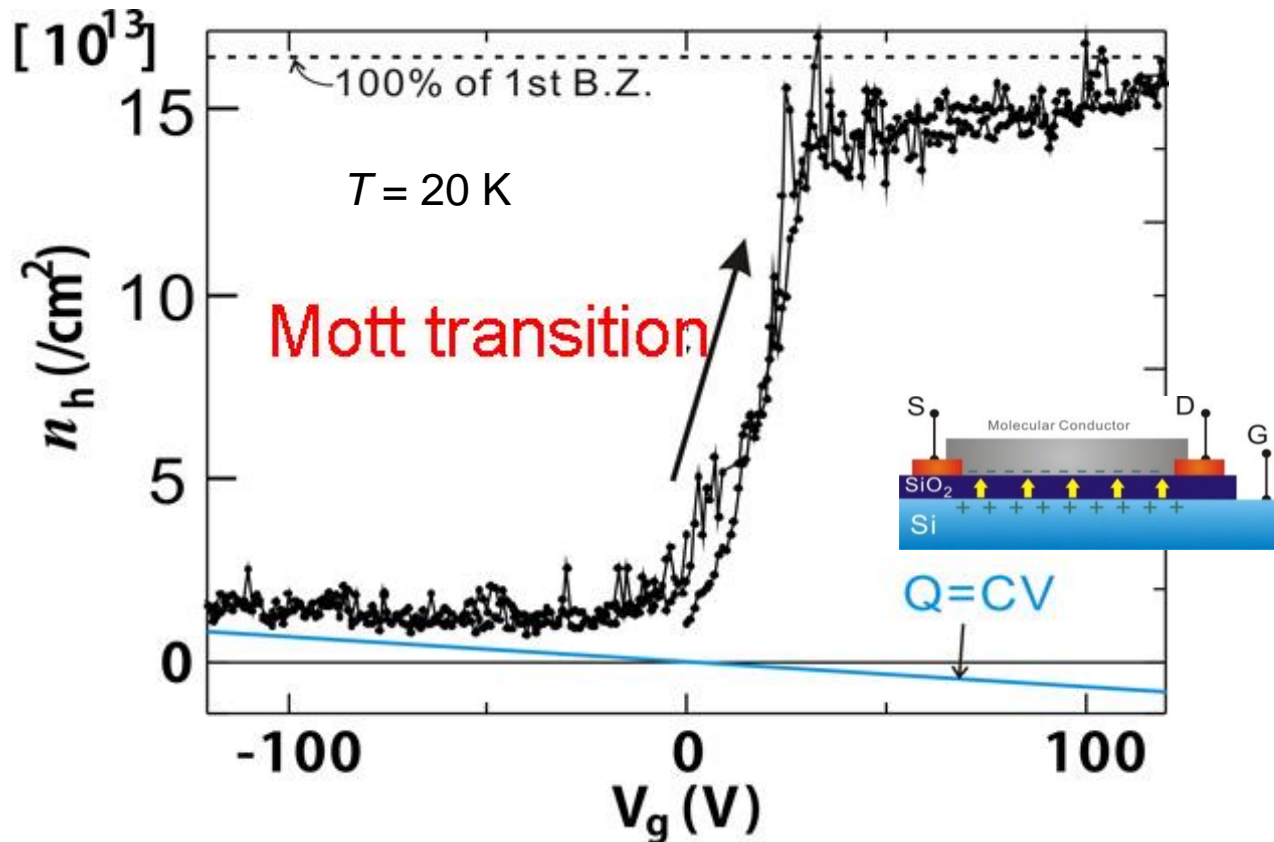
$\kappa$ -Br ( $\text{Cu}[\text{N}(\text{CN})_2]\text{Br}^{-1}$ ) crystal structure



# Temperature dependence of carrier mobility



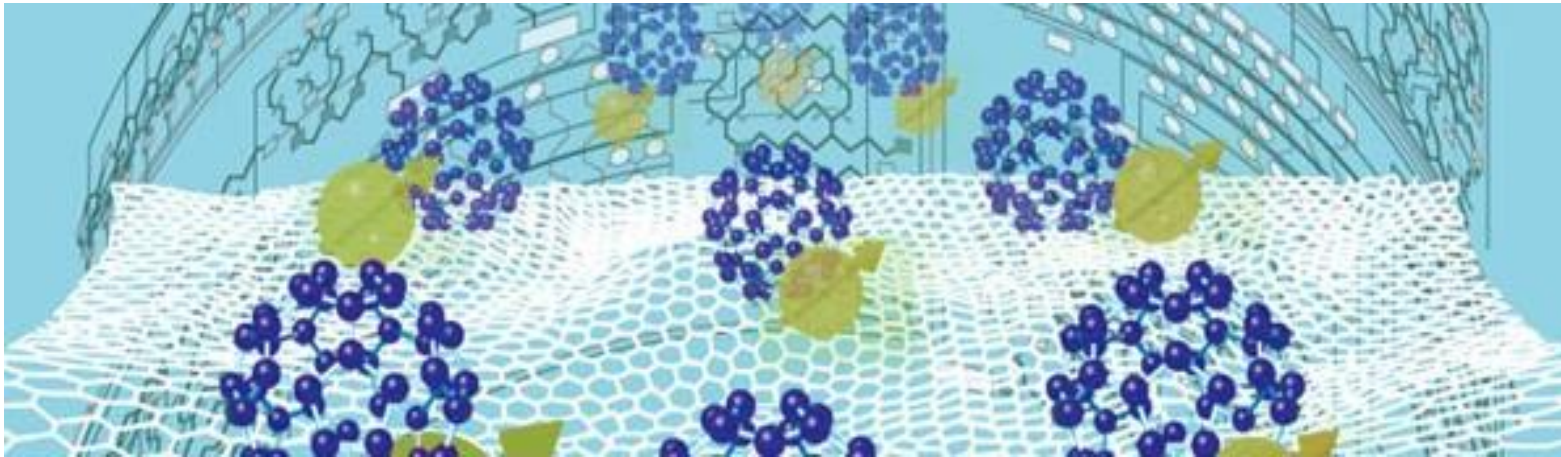
# Gate-voltage dependence of carrier concentration



90% of 1<sup>st</sup> BZ carriers appear by application of gate voltage of 40V assuming 1monolayer active layer

計算より求めた  
 $\kappa$ -Br のフェルミ面





## Products of the Research Project

# Outcomes

(1) Contribution to Scientific Progress, (2) Development to Practical Application, (3) Results for future innovation, (4) Promising challenging technology, (5) Nurture of future scientific leader

## (1) Contribution to Scientific Progress

- Eiji Saitoh: Establishment of Concept of Spin Current in Insulator, Discovery of Spin Seebeck Effect
- Masashi Shiraishi: First Verification of Injection of Pure Spin Current into Graphene, and Graphene-based GMR Device
- Tomoteru Fukumura: Realization of Voltage-Controlled Magnetization Change in  $\text{TiO}_2\text{:Co}$  Room-Temperature Ferromagnetic Semiconductor
- Kohei Hamaya: Establishment of Spin Injection to Nondegenerate Semiconductor Silicon

## (2) Development for Practical Application

- Mitsuru Takenaka : Monolithic Integration of Ge-Channel High Performance MOS Transistor and Ge-Photodetector
- Katsuhiro Tomioka : World Record SS-value of 21mV/dec in Tunnel FET using InAs Nanowires on Si
- Akira Tsukamoto: Elucidation of Ultra-High Speed Light-Induced Magnetization Reversal Mechanism for Next-Generation Magnetic Recording
- Tomoki Machida: High Sensitivity THz Detector Using Graphene Quantum Dot

### (3) Results for future innovation

- Norikazu Mizuochi: Single photon source for quantum information communication which can be operated at Room Temperature using NV center in Diamond LED
- Yasushi Takahashi: Realization of silicon Raman laser using extremely high Q value of photonic crystal
- Suguru Noda: Direct growth of metal-free graphene on quartz using novel etching deposition technique.



## (4) Promising challenging technology,

- Hiroshi Yamamoto: Realization of Phase-Transition Transistors using organic materials
- Yutaka Noguchi: Photosensitive SET (single electron transistor) action using nanogap and gold particle coated by organic molecules and pigments
- Jiro Nishinaga: Introduction of C60 molecules during GaAs growth without defect

## (5) Nurture of future scientific leader

Many scientific leaders have been nurtured from our project

- Six researchers got professorship
- Total of 55 awarded such as Japan Academy Prize, IBM Science Prize, Sir Martin Wood Prize, etc.
- Book of Spintronics is under editing by Eiji Saitoh and K. Sato

# Are our achievements in accordance with the *Strategic Sector* (initial target) provided by MEXT?

## (1) Development of non silicon materials for beyond-CMOS→

**Yes**: Vertical T-FET using InAs nanowire (Tomioka), Ge-n MOSFET and PD(Takenaka), C60 doped GaAs thin film(Nishinaga), polarity-control of GaN (Katayama)...

## (2) Pioneering materials for novel concept-devices by using combined functionalities of photon, electron and spin→

**Yes**: Spin current devices (Saitoh), Quantum information devices using diamond NV-center (Mizuochi), TiO<sub>2</sub>-based room temperature ferromagnetic semiconductors (Fukumura), Heusler alloys with highest spin polarization (Y.Takahashi), Femtosecond magneto-optical recording (Tsukamoto)

## (3) Development of novel devices based on nano-scale fabrication→

**Yes**: Graphene Q-dot (Machida), Nanogap single electron device (Noguchi)...

## (4) Development of thin flexible resilient materials→

**Yes**: Graphene growth on sapphire (Noda), Graphene spintronics (Shiraishi), Heteroacene-based organic semiconductor (Nakano), Electron correlation driven organic FET (Yamamoto)



## JST SATO-PRESTO PROJECT Materials and Processes for Next-Generation Innovative Devices

# How the Project MANAGED?



## Duration and Budgets

- Duration: 3.5 years
- Budget: 40MYen (~400KEuros) per person
- Members: 33 (Total 1.4BYen~14MEuro)
- Average age at adoption: 34.5 years old
- Affiliation: Universities: 25, Government Agencies: 8

For Comparison: Case of Watanabe-CREST

Duration Max 5.5 years

Budget 150-500 M Yen (1.5-5 M Euro) per team

Teams: 18

## “Site-Visit” to individual researcher’s labs

- The **Research Supervisor visits the laboratories of individual researcher’s affiliation** and *grasp research environment and explain to his or her boss about the mission of the Program and ask to allow to conduct an independent research.*
  - This process has an indispensable importance for researcher to conduct researches on a theme independent from the affiliation.
  - Supervisor can conduct careful management in accordance with the situation of the researcher.



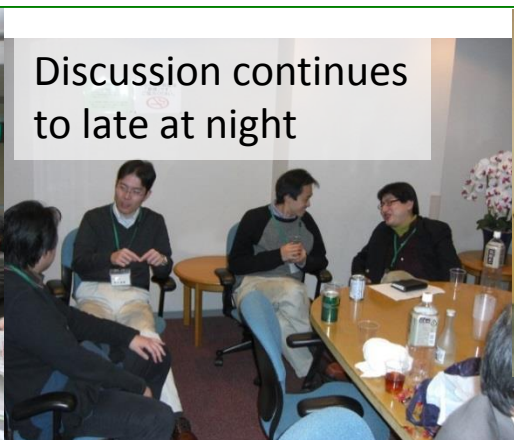
# Research Area Meetings

- JST holds *Research Meetings* sponsored by the Supervisor **twice a year** to discuss the research plan, to report the progress or to promote communication among researchers in the research area.
- Researchers are **very much activated** by joining the Meeting through severe discussion with Supervisor, Advisors and other researchers.
- These research meetings help researchers to build wide personal networks across the organization and position.



Active discussion among  
researchers

Discussion continues  
to late at night



Hot discussion among researchers,  
advisors and supervisor

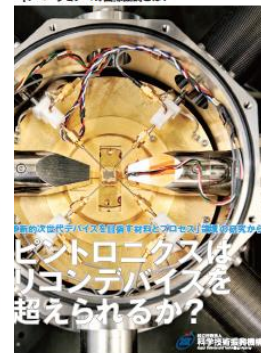


# Publicity of Achievements by JST staffs

- Dept. of Public Relations & Science Portal help Press Release
  - Press releases and press lecture of research achievements are conducted by JST specialist of publicity.
  - JST News, a monthly magazine, introduce the research outcomes
- Science Communication Center send introduction video to Web
  - Science News, a JST Web Animation Site dispatches the contents of researches



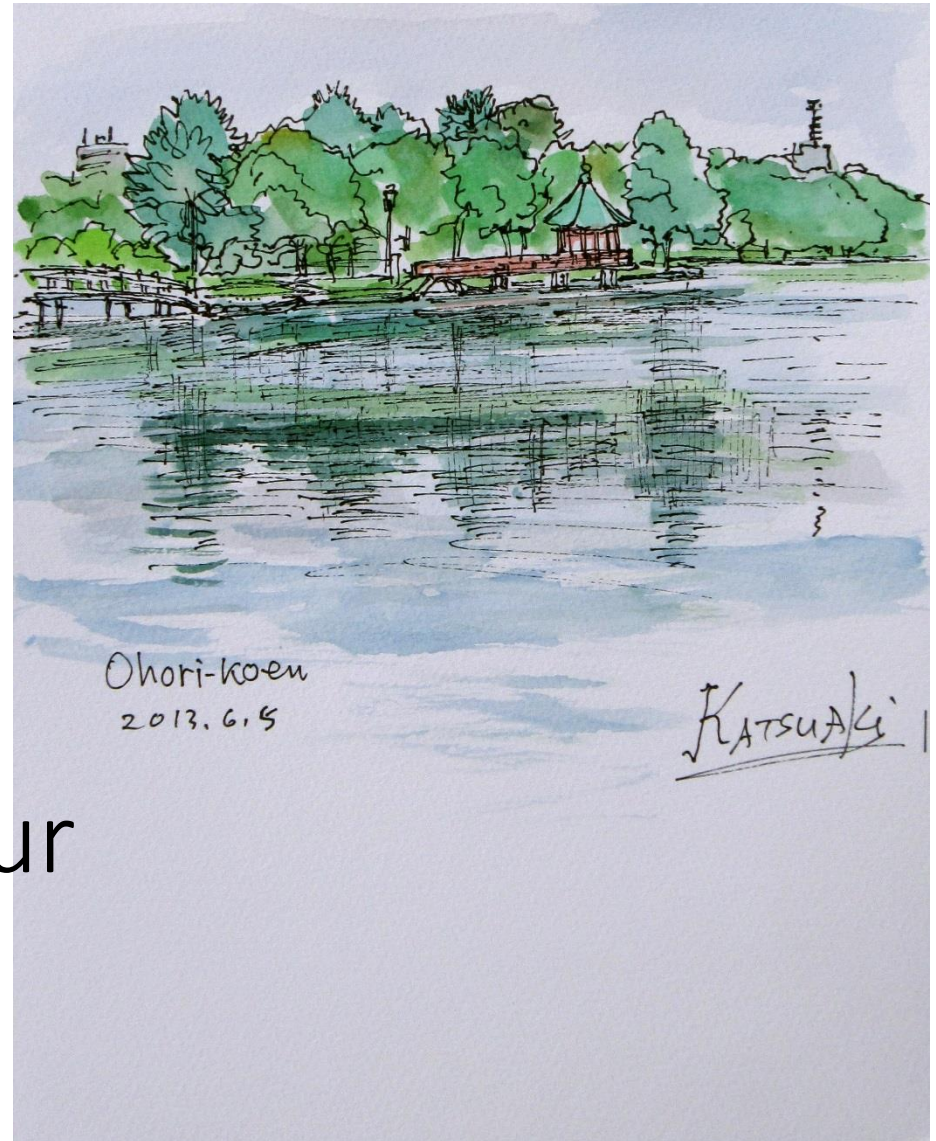
JST NEWS  
Vol.1 2010 June 6





## PRESTO is a unique virtual laboratory to promote young researchers

- Individual Research Themes independent from affiliation
- Reasonable amount of budget
- Flexible managements of research fund
- Acceleration of research by leadership of Supervisor
- Management such as Research Meetings, Site-Visits as Virtual Institute
- Support by Research Office : Research Administrators
- Recommendation to Awards
- Confidence and Aggressive Minds by stimulation by Colleagues
- Interdisciplinary relationship to build wide personal networks across the organization and position.



Thank you for your  
attention

# appendix

# Promotion System of S & T Policy in Japan

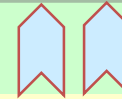
Cabinet  
Office

**Prime Minister**

Consultation



Response



Opinion

## Council for Science & Technology Policy (CSTP)

### *Member:*

- Prime Minister (Chair)
- 6 Ministers
- 8 Executive members
  - Academia: 6
  - Industry: 2

### *Mission:*

- 1) Investigations and deliberations on basic policies of S&T
- 2) Investigations and deliberations on the resource allocation in S&T policy
- 3) Evaluations of nationally important R&D



Consultation



Response



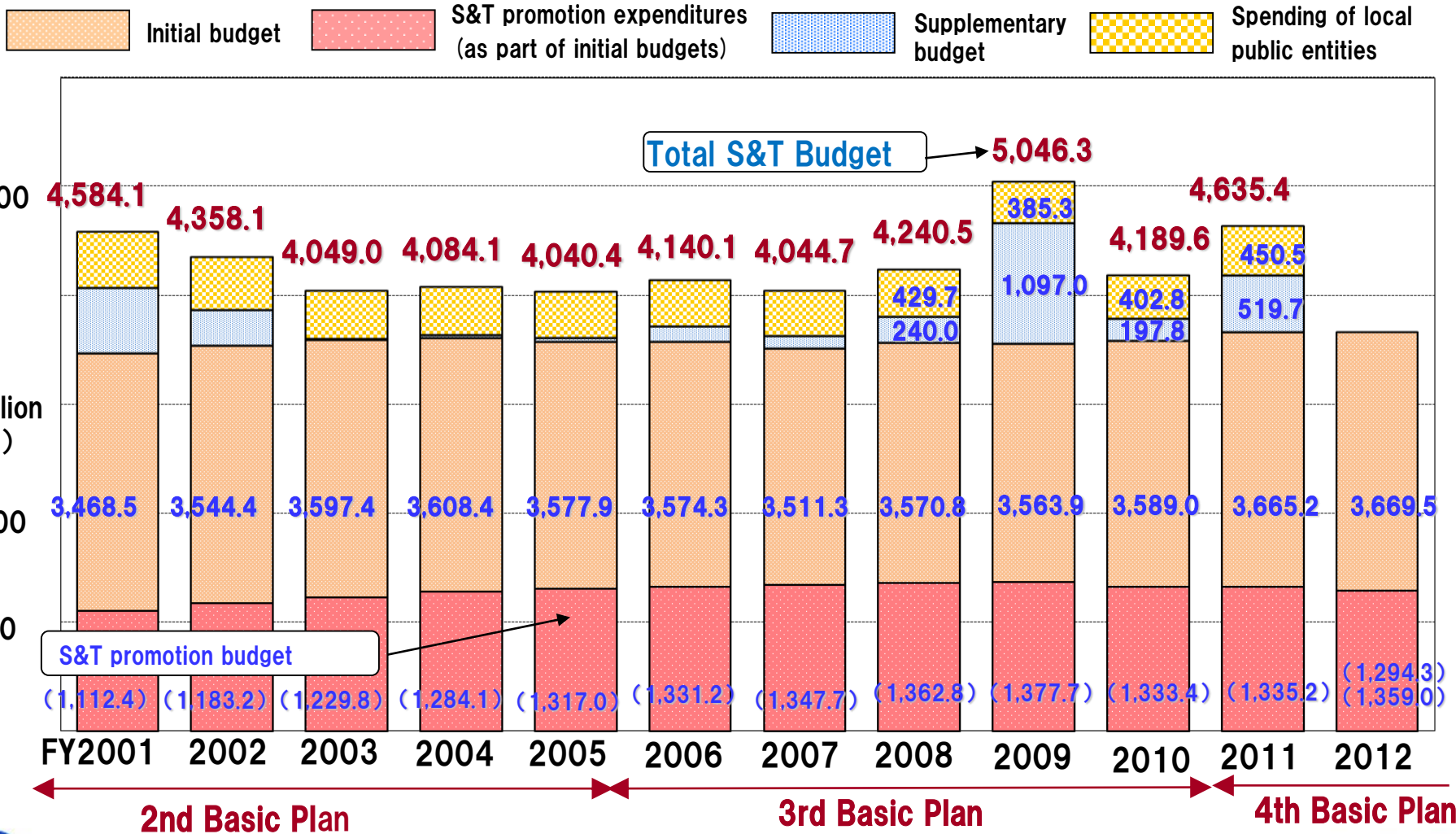
Opinion

## Relevant Ministries and Agencies

- Internal Affairs and Communications (IAC)
- Health, Labor and Welfare (MOH)
- **Economy, Trade and Industry (METI)**
- Environment (MOE)
- **Education, Culture, Sports, S&T (MEXT)**
- Agriculture, Forestry and Fisheries (MAFF)
- Land, Infrastructure and Transport (MLIT)



# Japanese Government S&T Budget



## Strategic Sector (Target of Research)

- Center of R&D Strategy (CRDS), a *think-tank* of JST, works out proposals through survey S&T fields, by drawing "bird's-eye view maps", and by listing up important R&D subjects  
→ MEXT designates **Strategic Sectors** using the proposals as well as those from other government sections including those of CSTP



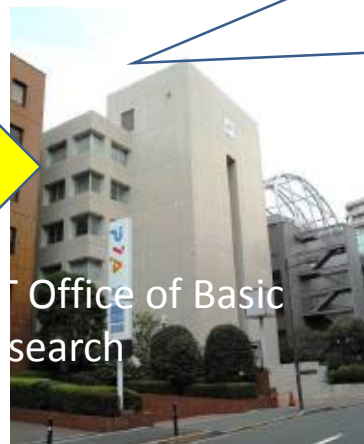
## Research Areas based on the Strategic Sector

- Based on strategic sectors, JST establishes research areas.
  - My case :  
Strategic Sector is “R & D for beyond-CMOS Devices”  
Designated Project Name is  
“Materials and Processes for Next-Generation Innovative Devices”

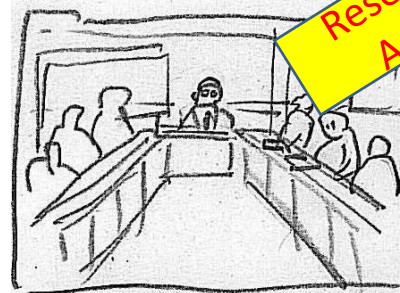


MEXT

Strategic  
Sectors



Office of Basic  
Research



PD Meeting

Research  
Areas



## Research Office

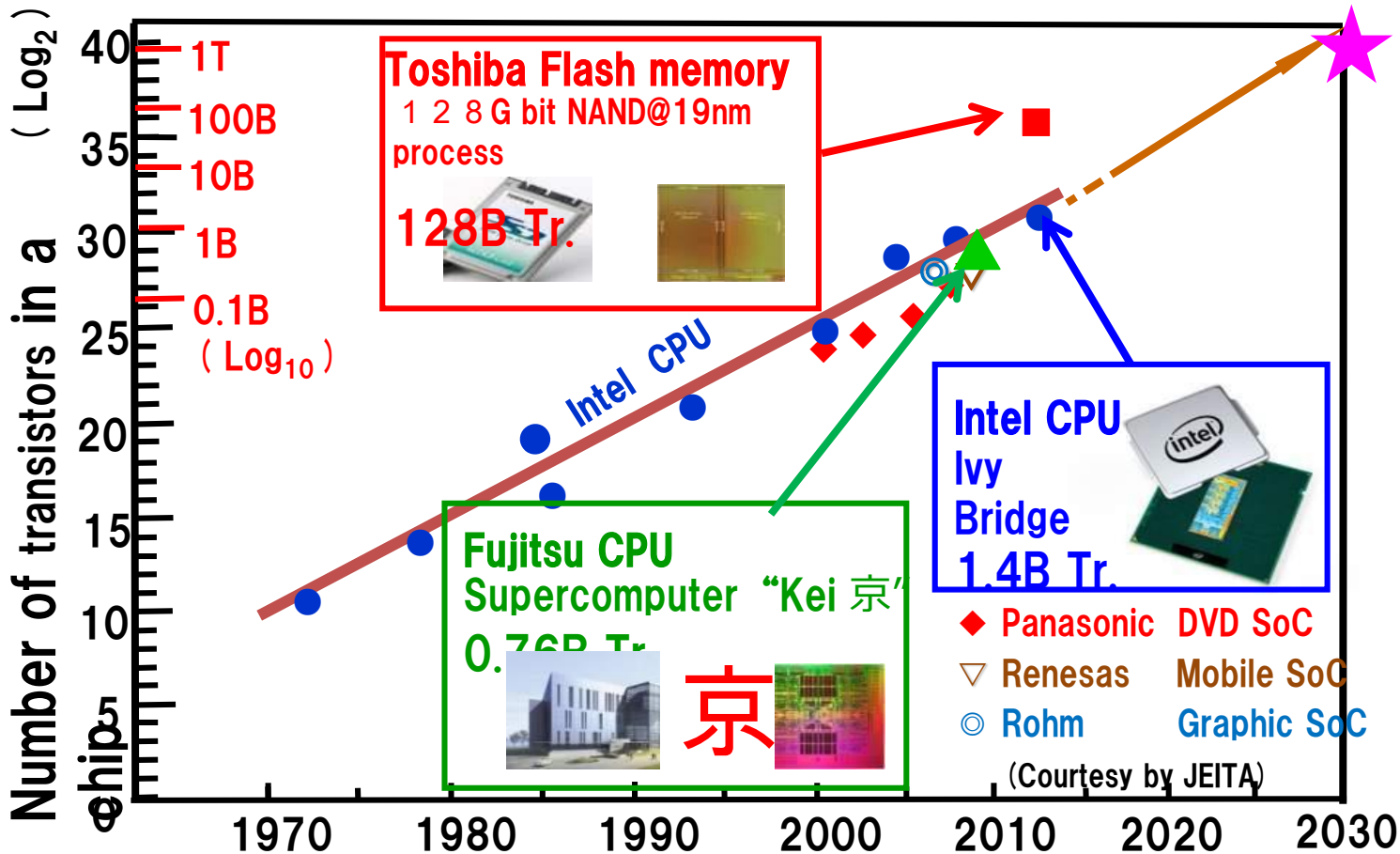
- Research offices are established for each research area and take daily care of researches under the guidance of Supervisors.
- Research managers (who coordinate the research, determine research progress and give support for presentations), administrative managers (who purchase equipment and materials and deal with procedures for business trips) and office staffs are stationed in all research offices.





# Demand for more integration : Moore's Law

Intel CPU plots, except Ivy Bridge, are shown in [http://www.intel.com/jp/technology/mooreslaw/index.htm?iid=jplIntel\\_tl+moores\\_law](http://www.intel.com/jp/technology/mooreslaw/index.htm?iid=jplIntel_tl+moores_law)



# Demand for more miniaturization

