

Experience feedback from Tohoku University researchers - HARFIR project -

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Institute for Materials Research, Tohoku University



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Outline



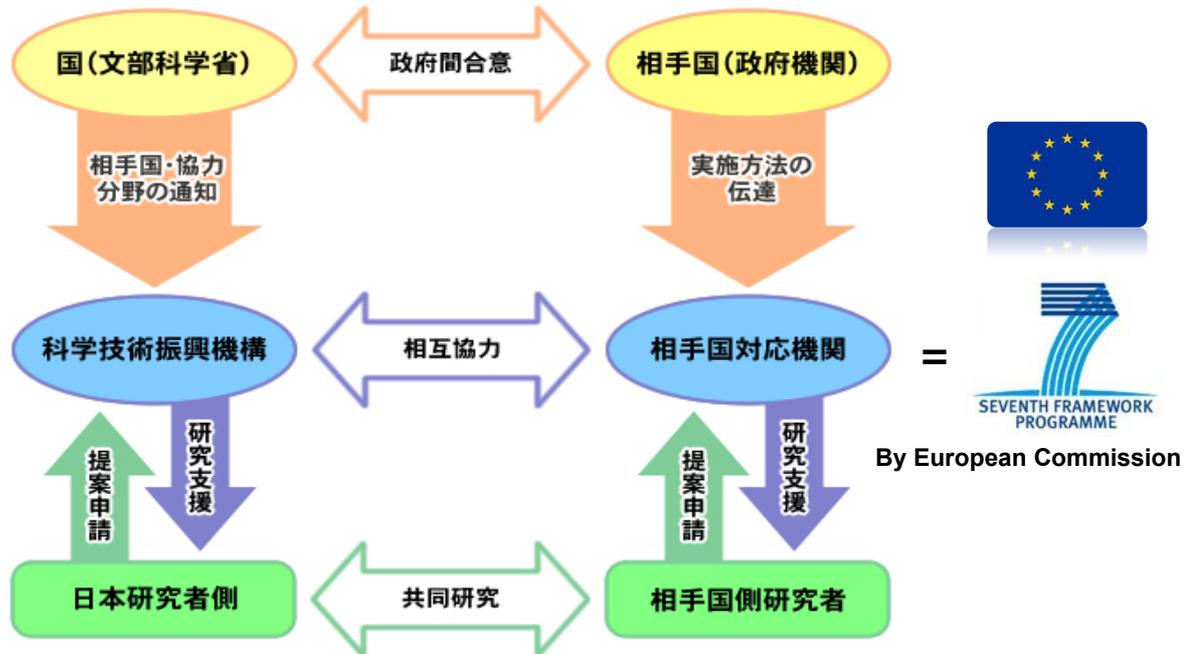
HARFIR:
Heusler Alloy Replacement For Iridium (Ir)

- Partners & Objective
 - Project outline & Partners
 - Background: the scarcest element, Iridium
 - Iridium for Spintronics
- Achievements
 - Collaboration
 - Workshop & Social communication
- Summary

JST SICORP-EU Project



SICORP: Strategic International Collaborative Research Program
 国際科学技術共同研究推進事業(戦略的国際共同研究プログラム)



EUの研究グループとの相乗効果により優れた研究成果を世界へと発信することを目指す

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Partners



TOHOKU
UNIVERSITY

Tohoku Univ.

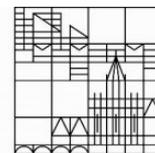


The Univ. of York



The Univ. of Bielefeld

Universität
Konstanz



The Univ. of Konstanz



KEK



Budapest Univ. of Technology and Economics



Mackintosh Consultants

Project Period: 3.5 years (2013.9 – 2017.3)

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Collaborators



**Institute for Materials Research (IMR),
Tohoku University**

Prof. Koki Takanashi (JP Leader)
Assist. Prof. Takahide Kubota
Tomoki Tsuchiya (Ph.D. Student)
Tomoko Sugiyama (Technical staff)



University of York (UK)

Prof. Atsufumi Hirohata (EU Leader)
Prof. Kevin O'Grady

Universität Bielefeld (Germany)

Prof. Günter Reiss

Universität Konstanz (Germany)

Prof. Ulrich Nowak

Budapest University (Hungary)

Prof. Laszlo Szunyogh

Mackintosh Consultants (UK)

Dr. Nigel Mackintosh

**High Energy Accelerator Research Organization
(KEK)**

Assoc. Prof. Kanta Ono
Assist. Prof. Nobuhito Inami
Dr. Kotaro Saitoh
Dr. Tetsuro Ueno



Universität
Konstanz



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Work Packages and Partners



WP6 : Device concept and evaluation
Bielefeld / York / Tohoku
TMR / GMR / GMR



WP2 : Alloy selection and growth
York / Bielefeld / Tohoku
polycrystalline / epitaxial / epitaxial
antiferromagnet / ferrimagnet / antiferromagnet



WP3 :
Alloy modeling
Konstanz / Budapest
exchange / atomistic

WP4 :
Structural studies
York / Bielefeld / KEK
TEM / XMLD / XMCD, PNR

**WP5 : Magnetic and
electrical studies**
York / Bielefeld / Tohoku
York model / VSM / Resistivity

WP1 : Financial and administrative management
WP7 : Dissemination and exploitation
MACK / York / Tohoku / Bielefeld / Konstanz / Budapest / KEK

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IMR, Tohoku Univ.

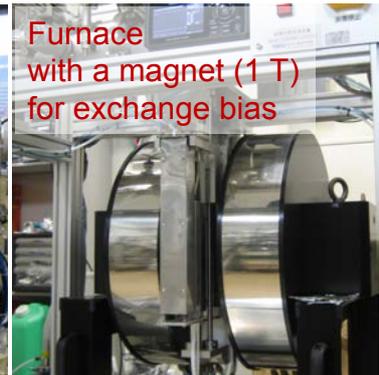
- **Epitaxial films**

by UHV sputtering

- Basic characterization (structure, transport, magnetic)



UHV Sputtering system for epitaxial-films



Furnace with a magnet (1 T) for exchange bias

KEK

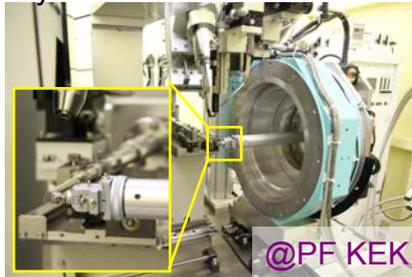


- **Advanced characterization**

Neutron diffraction

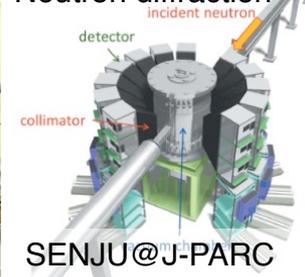
Synchrotron XRD, XMCD

Synchrotron XRD



@PF KEK

Neutron diffraction



SENJU@J-PARC

High-quality samples & Advanced characterization & collaboration with EU partners 7

The Scarcest Material: Iridium, Ir



PRODUCED BY THE FOUNDATION FOR EDUCATION, SCIENCE AND TECHNOLOGY FOR NATIONAL SET WEEK 2002

PERIODIC TABLE of the ELEMENTS

DEPARTMENT OF SCIENCE, UNIVERSITY OF TORONTO

SPONSORED BY THE SHUTTLEWORTH FOUNDATION

Ir
Iridium 77
192.22

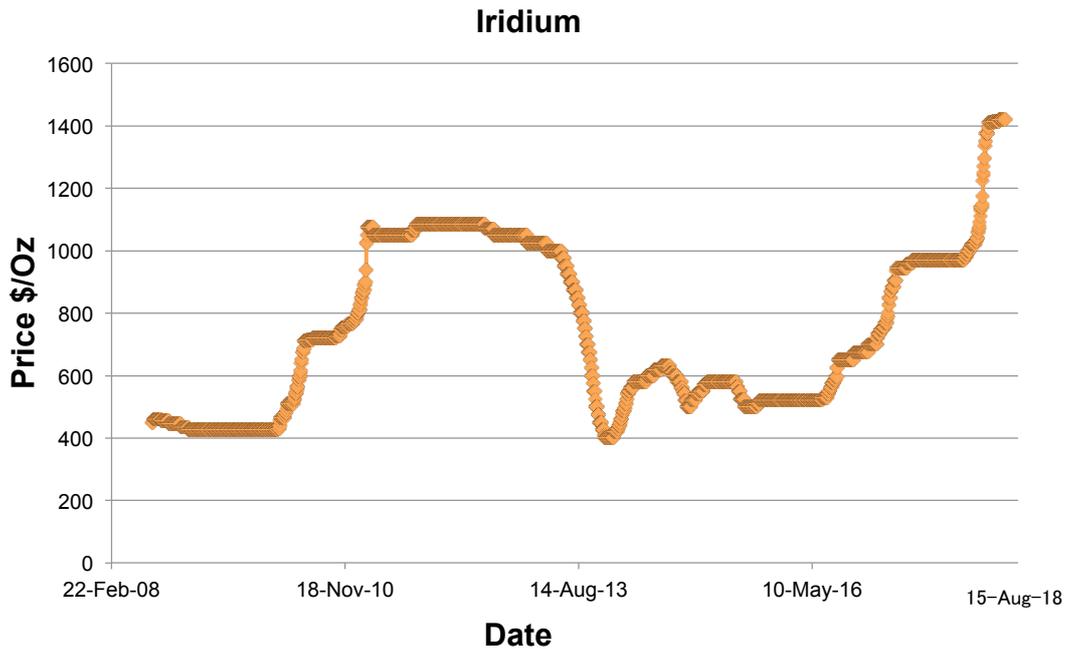
- Melting point : > 3,000°C
→ **Very stable**
- Almost no applications previously
- World supply : ~ 5.8 t / yr
→ 87 % from South Africa
- 1 ~ 2 % in Pt and Rh ore
- **The scarcest element**
→ 4×10^{-4} ppm

Comparisons

Nd	33 ppm
Li	17 ppm
Dy	6.2 ppm
Pt	3.7×10^{-3} ppm
Au	3.1×10^{-3} ppm
Ru	1×10^{-3} ppm

* <http://www.atheistfrontier.com/people/dmitri-mendeleev/periodic-table-of-the-elements-for-kids.jpg>

Iridium Price



Price is increasing (> x3 in 10 years) with large fluctuation :

<http://www.platinum.matthey.com/prices/>

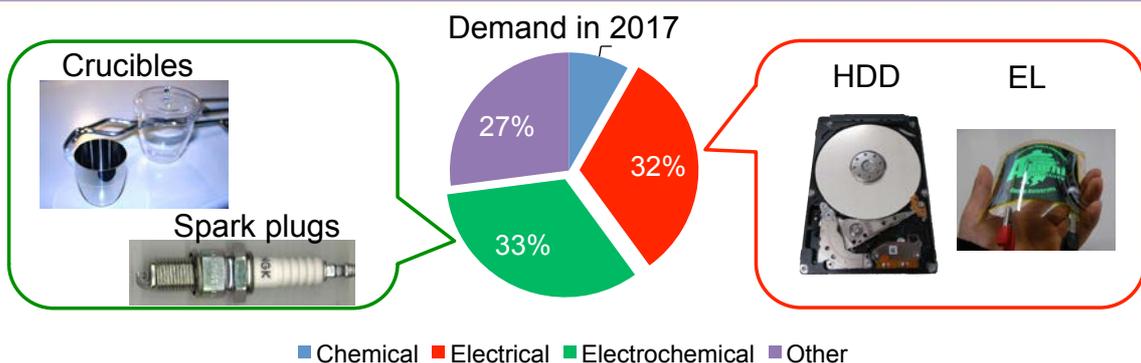
Demand for Iridium



<http://www.platinum.matthey.com>

Increasing demand in crucible applications :

		IRIDIUM Tonnes - Demand					
		2013	2014	2015	2016	2017	2018
		2018 numbers are a forecast					
Demand	Chemical	0.7	0.7	0.7	0.7	0.7	0.7
	Electrical	1.1	1.5	2.8	3.5	2.7	2.1
	Electrochemical	1.3	1.2	1.3	1.8	2.8	1.8
	Other	2.1	2.2	2.4	2.5	2.3	2.5
	Total Demand	5.2	5.6	7.2	8.5	8.5	7.1

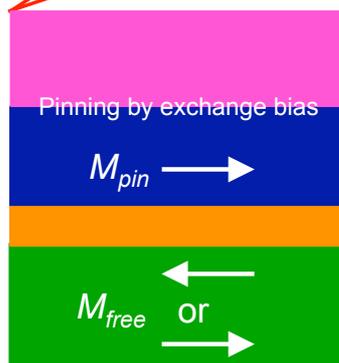
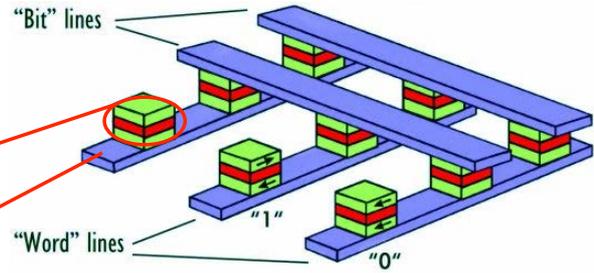


Iridium Alloy for Spintronics

HDD read head :



Magnetic random access memory (MRAM) :



Spin-valve structure

Antiferromagnet
Pinned ferromagnet
Non-magnet
Free ferromagnet

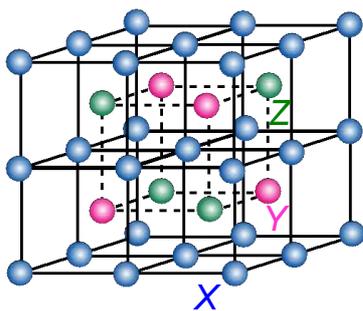
Current → IrMn

- Large exchange bias (> 3.5 kOe)
- Low set temperature (~ 250°C)
- Thin-film form (~ 6 nm)

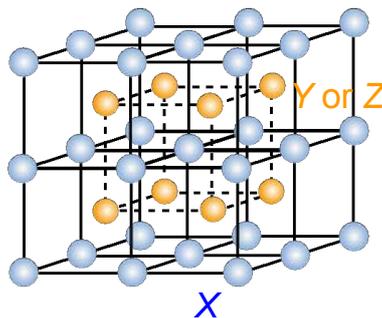
Replacement with a Heusler alloy

Three Phases for Heusler Alloys

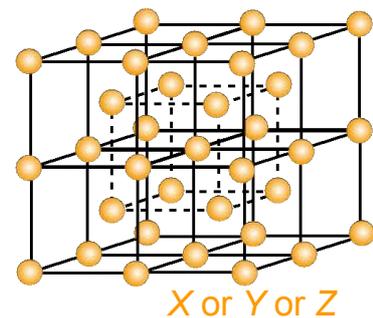
$L2_1$ phase

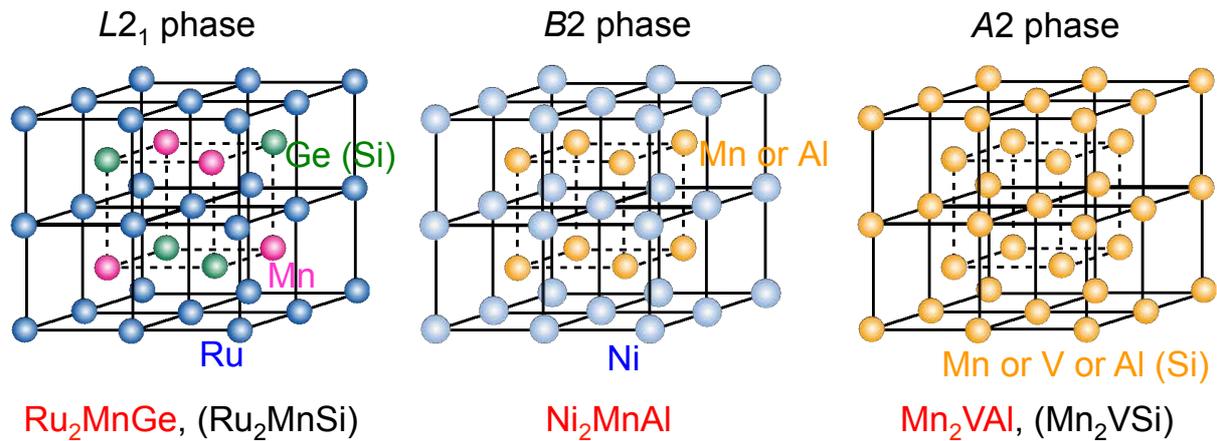


$B2$ phase



$A2$ phase





Films by WP2

Bielefeld

Tohoku & York

Tohoku (& York)

- One material for each phase has been studied for HARFIR.
- JP-consortium has worked on **B2-type** and **A2-type** alloys.

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Antiferromagnetic Heusler alloys: **Before** HARFIR

	L2 ₁	B2	A2
Material	Ru ₂ MnGe	Ni ₂ MnAl	?
Néel temp. T _N (K)	316	313	?
Exchange bias J _k (erg/cm ²)	0.025	? (H _{ex} : 35 Oe@LT)	?
Blocking temp. T _B (K)	?	?	?



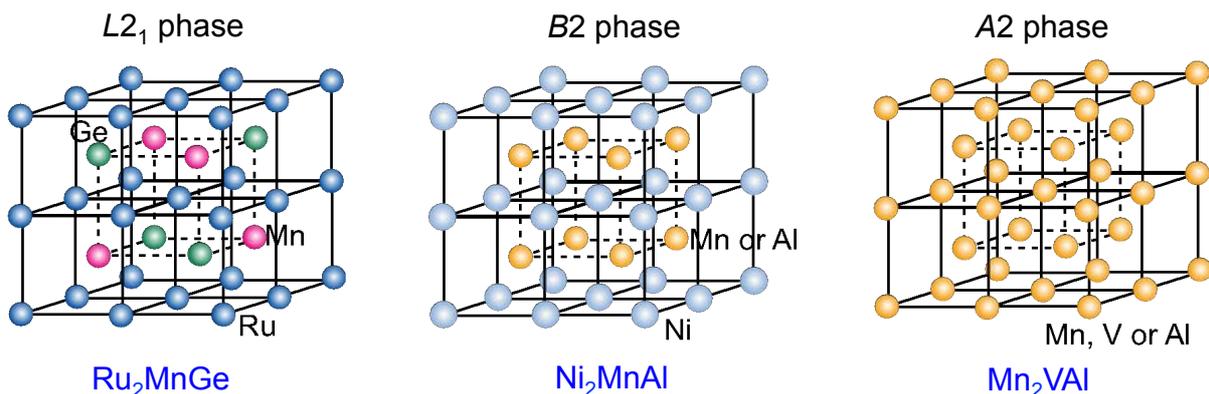
- Mechanism for antiferromagnetism in Heusler alloys?
- Guiding principle for a large exchange bias at room temp. using antiferromagnetic Heusler alloys?

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	$L2_1$	$B2$	$A2$
Material	Ru_2MnGe	Ni_2MnAl	Mn_2VAI
Néel temp. T_N (K)	316	313 ~ 300 (film)	500 – 600 (bulk) ~ 560 K (film)
Exchange bias J_k (erg/cm ²)	0.24 (H_{ex} : 600 Oe)	0.04 (H_{ex} : 90 Oe)	0.07 (H_{ex} : 120 Oe)
Blocking temp. T_B^{max} (K)	126	100	~300

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HARFIR Achievements

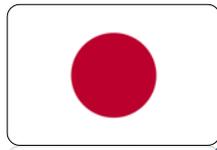


- ✓ The comprehensive study on exchange bias using Heusler alloys antiferromagnets with $L2_1$, $B2$ and $A2$ phases
- ✓ *Enhanced blocking temperature using newly developed Heusler alloy antiferromagnet, Mn_2VAI*

*Heusler alloy antiferromagnets with **ubiquitous elements** are developed for Iridium-free-spintronic devices*

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Students' Exchange



- Sample Fabrication
 - Advanced characterization with the synchrotron facility
 - Advanced characterization with TEM facility
 - Specialists for *ab initio* study & large-scale simulation
 - Established know-how for the blocking temperature evaluation
- Four PhD students completed thesis (Tohoku, Bielefeld, York)*

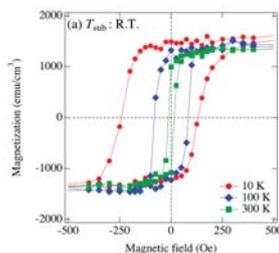
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Student's Exchange from JP to EU



A case for a PhD Student...

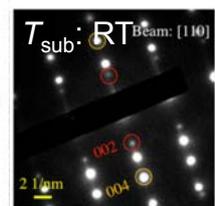
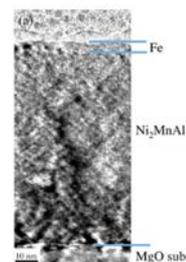
Total 186 days in EU groups*



- Samples fabrication
- Basic characterizations

*Including the period after HARIR

PhD thesis



- Advanced TEM studies

→ J. Phys. D: Appl. Phys. **49**, 235001 (2016).
Joint-paper by Tohoku & York



Universität
Konstanz



- Theoretical studies for the samples

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Extended Activity by Students



Joint International Seminar
organized by students

- 2 Special lecture
by senior professors
- 5 invited talks
by young professors
- 11 talks by students
& a poster session
- Approx. 40 participants

Organized by Students of Graduate Program in Spintronics
2016 Tohoku University and University of York Joint Seminar :



Prospect of Future Spintronics

~ from physics to devices ~

2016 Aug. **29-30** | Sakura Hall, 2F, Conference Room, Katahira Campus, Tohoku Univ.

Program

Aug. 29 (Mon)	Aug. 30 (Tue)
Opening Address 9:10 - 9:30	Session5 9:30 - 10:40 Magnetoresistance
Session1 9:30 - 10:40 Spin Dynamics	Special Lecture 2 11:00 - 12:00 "All-optical helicity-dependent switching in magnetic nano-structures and devices"
Special Lecture 1 11:00 - 12:00 "Nano Spintronics "	Session6 13:30 - 14:40 Spin Orbit Interactions
Session2 14:00 - 15:25 Antiferromagnetic Materials	
Session3 15:40 - 16:50 Semiconductor Spintronics	
Session4 16:50 - 17:50, 19:00 - 20:00 Poster Sessions	

Invited speakers

Yoshichika Otani (Special Lecture 1) (The Univ. of Tokyo)	Stephane Mangin (Special Lecture 2) (Univ. de Lorraine)
Atsufumi Hirohata (Univ. of York)	Makoto Kohda (Tohoku Univ.)
Shun Kanai (Tohoku Univ.)	Ken-ichi Uchida (Tohoku Univ.)
	Takahide Kubota (Tohoku Univ.)

Access and Contact



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2-1-1
Katahira, Aoba-ku,
Sendai JAPAN
980-8577

Contact Us
joint2016@ml.tohoku.ac.jp

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Symposia and Workshops



Total, 6 open Symposia&workshops

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25 internal meeting and...



May 2016, Konstanz



Nov 2015, Tsukuba

A few social events

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Statics

- 3 *joint* journal articles (during 3.5-year-pj-period)
*11 articles in total & 4 articles, after the pj-period
- 3 *joint* popularization articles
- 7 *joint* presentation at international conference
*89 presentations including 18 invited talks
- 6 open Symposia and workshops
- 25 internal joint meeting
- Exchange:
270 person-days from JP to EU, 184 person-days from EU to JP
- Project Website: <http://www.harfir.eu/>

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- Project Period: preferred ~ 5 years or longer
- Scheme for *Extension* may be necessary
- Joint system for administrative work
e.g. Similar 2 – 3 documents have been submitted to both JST & EC