9. Superconducting Properties of FeSe and FeTe

Yoshihiko Takano[1,2,3]

[1]National Institute for Materials Science, 1-2-1, Sengen, Tsukuba, 305-0047, Japan
[2]University of Tsukuba, 1-1-1, Tennodai, Tsukuba, 305-8577, Japan
[3]JST, TRIP, 1-2-1, Sengen, Tsukuba, 305-0047, Japan

Soon after the discovery of iron based superconductor LaFeAsO1-xFx with the superconducting transition temperature of Tc=26K by Kamihara et al., superconductivity in PbO-type FeSe at 8K was reported. The FeSe layer is analogous to the FeAs layer, which implies that FeSe has the simplest crystal structure in the iron-based superconductors. FeSe samples were prepared using the solid-state reaction in the quartz tube. The structural phase transition from tetragonal to orthorhombic was observed by high-resolution synchrotron X-ray diffraction. We observed the extremely huge pressure effect of the superconducting transition temperature. Surprisingly, the superconducting transition temperature Tc raised from13K to 27K at 1.48GPa. The Tc also raised by the substitution of Se by Te. However, FeTe is not superconducting. Recently we have succeeded to realize superconductivity in FeTe by S doping. Superconducting transition temperature is around 10K and upper critical field is estimated to be 70T. This result suggest that all of FeAs, FeP, FeSe, FeTe layers have potential of superconductivity. We will also report the valence band photoemission spectra and NMR measurements of FeSe. We think that the detailed investigation of FeSe and FeTe system will provide us the clues to understand the mechanism of superconductivity in iron-based superconductors.

References

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[2] Y. Mizuguchi, F. Tomioka, S. Tsuda, T. Yamaguchi and Y. Takano, Appl. Phys. Lett. 93, 152505 (2008)
[3] S. Margadonna, Y. Takabayashi, M. T. McDonald, K. Kasperkiewicz, Y. Mizuguchi, Y. Takano, A. N. Fitch, E. Suard and K. Prassides, Chem. Commn. 5607-5609 (2008).
[4] H. Kotegawa, S. Masaki, Y. Awai, H. Tou, Y. Mizuguchi and Y. Takano, J. Phys. Soc. Jpn., 77, 113703 (2008).
[5] Y. Mizuguchi, F. Tomioka, S. Tsuda, T. Yamaguchi and Y. Takano, cond-mat:0811.1123.
[6] Y. Mizuguchi, F. Tomioka, S. Tsuda, T. Yamaguchi, Y. Takano, cond-mat:0811.0711. (APL in printing)

Superconducting Properties of FeSe and FeTe

Yoshihiko Takano
National Institute for Materials Science (NIMS)
Nano Frontier Materials Group

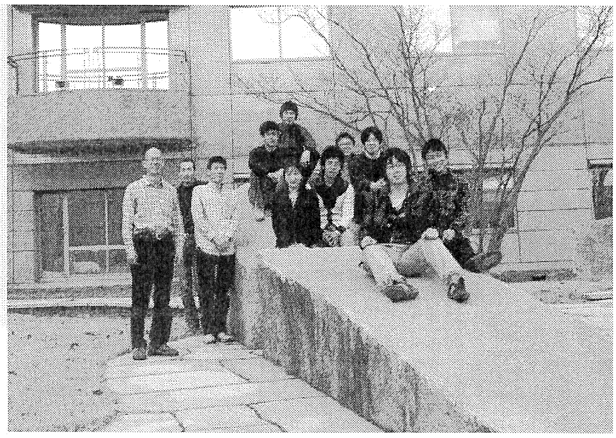
PES: Okayama University, T. Yokoya Group
NMR: Kobe University, H. Tou Group

Group members:

山口　尚秀	Staff
津田　俊輔	Staff-MANA
石井　　聡	PD
冨岡　史明	PD
久保　結丸	D3
水口　佳一	D1
小河原昭吾	M1
渡邊　　徹	M1
出口　啓太	B4
黒川みどり	Secretary

IRiSes2009

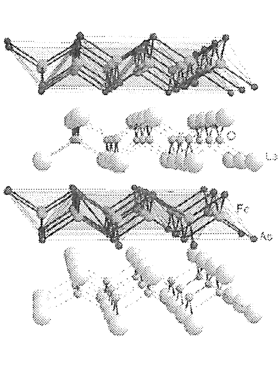
January 25, 2009, Ueno, Tokyo, Japan



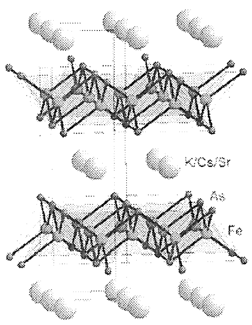
Crystal structures of Fe-based superconductors

Y.Kamihara et al.

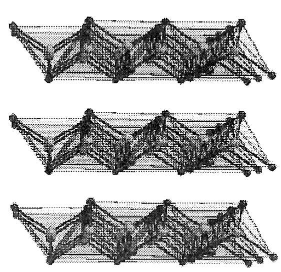
Simplest structure



LaFeAsO



$BaFe_2As_2$



FeSe

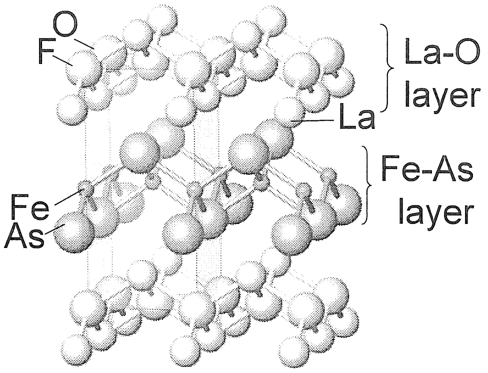
G. Hägg and A. L. Kindstrom, Z. Phys. Chem. 22, 455 (1933).
F. C. Hsu and M. K. Wu *et al*., Proc. Nat. Acad. Sci. 105, 14262 (2008).

Introduction for iron-based superconductor

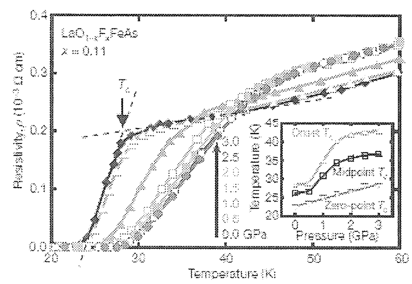
ZrCuSiAs-type structure

$LaFeAsO_{1-x}F_x$ (T_c = 26 K)[1]

$NdFeAsO_{1-\delta}$ (T_c = 54 K)[2]



Huge pressure effect



T_c increased to 43 K under high pressure.[4]

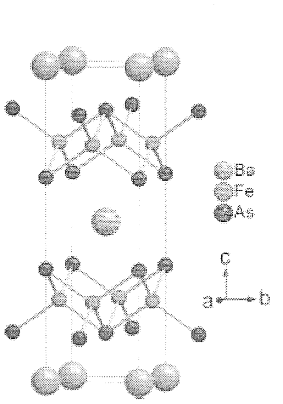
[1] Y. Kamihara *et al.*, *J. Am. Chem. Soc.* **130**, 3296 (2008).
[2] H. Kito *et al.*, *J. Phys. Soc. Jpn.* **77**, 063707 (2008).
[3] S. Matsuishi *et al.*, *cond-mat*:0810.2351.
[4] H. Takahashi *et al.*, *nature (London)* **453**, 376 (2008).

Introduction for iron-based superconductor

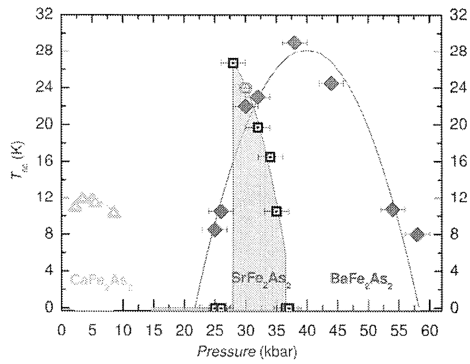
$ThCr_2Si_2$-type structure

$Ba_{1-x}K_xFe_2As_2$ (T_c = 38 K)[5]

$Ba(Fe_{1-x}Co_x)_2As_2$ (T_c = 22 K)[6]



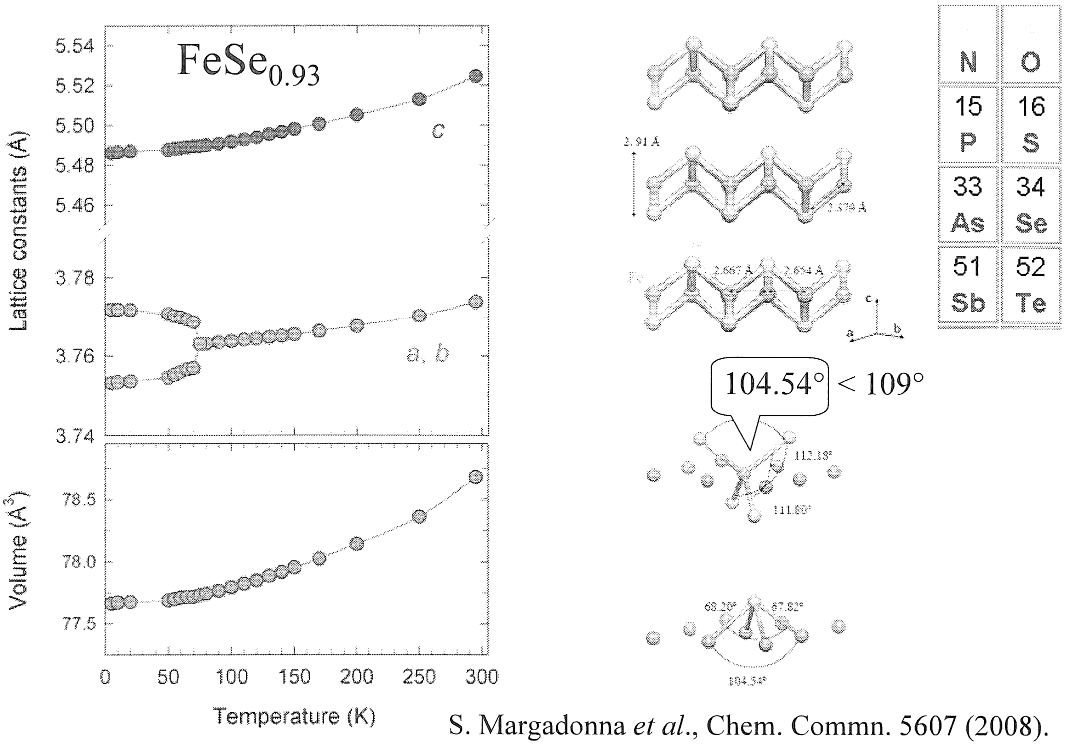
Pressure induced SC



Parent compound shows superconductivity under high pressure without carrier doping.[7,8]

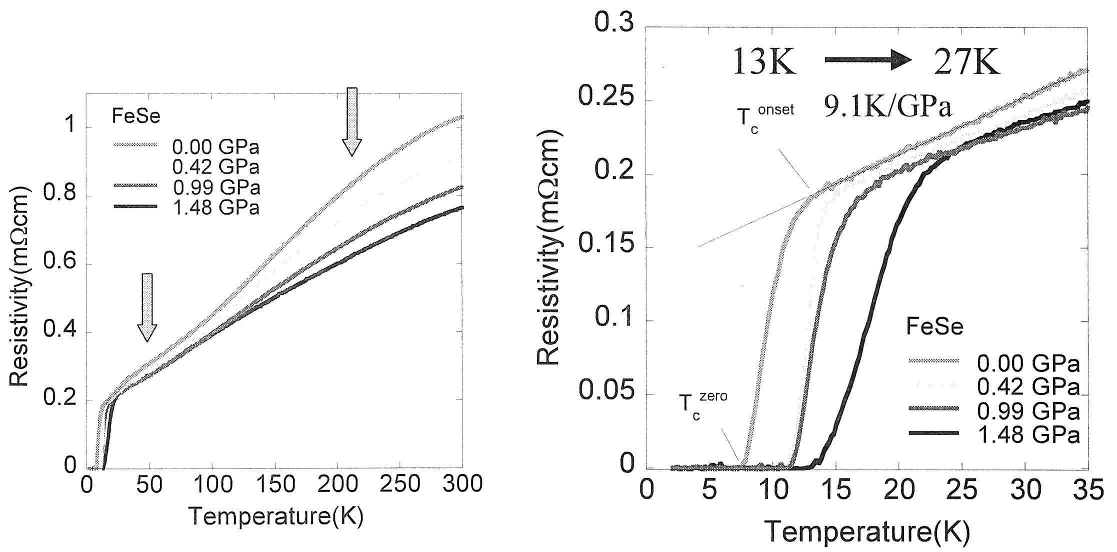
[5] M. Rotter *et al.*, *Phys. Rev. Lett.* **101**, 107006 (2008).
[6] A. S. Sefat *et al.*, *Phys. Rev. Lett.* **101**, 117004 (2008).
[7] M. S. Torikachvili *et al.*, *Phy. Rev. Lett.* **101**, 057006 (2008).
[8] P. L. Alireza *et al.*, *cond-mat*:0807.1896.

FeSe: Crystal structural transition around 70K



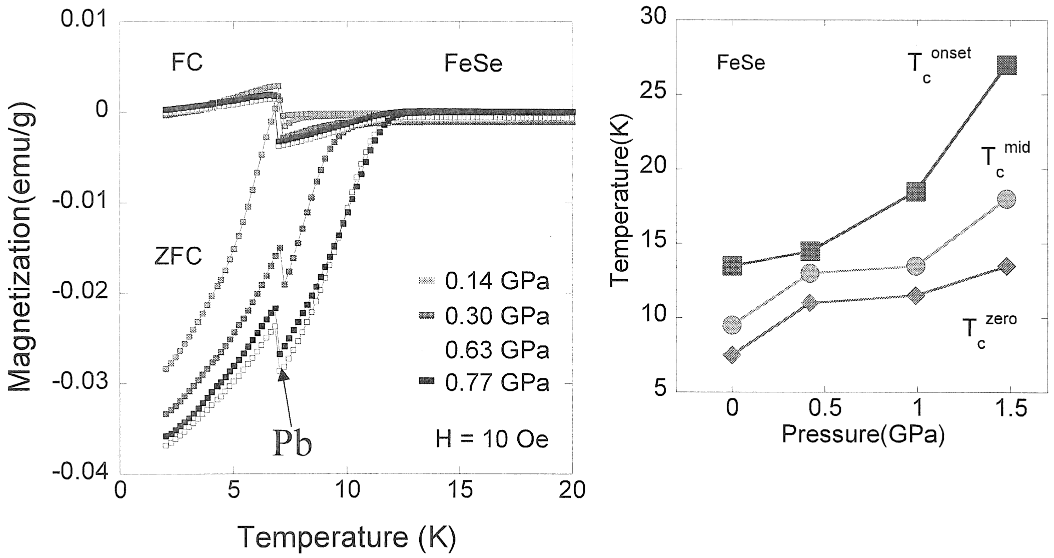
S. Margadonna *et al.*, Chem. Commn. 5607 (2008).

Transport properties of FeSe under pressure



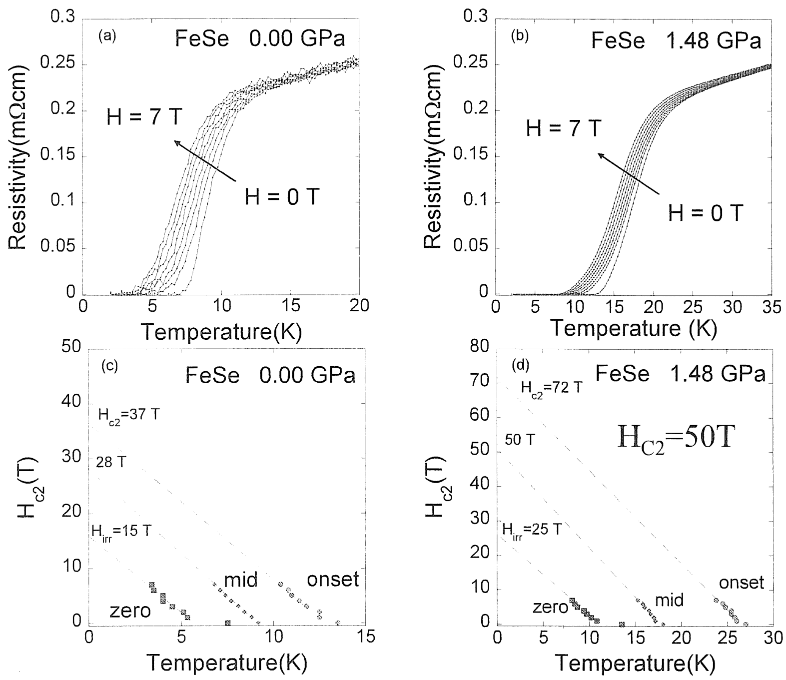
Y. Mizuguchi *et al.*, APL 93, 152505 (2008).

Magnetization properties of FeSe under pressure



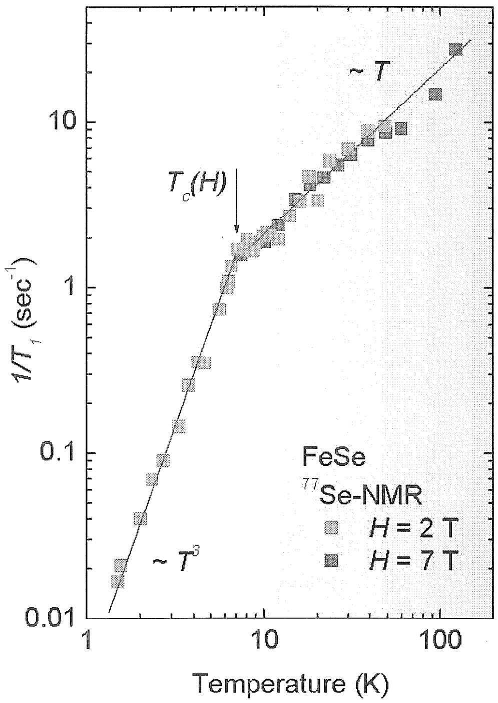
Y. Mizuguchi *et al.*, APL 93, 152505 (2008).

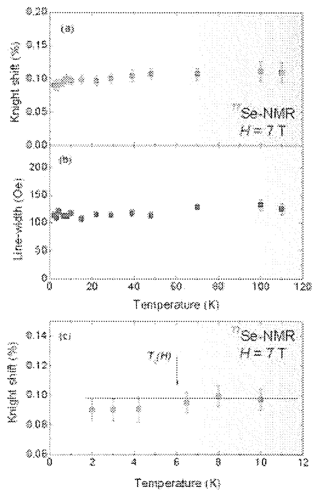
H_{C2} and H_{irr} of FeSe



Y. Mizuguchi *et al.*, APL 93, 152505 (2008).

NMR

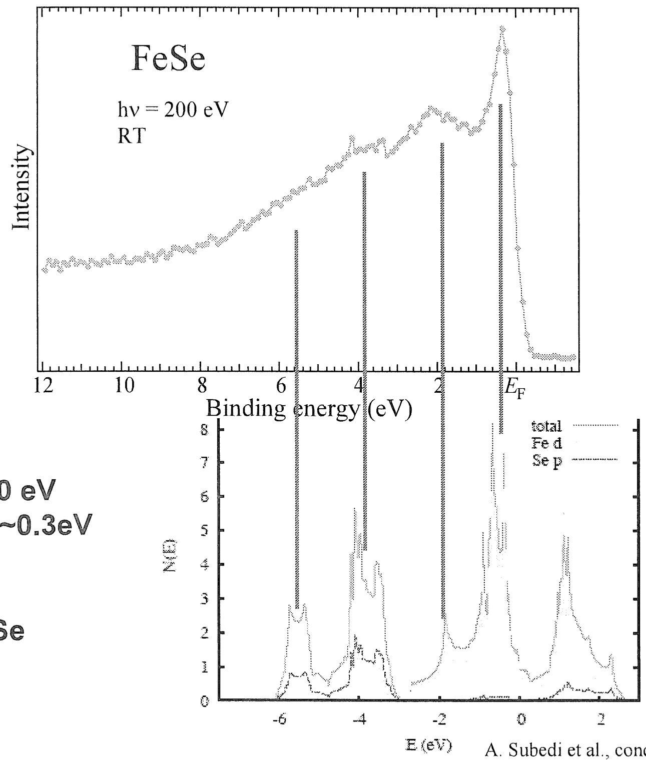




H. Kotegawa *et al.*, JPSJ 77, 113703 (2008).

Valence band photoemission spectra of FeSe

R.Yoshida et al.,
cond-mat:0811.1507.
JPSJ in printing.

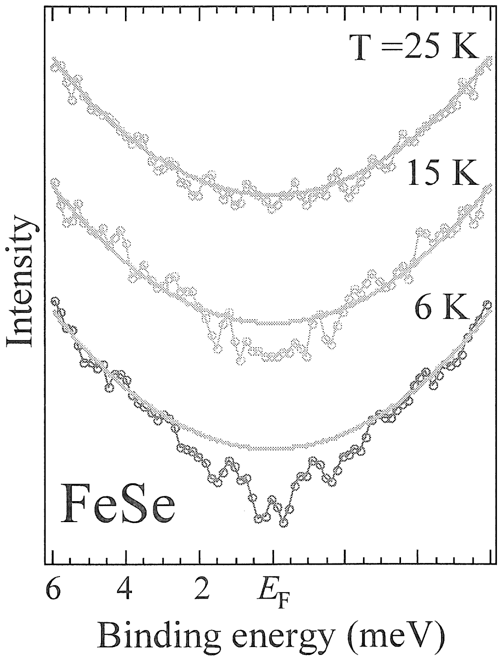


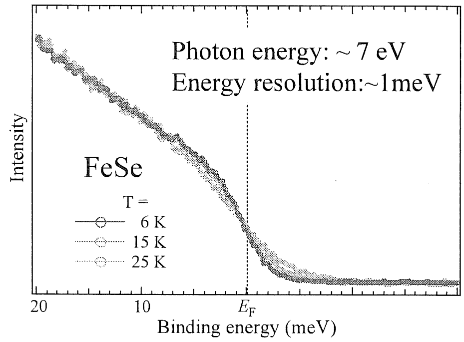
A. Subedi et al., cond-mat0807.4312v2.

HiSOR BL5
Photon energy: 200 eV
Energy resolution:~0.3eV

Sample
Polycrystalline FeSe
$T_{c\ mag}$ = 9K

AIPES of FeSe using Laser-PES in ISSP





Intensity reduction at E_F starts above Tc.

Two possibilities:

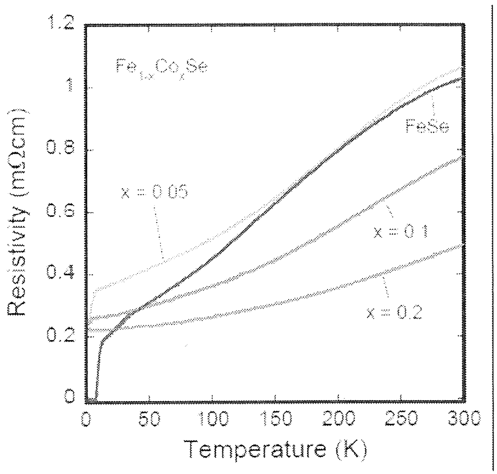
(1) Pseudogap formation above Tc as observed for FeAs compounds.

(2) Tc of measured area indeed higher than bulk Tc.

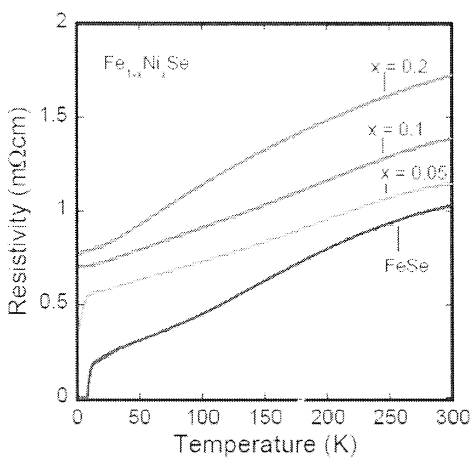
R.Yoshida et al., cond-mat:0811.1507. JPSJ in printing.

Substitution effects of FeSe

$Fe_{1-x}Co_xSe$



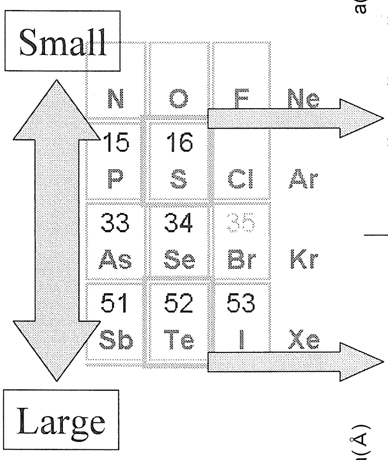
$Fe_{1-x}Ni_xSe$

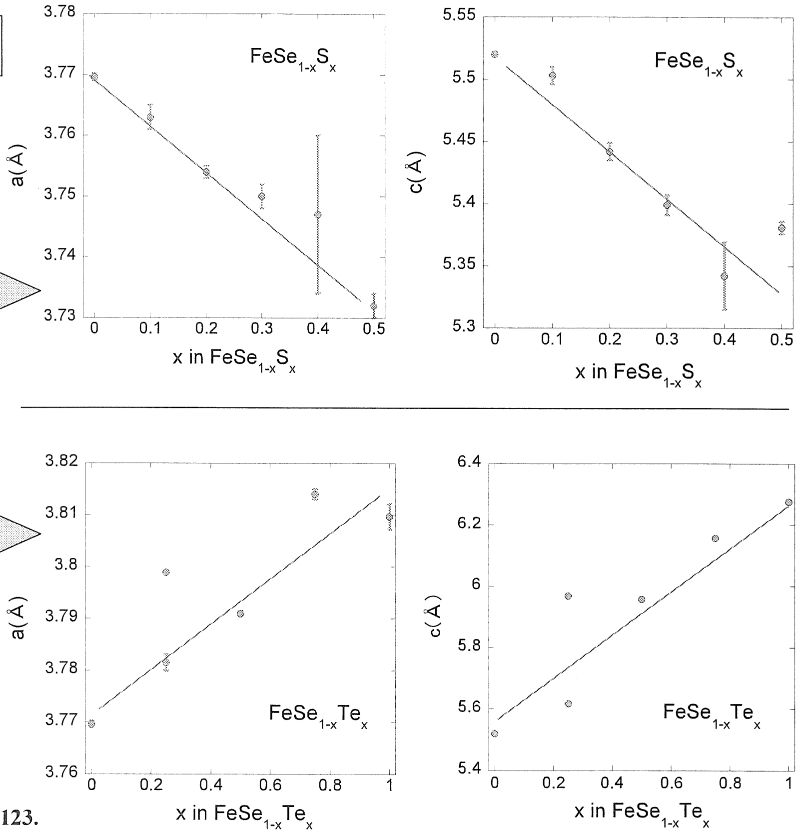


Superconductivity was suppressed strongly by Co or Ni doping contrary to 1111 system.

Y. Mizuguchi et al., arXiv:0811.1123.

Substitution effects



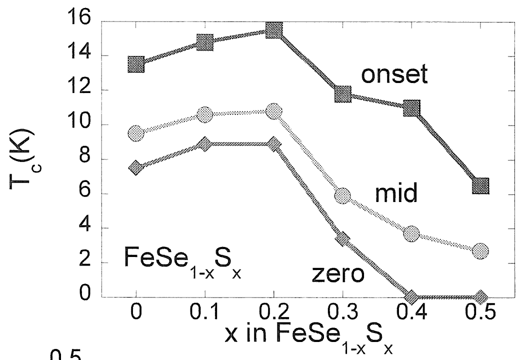


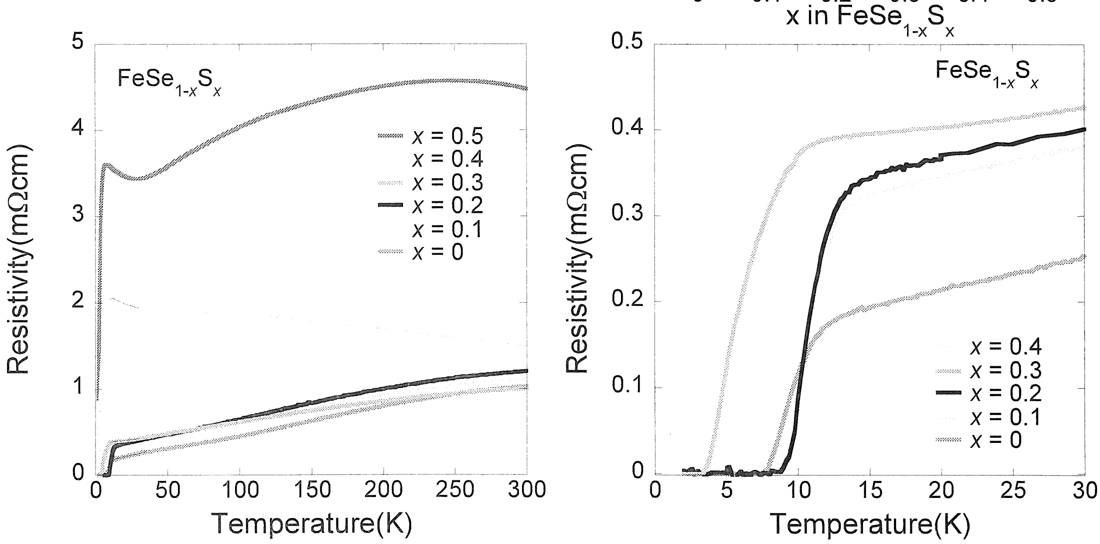
Y. Mizuguchi et al., arXiv:0811.1123.

FeSe1-xSx

T_c shows maximum around $x = 0.2$.

Y. Mizuguchi et al., arXiv:0811.1123.

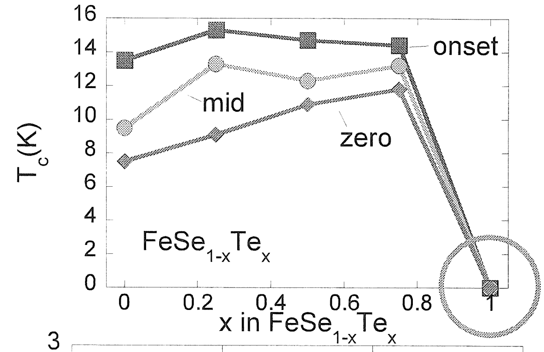


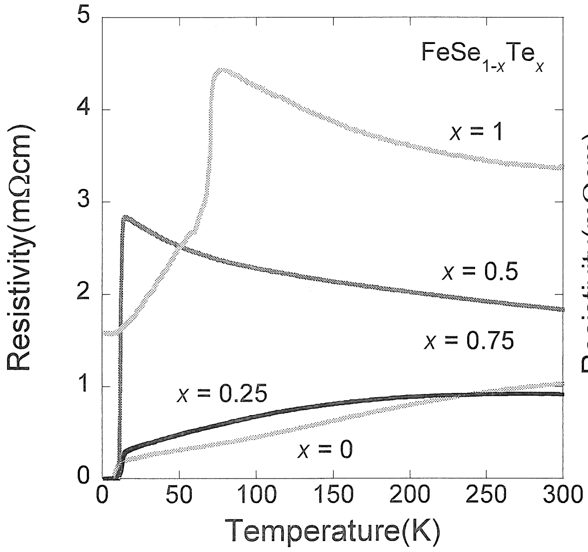


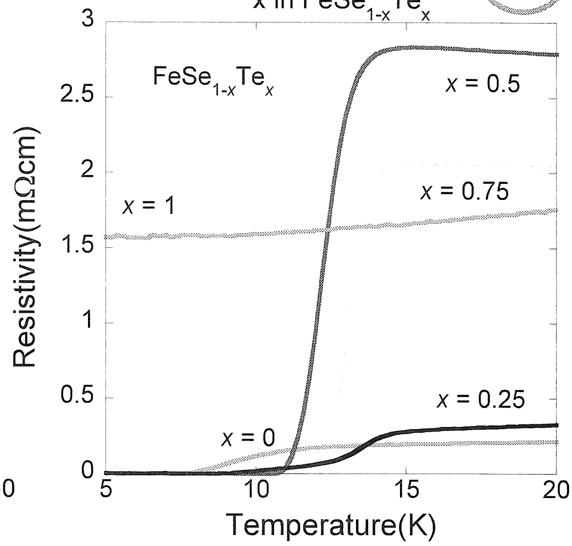
FeSe1-xTex

T_c shows maximum around $x = 0.75$.

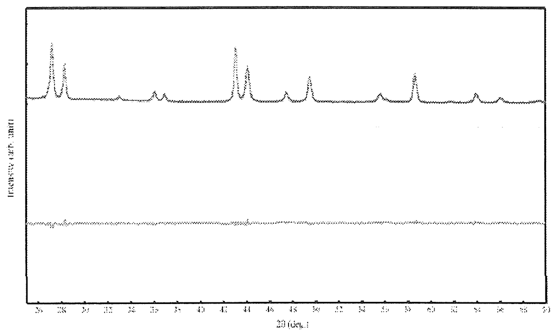
Y. Mizuguchi et al., arXiv:0811.1123.







X-ray diffraction pattern & Rietveld refinement FeTe



$a = 3.8248(3)$ Å

$c = 6.2910(3)$ Å

$V = 92.03(1)$ Å^3

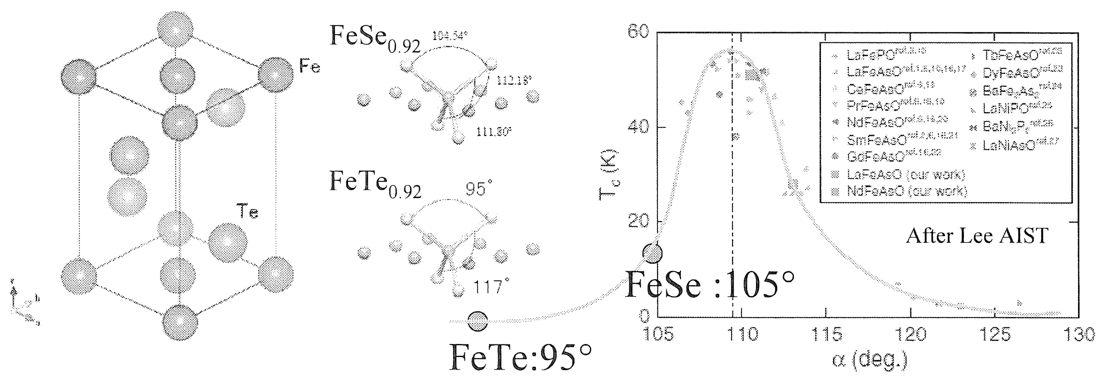
Space group: *P4/nmm*

$R_{WP} = 10.1\%$

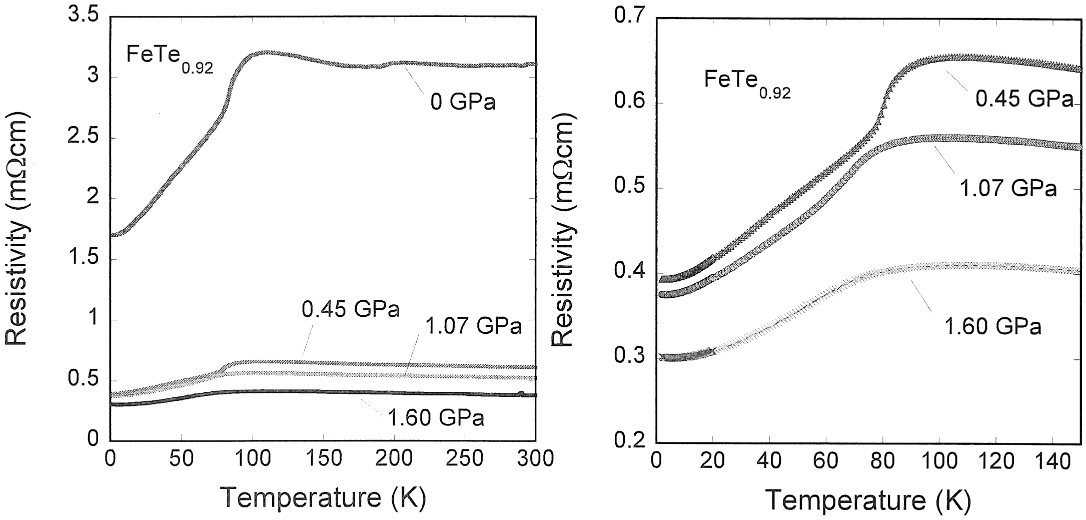
Occupancy of Te: 0.937(11)

z(Te) = 0.2790(2)

Te-Fe-Te = 95°.



Temperature dependence of resistivity under pressure

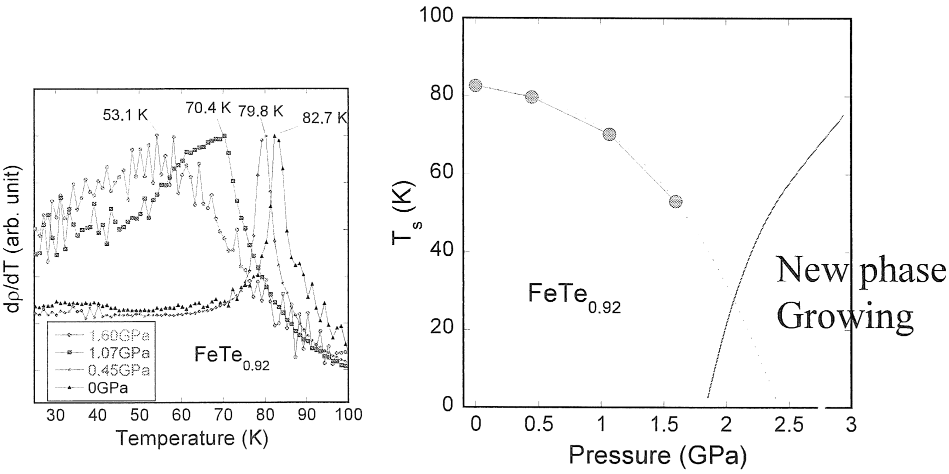


An anomaly corresponding to a structural transition was observed around 80 K.

With increasing pressure, resistivity at 300 K decreased and the transition broadened.

Y. Mizuguchi *et al.*, arXiv:0810.5191

*d*ρ/*dT* plots of resistivity under pressure



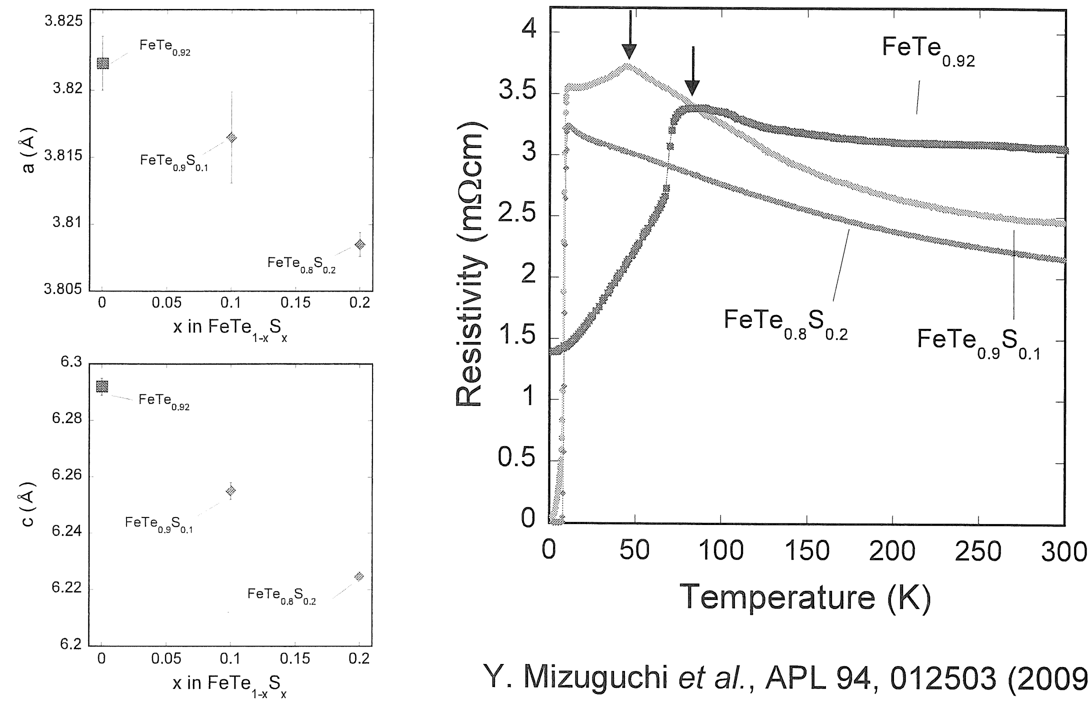
We defined T_s as the maximum temperature in $d\rho/dT$.

T_s clearly decreases with increasing pressure.

Y. Mizuguchi *et al.*, arXiv:0810.5191

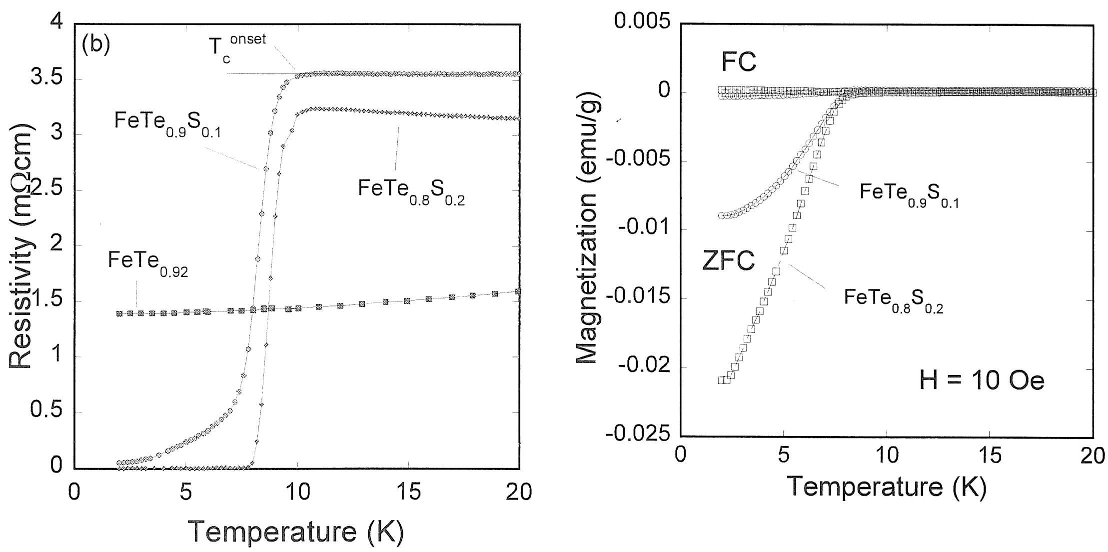
S substituted FeTe

Composed of nontoxic elements



Y. Mizuguchi *et al.*, APL 94, 012503 (2009).

Magnetization and H_{C2} of $FeTe_{1-x}S_x$

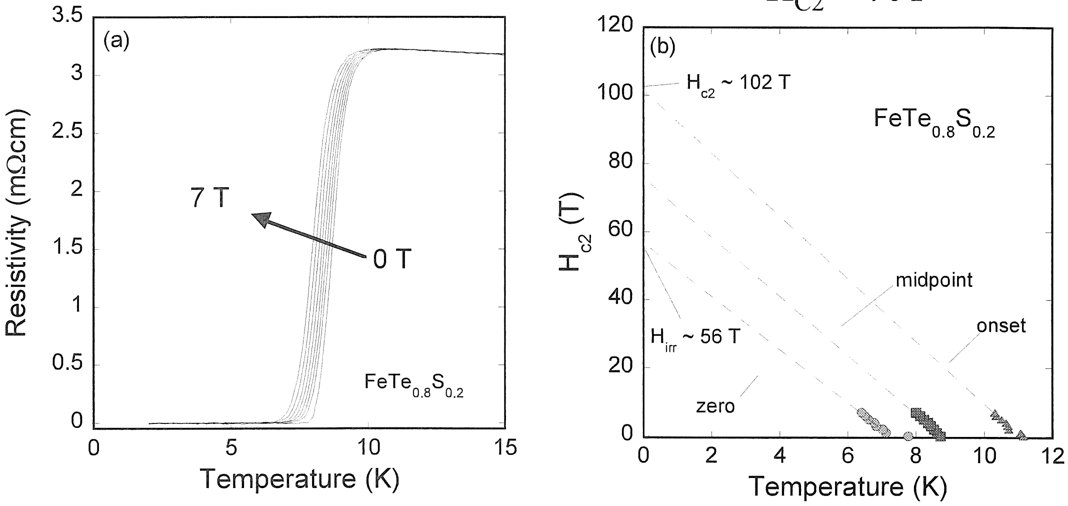


Superconductivity was found in S doped FeTe using nontoxic elements.

Y. Mizuguchi *et al.*, APL 94, 012503 (2009).

H_{C2} of $FeTe_{1-x}S_x$

$H_{C2} = 70T$



Y. Mizuguchi *et al.*, APL 94, 012503 (2009).

Summary

1. High pressure enhanced the Tc of FeSe up to 27K. Latest data shows Tc over 30K under higher pressure.

2. Gap-like properties was observed above Tc by AIPES.

3. Superconductivity was discovered in S doped FeTe around 10K.

Y. Mizuguchi *et al.*, APL 93, 152505 (2008).

S. Margadonna *et al.*, Chem. Commn. 5607 (2008).

H. Kotegawa *et al.*, J. Phys. Soc. Jpn., 77, 113703 (2008).

Y. Mizuguchi *et al.*, APL 94, 012503 (2009).

Thank you…

10. High-Pressure Synthesis and Physical Properties of New Iron Based Superconductors

P. M. Shirage[1], K. Miyazawa[1,2], H. Matsuhata[1], K. Kihou[1], C. H. Lee[1], N. Takeshita[1], R. Kumai[1], Y. Tomioka[1], T. Ito[1], M. Ishikado[1], H. Eisaki[1,3],H. Kito[1,3], A. Iyo[1,3]

[1]*Nanoelectronics Research Institute (NeRI), National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Central 2, Umezono, Tsukuba, Ibaraki, 305-8568, Japan.*

[2] *Department of Applied Electronics, Tokyo University of Science, 2641 Yamazaki, Noda, Chiba 278-3510, Japan*

[3] *JST, Transformative Research-Project on Iron Pnictides (TRIP), 5, Sanbancho, Chiyoda, Tokyo 102-0075, Japan*

Here we present a series of oxygen-deficient oxypnictide superconductors, $Ln\mathrm{FeAsO}_{1-y}$ (*Ln*: lanthanide elements) with *Ln*=La, Ce, Pr, Nd, Sm, Gd, Tb and Dy has been prepared using high-pressure synthesis technique. We demonstrate that the lattice parameters, the superconducting transition temperatures (T_c) and the phase purity of the samples strongly depend on the synthesis pressure, in particular for heavier *Ln*'s, such as Tb and Dy. Sharp superconducting transitions are observed at almost the same temperature both in resistivity and magnetic susceptibility measurements for each sample. It is demonstrated that the $Ln\mathrm{FeAsO}_{1-y}$ superconductor containing *Ln*'s (Nd, Sm, Gd, Tb and Dy) inherently possesses high-T_c exceeding 50 K while those with lighter *Ln's* (La, Ce and Pr) has been lower T_c's. The *a*- and *c*-parameters decrease with atomic number of *Ln* while T_c is constant for *Ln*=Nd to Dy, which suggests that the lattice parameters themselves are not dominant factors to determine the maximum T_c.

Also we show our first hand result on Fe-isotope effect in $Ba_{1-x},K_xFe_2As_2$ samples prepared by using high pressure synthesis technique. We have studied the effect of isotopic substitution on the superconducting transition temperature (T_c) by replacing ^{54}Fe by ^{57}Fe. We repeated experiment for eight set of samples and precisely determined and which demonstrate that iron isotope component α, ($T_c \sim M^{-\alpha}$) is negative.

E-mail: paras-shirage@aist.go.jp, iyo-akira@aist.go.jp

High-pressure synthesis and physical properties of new iron based superconductors

Ln La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

International Workshop on Iron Related high-Tc Superconductors (IRiSes2009)

Parasharam M. Shirage, K. Miyazawa, K. Kihou, M. Ishikado, H. Matsuhata, N.Takeshita, C. H. Lee, R. Kumai, Y. Tomioka, T. Ito, H. Eisaki,H. Kito, A. Iyo

National Institute of Advanced Industrial Science and Technology (AIST)

Outline

- Introduction
  - Crystal structures
  - High-pressure synthesis
- Physical properties
  - Oxygen deficiency dependence of T_c
  - Electronic phase diagram
  - Effect of Synthesis Pressure
  - *Ln* dependence of T_c
  - Fe-Isotope effect
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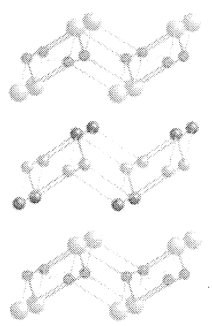
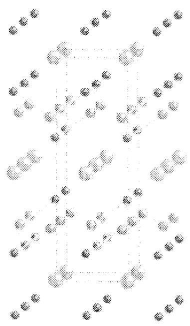
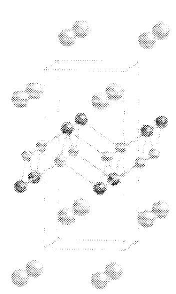
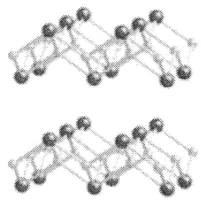
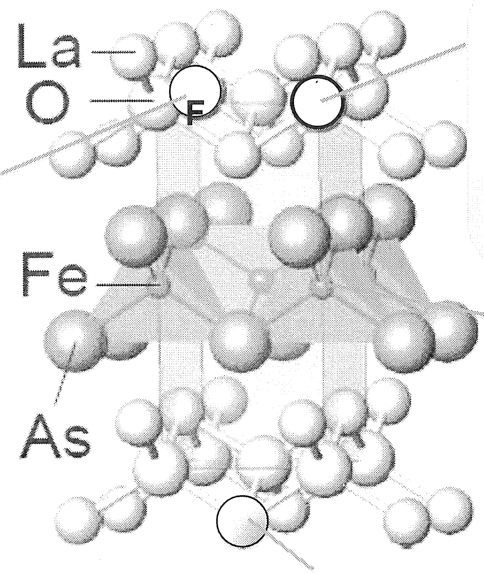
Crystal structures of Fe-based superconductors

"1111"	"122"	"111"	"11"
LaFeAs(O,F)	(Ba,K)Fe_2As_2	LiFeAs	FeSe
T_c=26~56K	T_c=38K	T_c=18K	T_c=8K
Y. Kamihara et al.	M. Rotter et al.	X.C. Wang et al.	F.C. Hsu et al.

Ways to induce superconductivity in "1111"phase

F substitution
$LaFeAsO_{1-x}F_x$
Y.Kamihara et al. JACS **130** (2008) 3296.



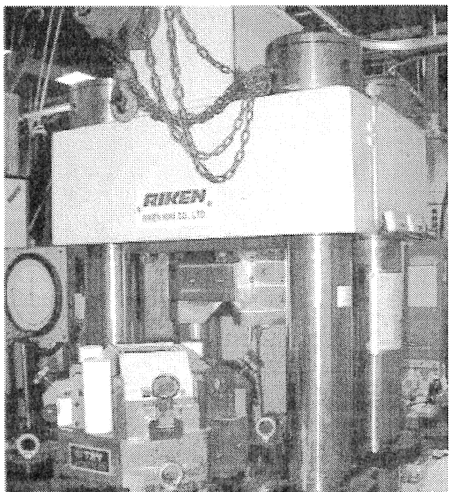
Oxygen deficiency
$\mathit{Ln}FeAsO_{1-y}$
H.Kito, H.Eisaki, A.Iyo, JPSJ **77** (2008) 063707.
Z.A. Ren et al. Europhys. Lett. **83** (2008) 17002.

Fe site substitution
Ca(Fe,Co)AsF
S. Matsuishi et al, JACS ***130*** (2008) 14428

Pressure
N.Takeshita et al. JPSJ **77** (2008) Suppl. C, 131.
H.Okada et al. cond-mat, arXiv:0810.1153.

Ln site substitution
$(Gd^{3+}Th^{4+})FeAsO$
C. Wang et al. arXiv:0804.4290

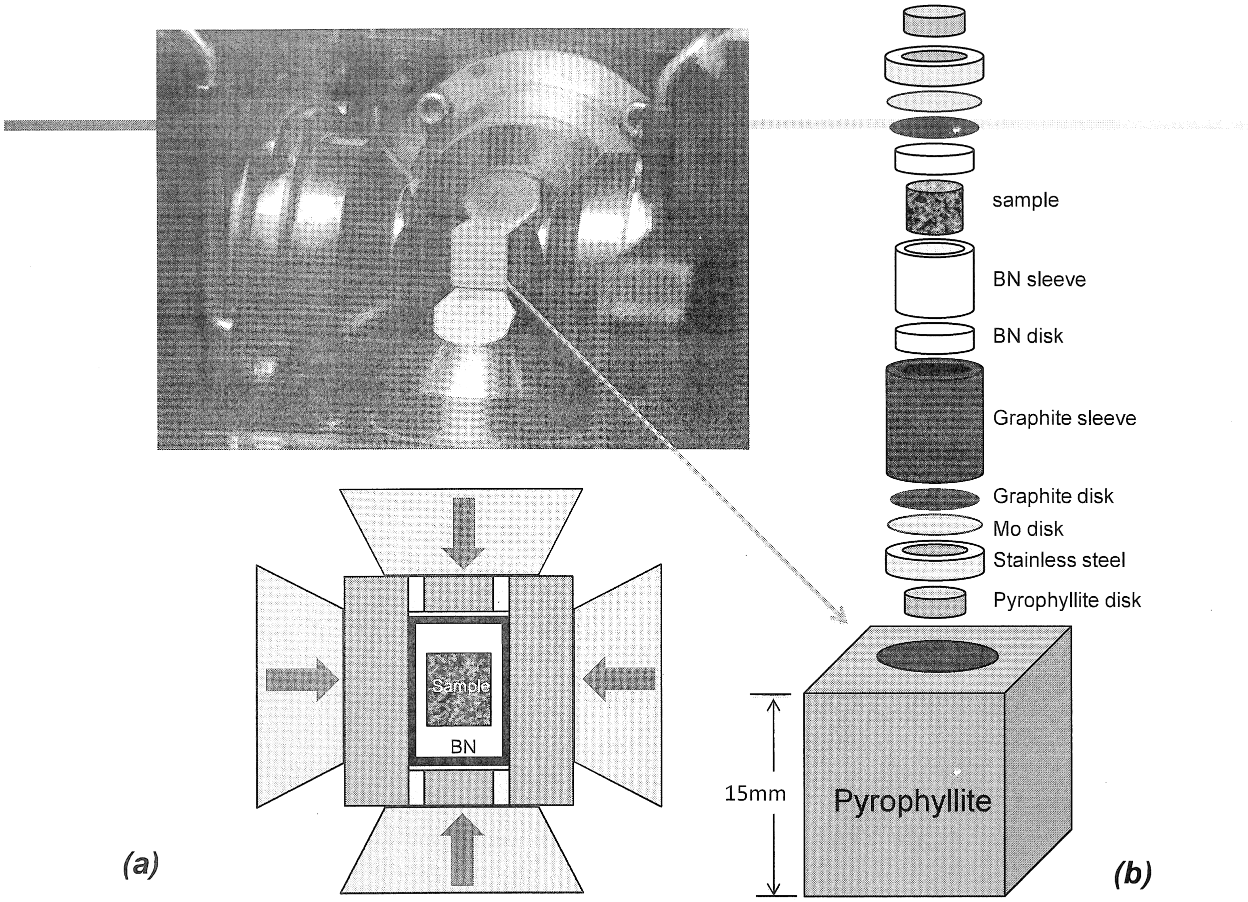
High-pressure synthesis method



Cubic-anvil type high-pressure apparatus CAP-07, RIKEN

Merits of high-pressure synthesis

- **New materials**
  -high-pressure phase $\mathit{Ln}FeAsO_{1-y}$
- **Safety**
  -evaporation of toxic As is suppressed
- **High productivity**
  -short reaction time ~2 hrs (3~4 samples /day)
- **High-purity samples**
  -crystal structure analysis
- **High-density samples**
  -transport measurements
- **Single crystal growth**
  $PrFeAsO_{1-y}$, $(Ba,K)Fe_2As_2$



High-pressure synthesis of *Ln*FeAsO$_{1-y}$

Starting Materials: *Ln*As, Fe (powder), Fe_2O_3

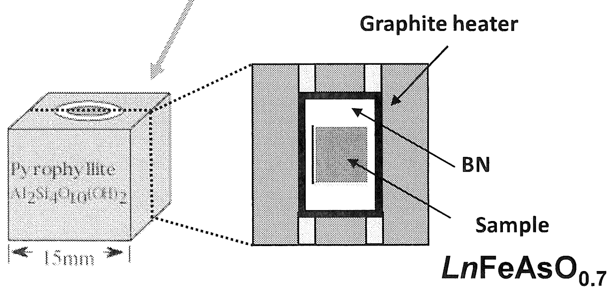
- Precursors of *Ln*As are prepared in quartz tube.
- Oxygen content of samples are controlled by Fe/Fe_2O_3 ratio.

Conditions

Pressure: 2.0~5.5 GPa

Temperature: 1050~1150 ℃

Time: 2 hours

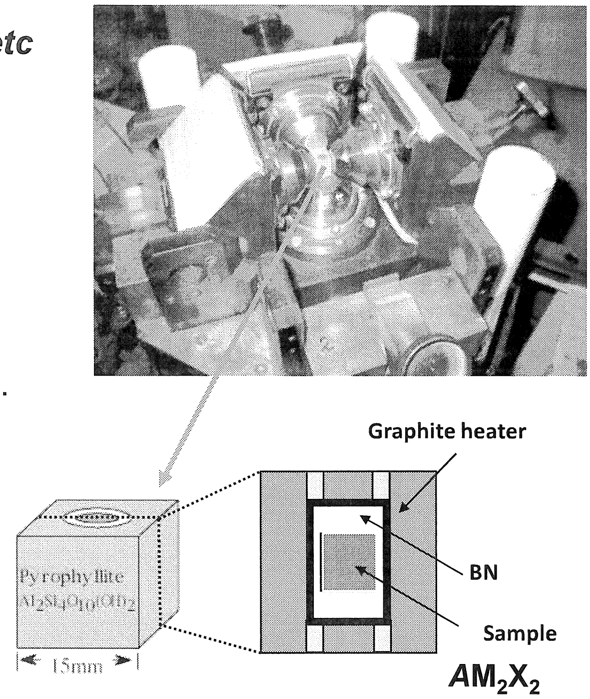


High-pressure synthesis of AM_2X_2

A = Ba,K,Ca; M= Fe, Ni; X= As, P etc

Starting Materials:
***BaAs*, KAs, Ca, Na, Fe (powder), As, P, etc.**

・Precursors of *Ba*As are prepared in quartz tube while KAs in alumina tube.



<u>Conditions</u>

Pressure: 1.0 GPa

Temperature: 950~1150 ℃

Time: 1-1.5 hours

Outline

- Introduction
  - Crystal structures
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- Physical properties
  - Oxygen deficiency dependence of T_c
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- Summary

Outline

- Introduction
  - Crystal structures
  - High-pressure synthesis
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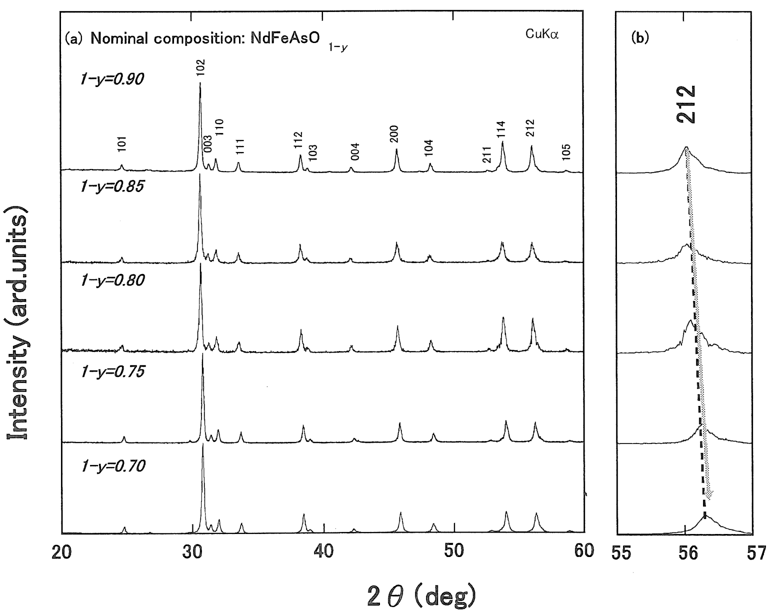
Oxygen-deficient NdFeAsO1-y

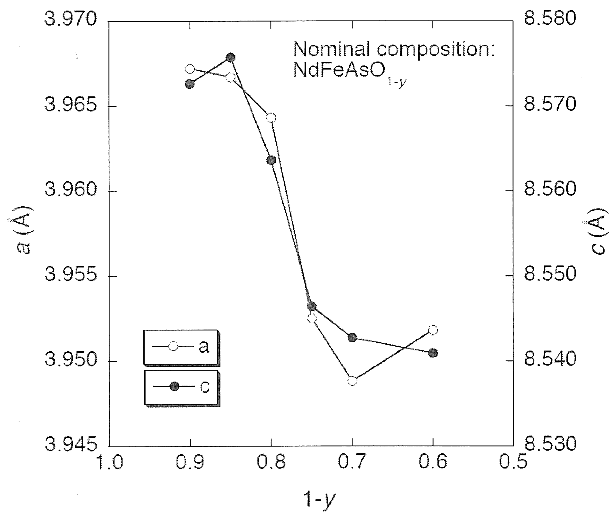


XRD Patterns of Oxygen deficient $NdFeAsO_{1-y}$

Peaks are indexed on the basis of tetragonal ZrCuSiAs type crystal structure, P4/nmm symmetry

- No impurity peaks, indicates pure phase.
- 212 diffraction peak systematically shift to higher diffraction angle with increase in oxygen deficiency.
- Indicates the shrinkage of lattice parameters.

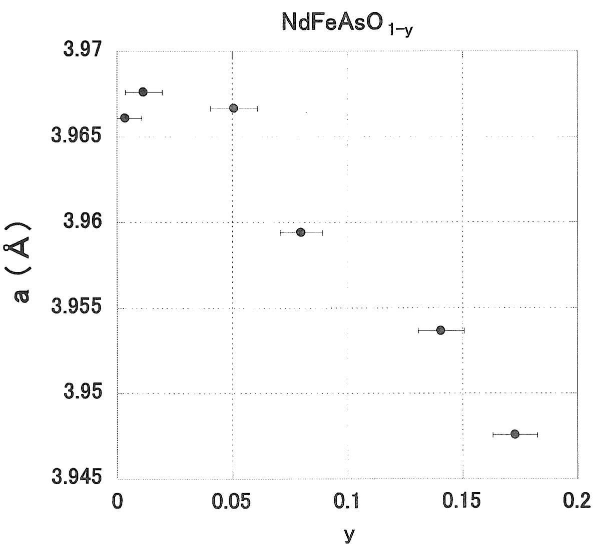
$NdFeAsO_{1-y}$ lattice parameters as a function of 1-y



- Lattice Parameters shrinks non-monotonously with oxygen deficiency.
- ~0.32 percentage change is lattice parameters, which is higher than substitution of F at O in $LaFeAs(O_{1-x}F_x)$.

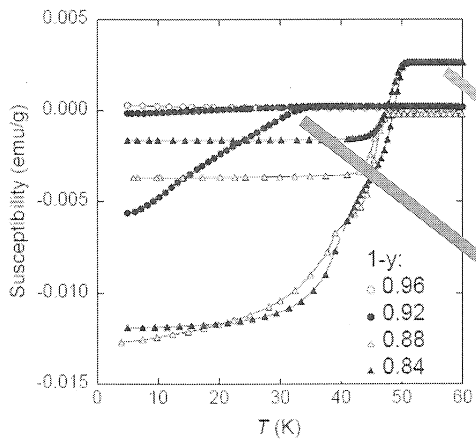
- Shrinkage of lattice parameter with 1-y is reasonable, as oxygen deficiency alters the charge distribution between NdO and FeAs.
- $(NdO)^{+1}$ and $(FeAs)^{-1}$ changes to $(NdO_{1-\delta})^{+1+2\delta}$ and $(FeAs)^{-1-2\delta}$.
- Causes displacement of these layers closer to each other.

Real Oxygen content

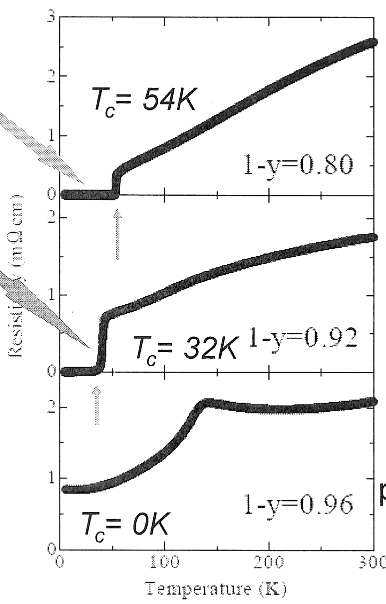


- Real oxygen content is determined by Rietvelt analysis.
- Real oxygen content in sample is different form the nominal, real is 0.12 higher than nominal.
- The relation between the real oxygen content and a-parameter is linear and which can be given by relation: $1-y = (6.637)a - 25.373$

Oxygen deficiency dependence of T_c



The temperature-dependence of magnetic susceptibility



the resistivity varies almost Linearly (or slightly curved into a s-shape)

SDW-a structural phase transition

The temperature-dependence of the resistivity

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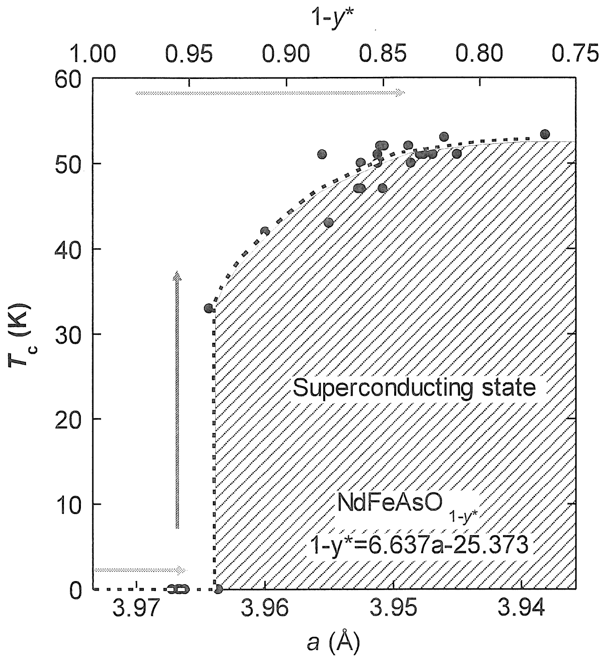
The electronic phase diagram



The *a*-axis length decreases as the oxygen deficiency increases, and superconductivity seems to develop discontinuously below a~3.964A.

The electronic phase diagram of oxygen-deficient NdFeAsO1-y samples synthesized by high-pressure technique.

Outline

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  - Oxygen deficiency dependence of T_c
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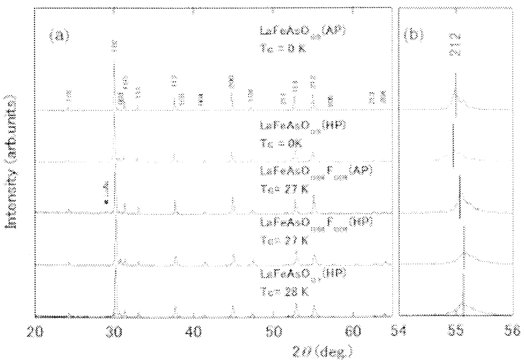
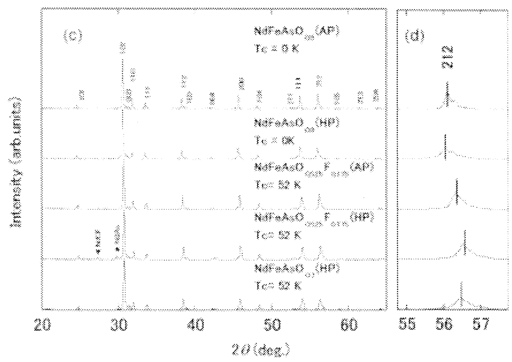
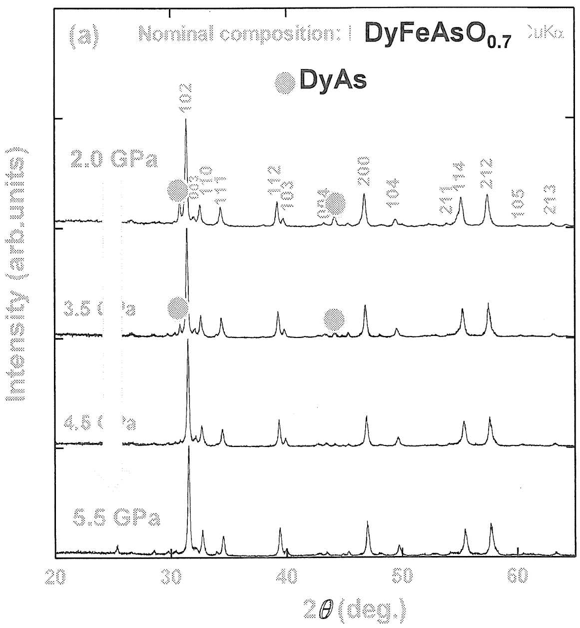
Structural parameters depend on the synthesis methods ?

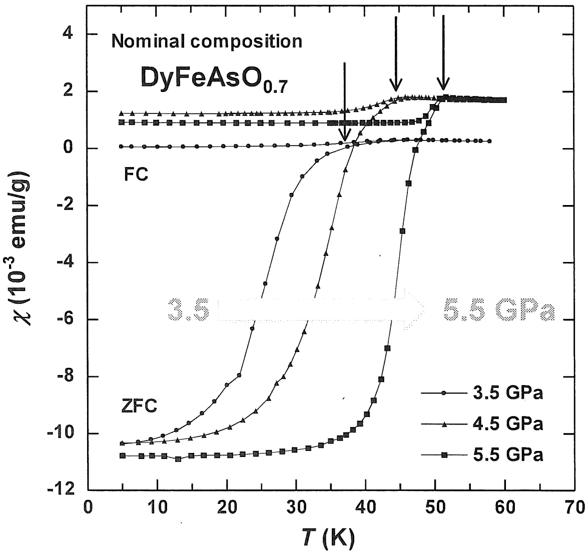




For Ln = La and Nd, structural parameters are not dependent on synthesis methods. How about *Ln* =Sm, Gd,Tb and Dy?

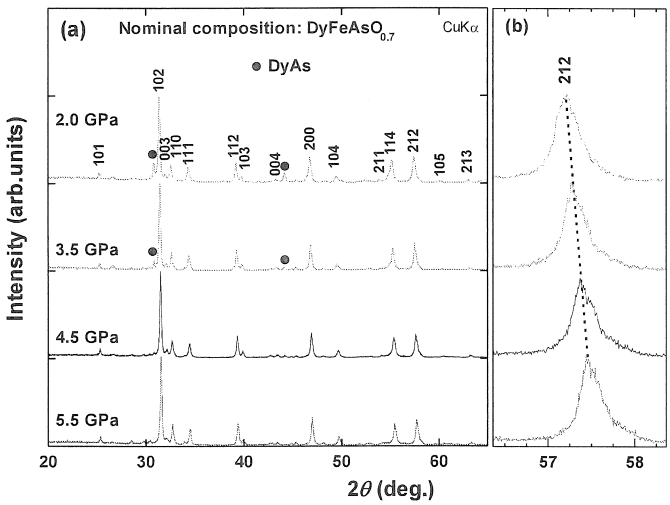
Effect of synthesis pressure





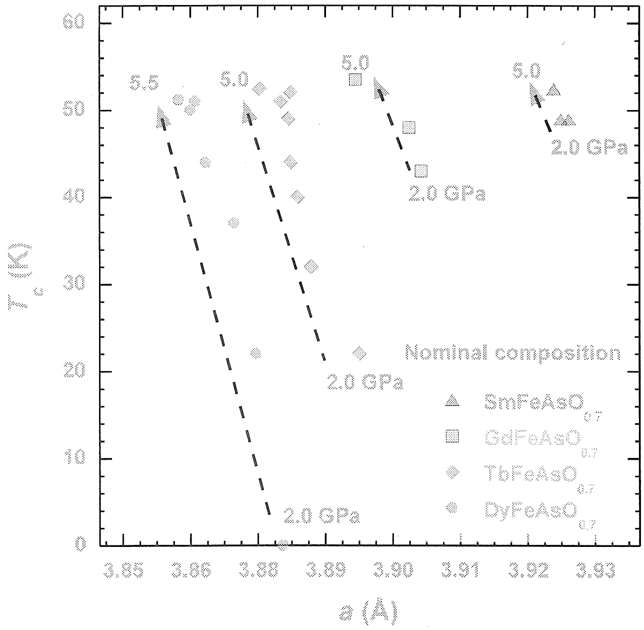
Purity and T_c are improved by increase of synthesis pressure.

XRD $DyFeAsO_{0.7}$



With increase in pressure from 2 Gpa to 5.5 Gpa

1. Impurity decreases
2. 212 peak shift to higher diffraction angle with decrease in lattice parameter
3. T_c increase
4. HP technique is effective for synthesizing heavier L_n-based superconductors.



(Ln=Sm,Gd,Tb and Dy) samples against the *a*-axis lattice parameter at various pressures, sample prepared by high pressure synthesis technique.

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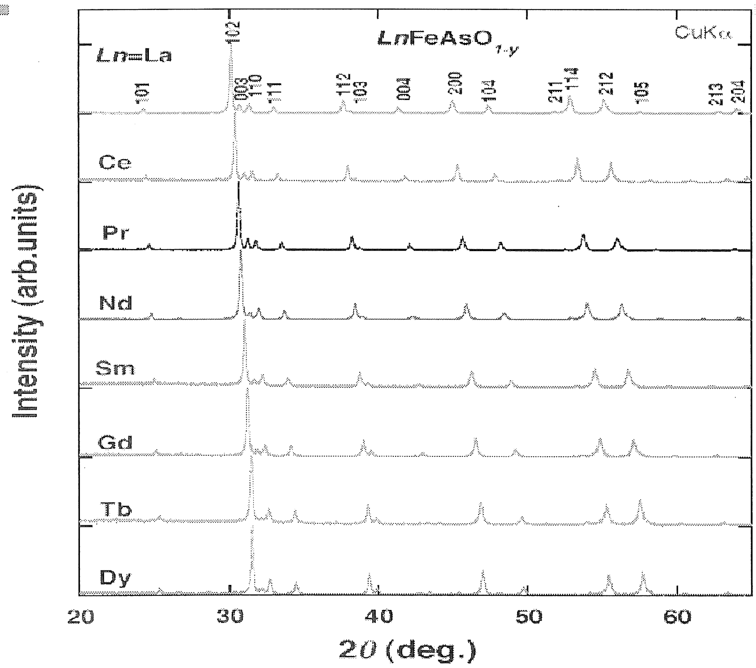
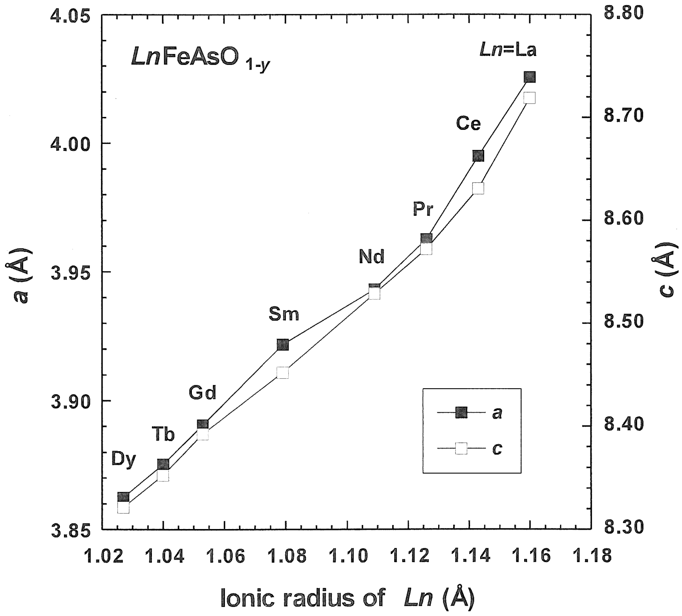
Powder XRD patterns of LnFeAsO$_{1-y}$



Synthesis pressure: 2GPa | 5~5.5GPa | > 6GPa ?

La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

Ln dependence of lattice parameters



Lattice parameters decrease almost linearly with atomic number of Ln^{3+} ionic radius.

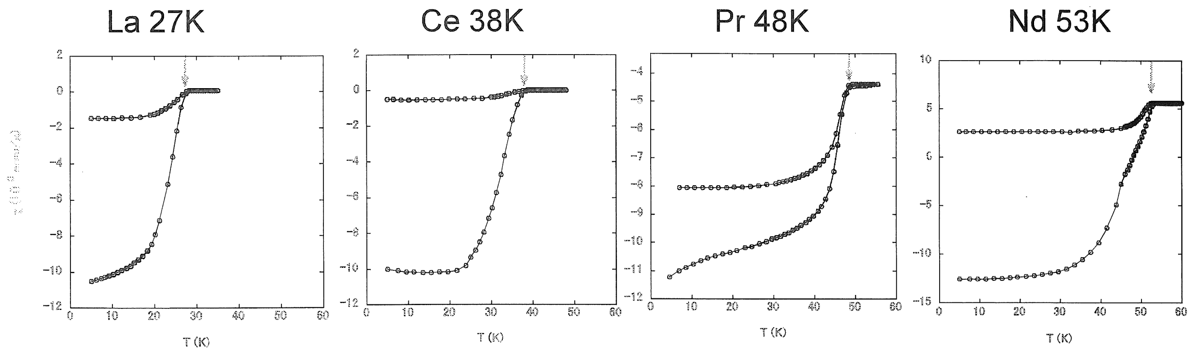
Ionic radius of Ln^{3+} decreases with atomic number.
(Lanthanide contraction)

Ln **La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu**

large **Ionic radius** small

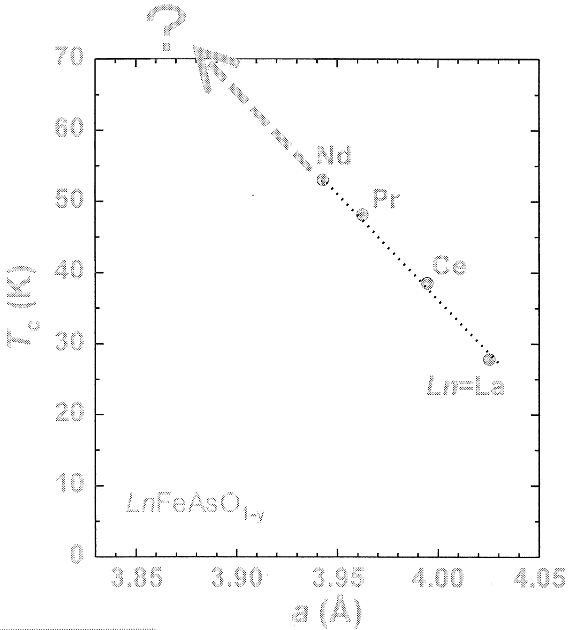
Ln dependence of T_c (susceptibility) (*Ln*=La, Ce, Pr and Nd)

T_c *increases steeply*



Ln **La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu**

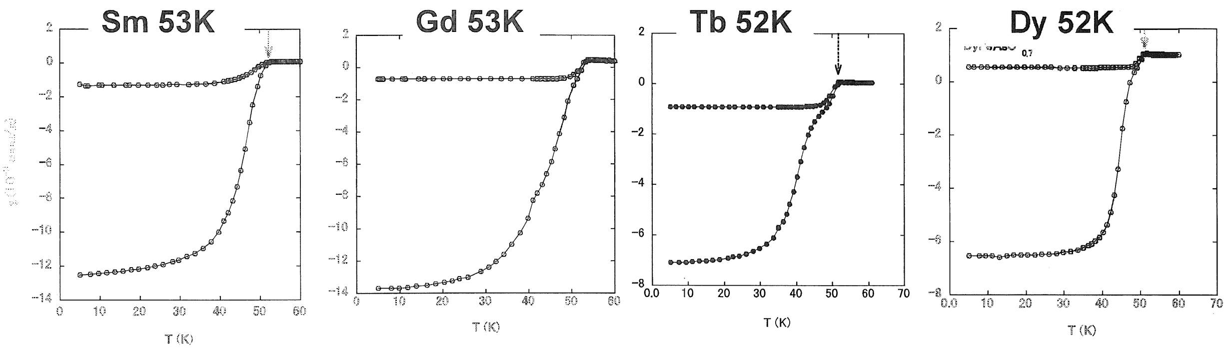
Ln dependence of T_c



La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

Will T_c increase?

Ln dependence of T_c (Susceptibility) (*Ln*=Sm, Gd, Tb and Dy)

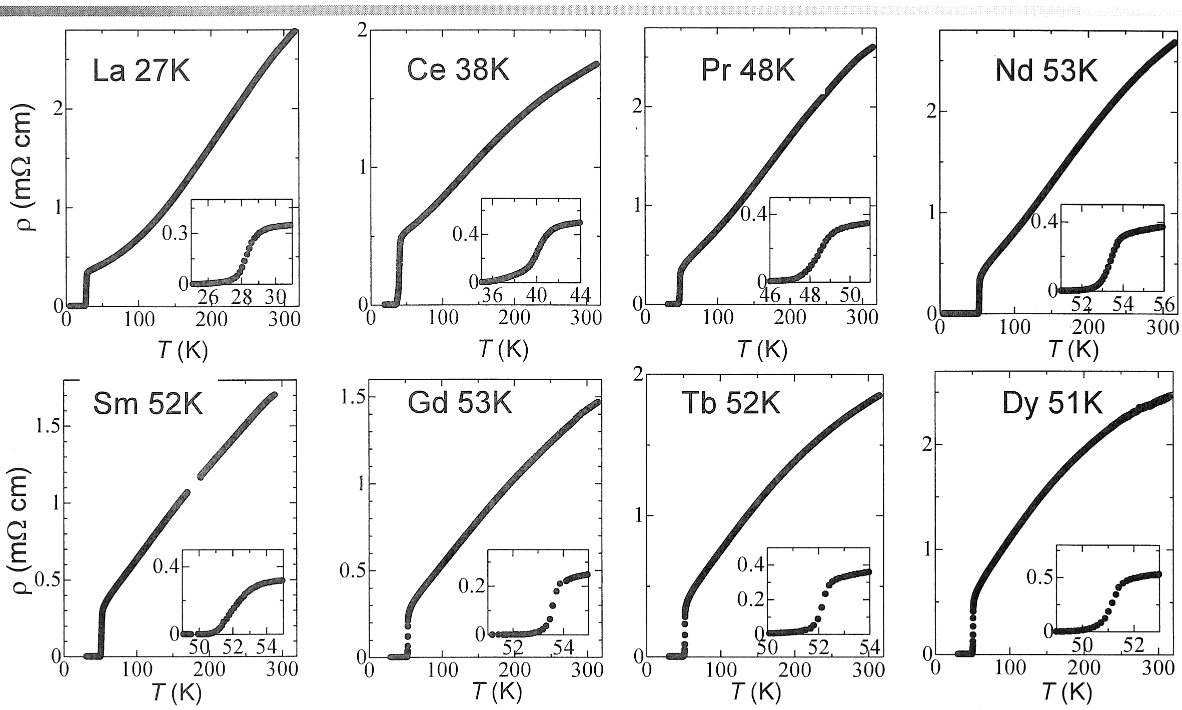


Ln La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

The highest T_c obtained so far are around 53 K

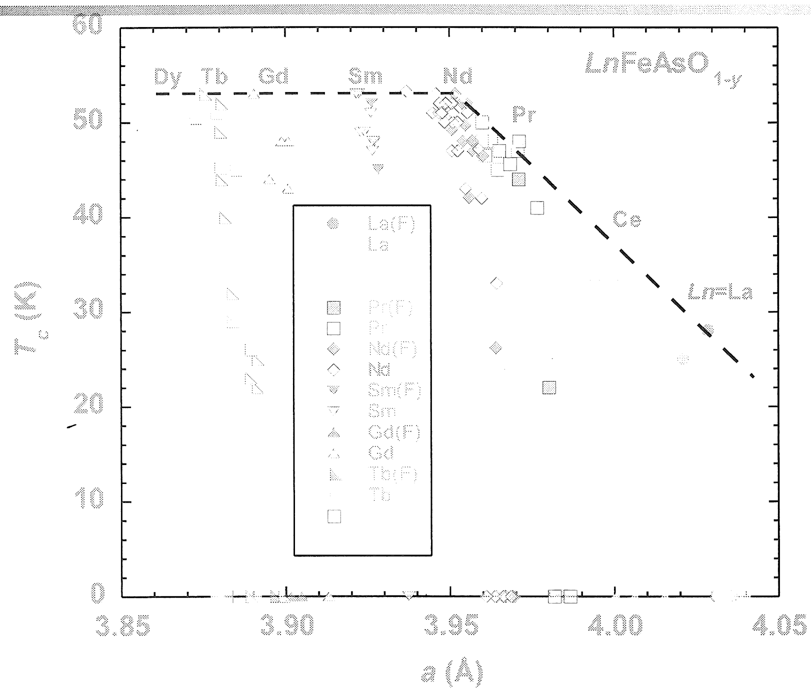
K. Miyazawa et al. submitted to JPSJ.
J-W. G. Bos et al. Chem. Commun. **31** (2008) 3634.
Y.G. Shi et al. cond-mat. arXiv:**0808.1948**.
J. Yang et al. cond-mat. arXiv:**0809.3582**.
J. Yang et al. Supercond. Sci. Technol. **21** (2008) 082001.

Ln dependence of T_c (Resistivity)
(*Ln*=La, Ce, Pr, Nd, Sm, Gd,Tb and Dy)



Ln | La Ce Pr Nd | Pm | Sm | Eu | Gd Tb Dy | Ho Er Tm Yb Lu

Ln dependence of T_c



For the lighter *Ln*'s (La, Ce, Pr, Nd), T_c increases monotonously with decreasing the lattice parameters, then stays at the constant value around 53 K for the heavier *Ln* (Nd, Sm, Gd, Tb and Dy)

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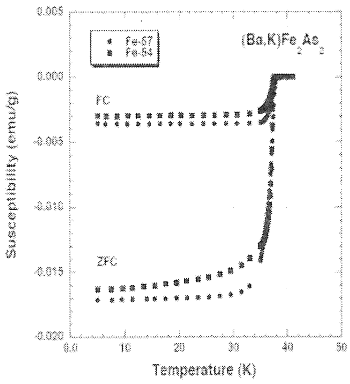
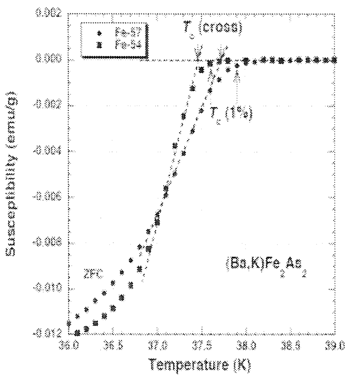
Fe-Isotope effect





Prepared 16 set of Fe-54 and Fe-57 , $Ba_{0.6}K_{0.4}Fe_2As_2$ samples by using High Pressure Synthesis Technique. Our data shows highly reproducible results.

Iron isotope component α, ($T_c \sim M^{-\alpha}$) is negative and small : (α= -0.1 ±0.1) by 1 % drop in susceptibility. (α= -0.02 ±0.12) by susceptibility cross defination.

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Summary

- **We have prepared high-purity oxygen-deficient LnFeAsO_{1-y} samples by optimizing conditions using high-pressure synthesis method.**
- **T_c increases monotonously with decreasing the lattice parameters for the lighter *Ln*'s (La, Ce, Pr, Nd), then stays at the constant value around 53 K for the heavier *Ln* (Nd, Sm, Gd, Tb and Dy).**
- **The *a*- and *c*-parameters decrease with atomic number of *Ln* while T_c is constant for *Ln*=Nd to Dy, which suggests that the lattice parameters themselves are not dominant factors to determine the maximum T_c.**
- **Fe-isotope effect shows very small and negative effect.**

11. Magnetism and Superconductivity in Actinide Compounds Related to Iron-Oxypnictide Structure

Y. Haga, H. Sakai and T. D. Matsuda

[1]Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Naka, Ibaraki 319-1195, Japan, [2]JST, TRIP, Tokyo 102-0075, Japan

Since the discovery of heavy fermion superconductivity in $CeCu_2Si_2$[1], a number of rare-earth and actinide compounds have been reported to exhibit unconventional superconductivity. More recently, transuranium-based superconductors such as $PuCoGa_5$ and $NpPd_5Al_2$ have also been reported. It is interesting to note that compounds with the $ThCr_2Si_2$-type tetragonal structure, which has similar crystallographic characteristics as oxypnictide superconductors, often show unconventional superconductivity ($CeCu_2Si_2$, URu_2Si_2, $CePd_2Si_2$ under pressure, etc). After reviewing the superconducting characteristics of these compounds, we mention the synthesis of actinide compounds with oxypnictide structure.

References

[1] F. Steglich, J. Aarts, C. D. Bredl, W. Lieke, D. Meschede, W. Franz and H. Schafer: Phys. Rev. Lett. **43** (1979) 1892.

[2] J. L. Sarrao, L. A. Morales, J. D. Thompson, B. L. Scott, G. R. Stewart, F. Wastin, J. Rebizant, P. Boulet, E. Colineau and G. H. Lander, Nature (London) **420** (2002) 297.

[3] D. Aoki, Y. Haga, T. D. Matsuda, N. Tateiwa, S. Ikeda, Y. Homma, H. Sakai, Y. Shiokawa, E. Yamamoto, A. Nakamura, R. Settai, Y. Onuki, J. Phys. Soc. Jpn. **76** (2007) 063701.

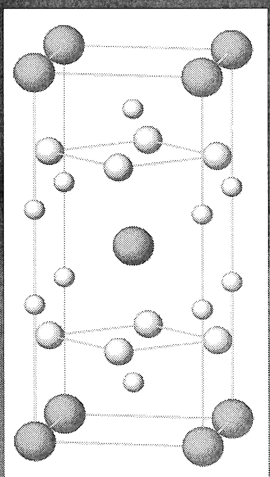
Magnetism and Superconductivity in Actinide compounds related to iron-oxypnictide structure

Yoshinori Haga, Hironori Sakai, Tatsuma D. Matsuda
Advanced Science Research Center, JAEA, TRIP

1. role of *f*-electrons in RE-oxypnictide : structural tuning ?
   how about 5*f*-electrons ?
2. single crystal growth of Actinide oxypnictide
   UCuPO : AF ground state
3. What happens when 5*f*-electrons superconduct ?
   New material : $NpPd_5Al_2$

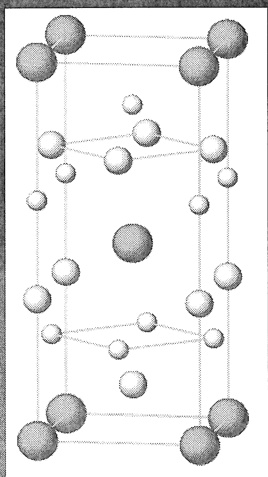
Crystal structure of '122' , '1111', '113' compounds

(a) $ThCr_2Si_2$-type I4/mmm



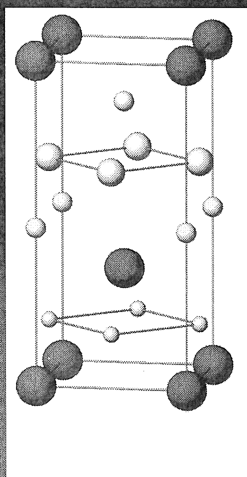
URu_2Si_2 etc.

(b) $CaBe_2Ge_2$-type P4/nmm



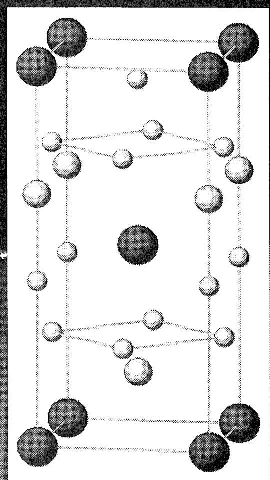
UAu_2Si_2 etc.

(c) ZrCuSiAs-type P4/nmm



LaFeAsO etc.

(d) $BaNiSn_3$-type I4mm



$CeIrSi_3$ & $CeRhSi_3$

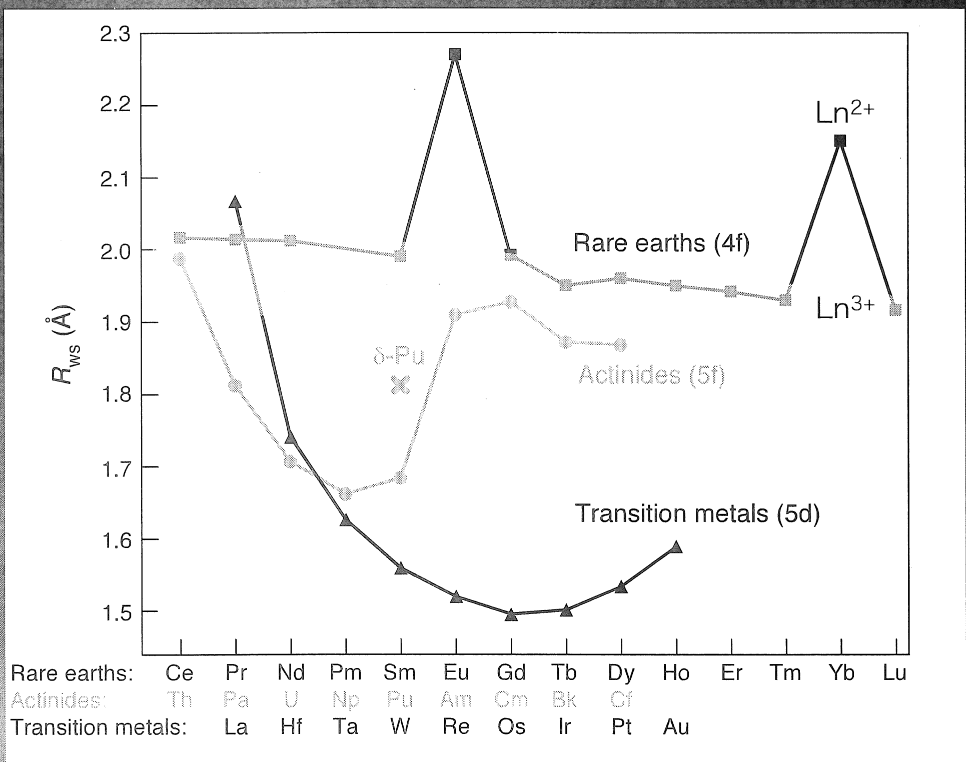
- (a) Superconductivity in URu_2Si_2 coexisting with 'Hidden order
- (b) no SC reported
- (c) oxypnictide
- (d) SC in non-centrosymmetric structure

f-electron Heavy Fermion superconductors

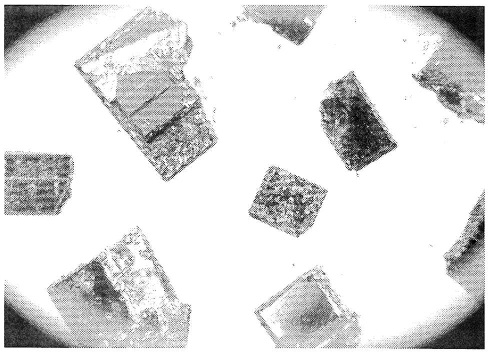
	compound	T_c (K)	C_e / T (mJ/K^2mol)	Magnetic Ordering
1979	$CeCu_2Si_2$	~ 0.5	~ 1000	complex
	UPt_3	0.45, 0.55	500	fluctuating AF at 5 K
	UBe_{13}	0.9	1000	Curie-Weiss
	URu_2Si_2	1.4	60	hidden order at 17.5 K
1990	UPd_2Al_3	2.0	145	AF at 14.3 K
	UNi_2Al_3	1.0	300	AF (SDW) at 4 K
	$CeIn_3$ (p), $CePd_2Si_2$ (p), $CeRh_2Si_2$ (p)			
2001	$CeCoIn_5$	2.3	500	Curie-Weiss
	$CeRhIn_5$ (p)			
	$CeIrIn_5$	0.4	500	Curie-Weiss
2002	$PuCoGa_5$	18.5	70	Curie-Weiss
	$PuRhGa_5$	8.5	70	Curie-Weiss
	URhGe	0.15	150	Ferromagnetic at 10 K
	$CePt_3Si$	0.5	300	AF at 2.3 K
	$PrOs_4Sb_{12}$	1.5	~ 500	paramagnetic
2006	$CeRhSi_3$ (p), $CeIrSi_3$ (p), $CeCoGe_3$ (p), UIr (p)			
2007	$NpPd_5Al_2$	4.9	200	Curie-Weiss
	UCoGe	0.8	150	Ferromagnetc at 3 K

1911 Hg
1961 Nb_3Sn
1986 HTSC
2001 MgB_2
2004 diamond
2008 Fe-related

Wigner-Seitz radius of 5d, 4f, 5f metal



UCuPO

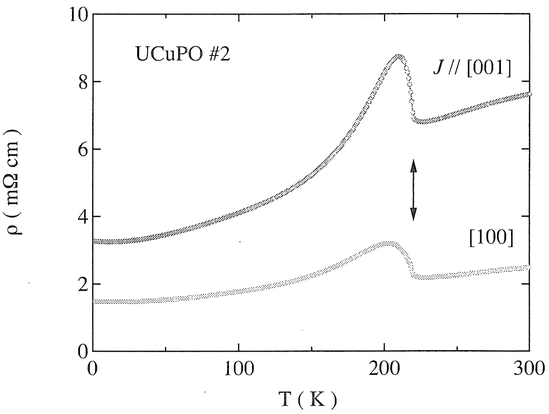


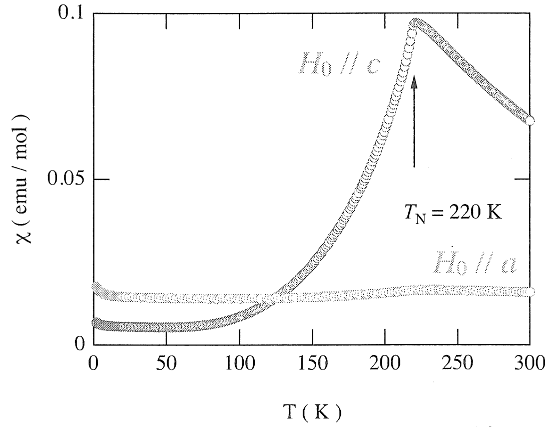
ThCuPO

UCuP2

Actinide-based oxypnictides:

Single crystals grown by chemical transport.
H. Sakai (JAEA)





Resistivity and susceptibility for UCuPO

Large ρ-values

semi-metallicity

ρ-jump at T_N

Strong anisotropy in χ

Sharp drop at T_N

Localized U-moment

Non-magnetic Cu ions (χ for ThCuPO)

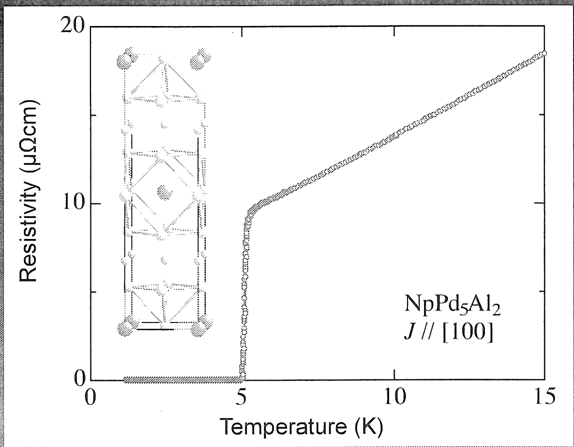
AF-structure?

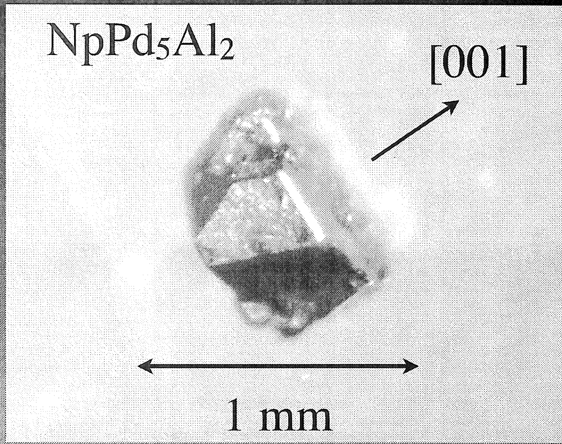
Polycrystal work reported by D. Kaczorowski et al. J. Alloys Compds. 216 (1994) 117.

$NpPd_5Al_2$
First Np-based HFSC

T_c=5K, large γ, 5f magnetism, 1st order-transition at H_{c2}....
new family of RE- An- intermetallics

UPd_5Al_2 (Haga, Ikeda, et al.), $PuPd_5Al_2$ (Gofryk et al.)
$CePd_5Al_2$ (Ribeiro et al.)





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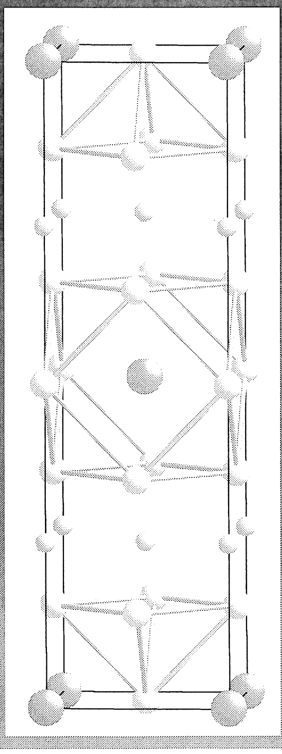
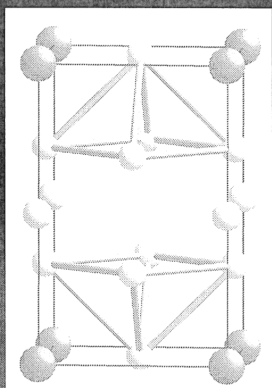
crystal structure

$NpPd_5Al_2$ $PuRhGa_5$ $T_c = 9$ K

Np
Pd
Al





Pu
Ga
Rh

- structural similarity with Pu-115 structure
- large coordination 12 Pd : 5f delocalization ?

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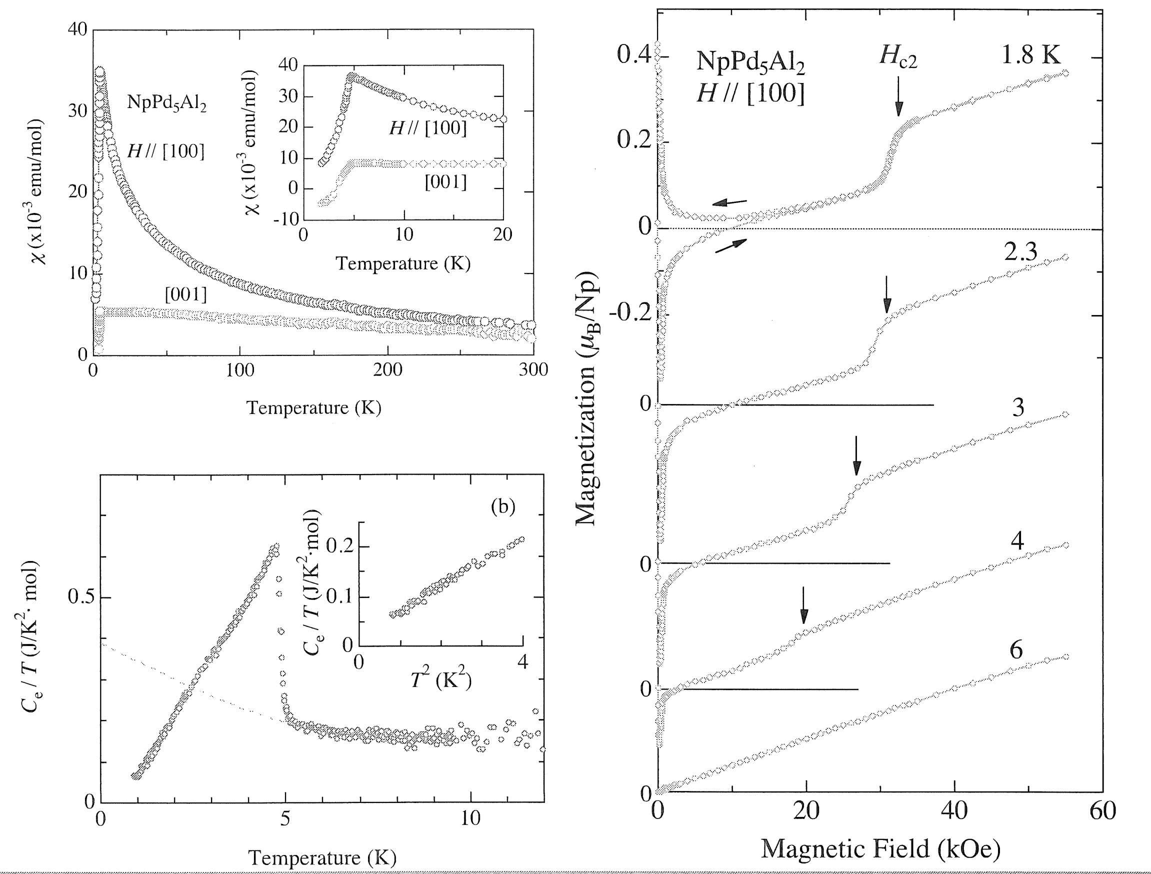

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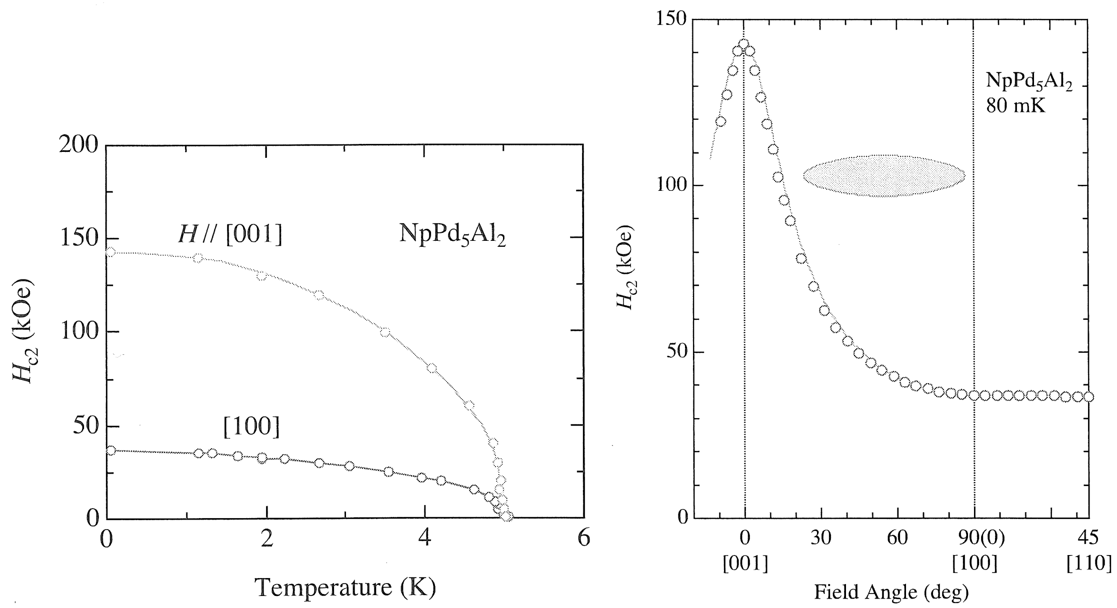
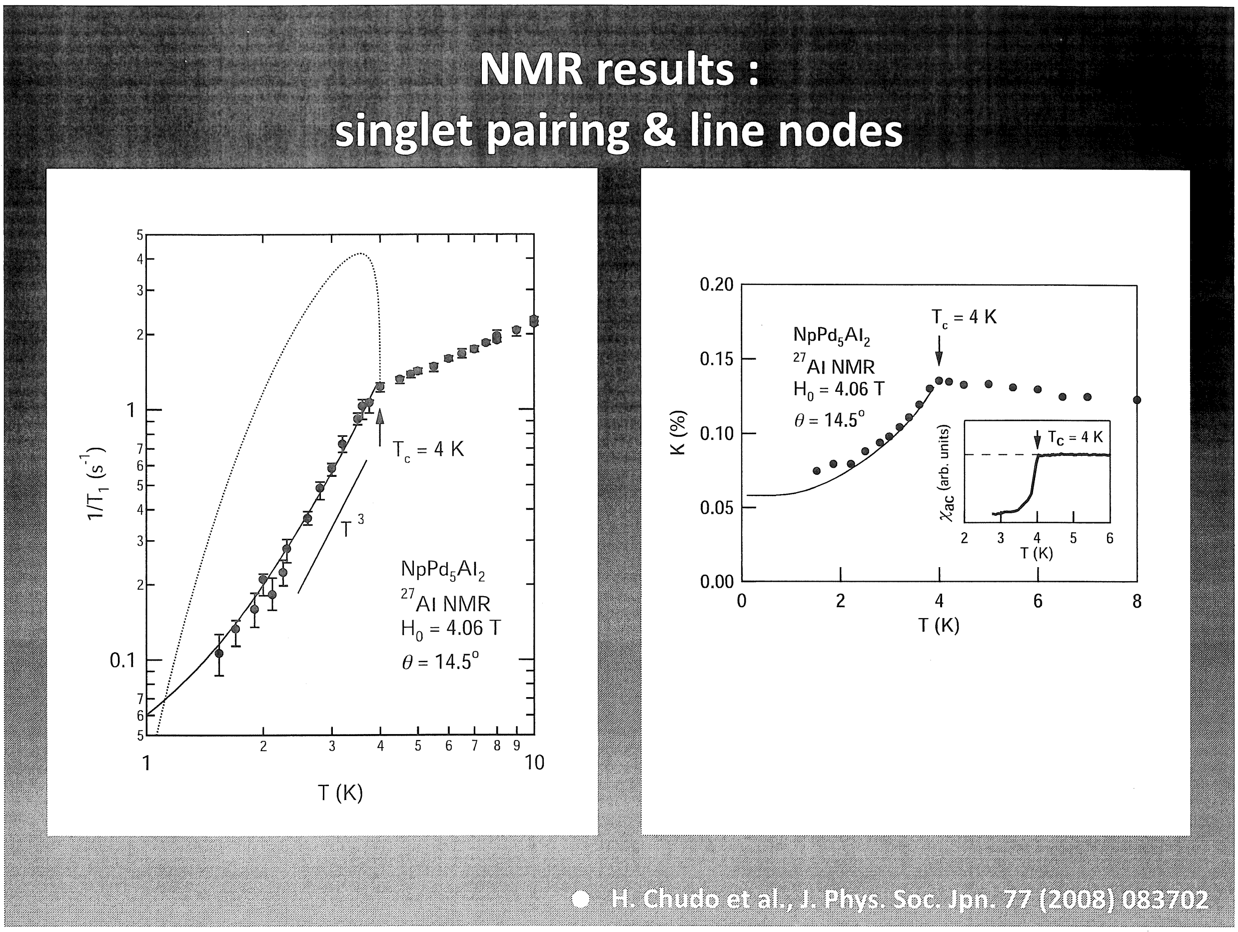
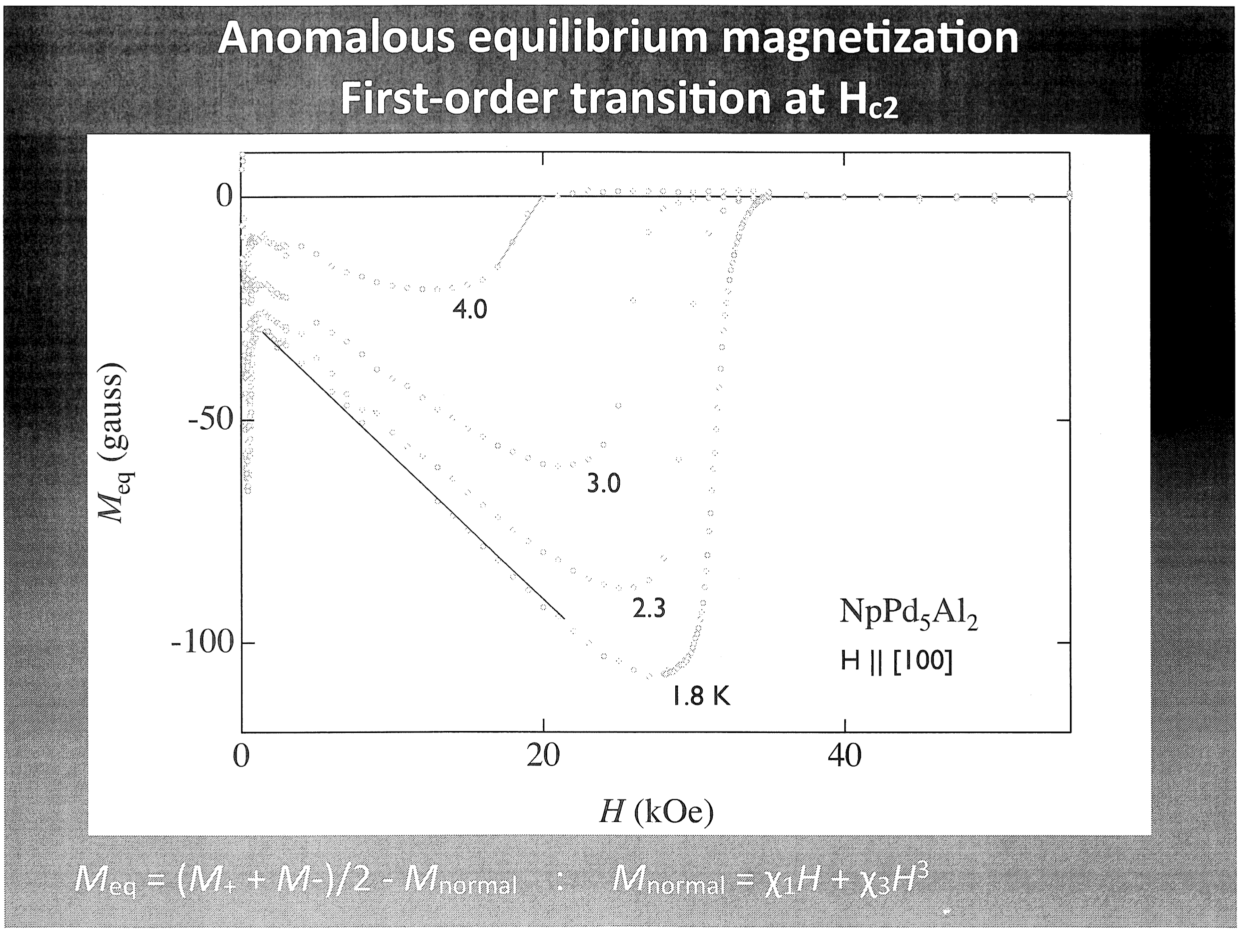
NpPd$_5$Al$_2$ superconductivity strongly anisotropic H_{c2}



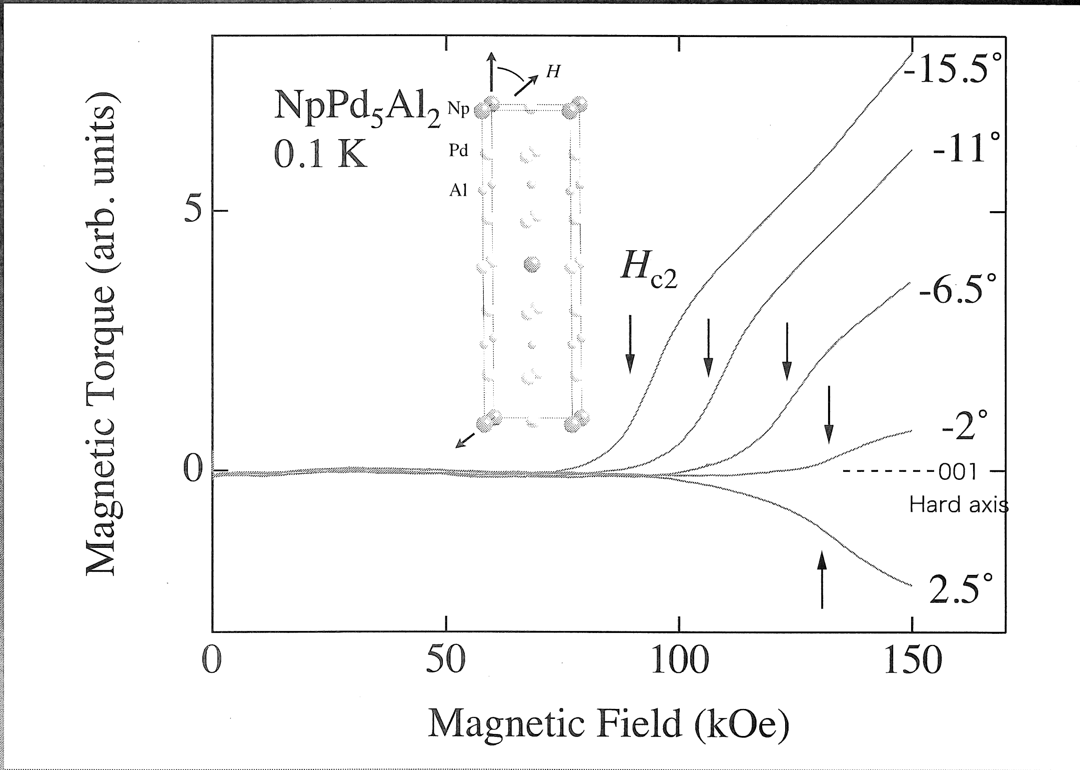
D. Aoki, Y. Haga et al., J. Phys. Soc. Jpn. 76 (2007) 063701.


NMR results :
singlet pairing & line nodes
1/T1 (s-1)
T (K)
Tc = 4 K
T 3
NpPd5Al2
27Al NMR
H0 = 4.06 T
θ = 14.5°
K (%)
χac (arb. units)
● H. Chudo et al., J. Phys. Soc. Jpn. 77 (2008) 083702


Anomalous equilibrium magnetization
First-order transition at Hc2
Meq (gauss)
H (kOe)
4.0
3.0
2.3
1.8 K
NpPd5Al2
H || [100]
Meq = (M+ + M-)/2 - Mnormal : Mnormal = χ1H + χ3H3

Magnetic Torque : First-order transition at H_{c2} in all directions

$$\tfrac{1}{2}\chi_a H_{c2}(a)^2 \approx \tfrac{1}{2}\chi_c H_{c2}(c)^2$$



Summary

1. role of *f*-electrons in RE-oxypnictide : structural tuning ?
   how about 5*f*-electrons ?

   5*f*-electrons usually delocarize to participate in conduction.
   Also show magnetism with strong anisotropy

2. single crystal growth of Actinide oxypnictide
   UCuPO : AF ground state

3. What happens when 5*f*-electrons superconduct ?
   New material : $NpPd_5Al_2$
   - strong Pauli-limited superdoncutor - 1st order H_{c2}
   - a new family of RE- and actinide-compounds
     UPd_5Al_2 : paramagnet, $PuPd_5Al_2$: AF
     $CePd_5Al_2$: AF, pressure-induced SC