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Interface enhanced superconductivity at 2D limit and potential to topological superconductivity in 3D Dirac semimetal

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量子物质科学协同创新中心

COLLABORATIVE INNOVATION CENTER OF QUANTUM MATTER

Supported by Ministry of Science and Technology of China & National Science Foundation of China

- **Part I: First direct evidences of high Tc in 0.55 nm thick FeSe films**

Chin. Phys. Lett. 31, 017401(2014)

Highlighted in Editors' Choice: Science 343, 230 (2014)

Scientific Reports 4, 6040(2014)

- **Part II: Detection of a new superconducting phase in 2D limit: a two-atom layer Ga film grown on semiconducting GaN(0001)**

Physical Review Letters 114, 107003 (2015) (Editors' Suggestion)

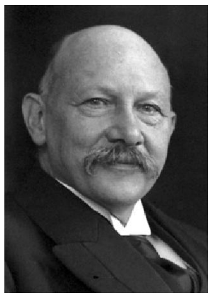
- **Part III: Potential to topological superconductivity in 3D Dirac semimetal**

arXiv:1412.0330

arXiv:1501.00418

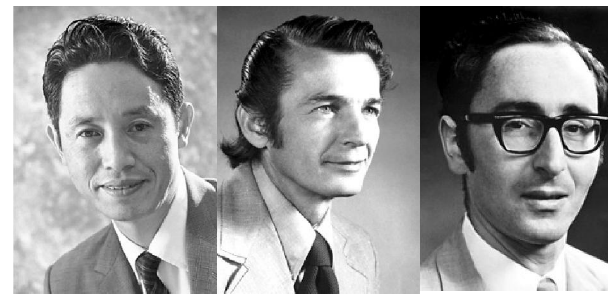
Nobel Prize

The Nobel Prizes in superconductivity 1913 1972 1973 1987 2003

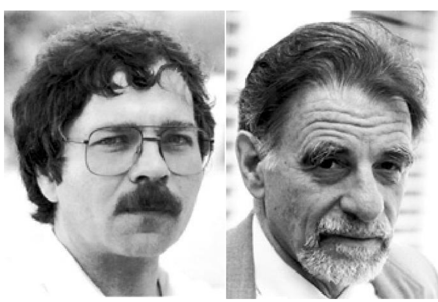


Heike Kamerlingh Onnes

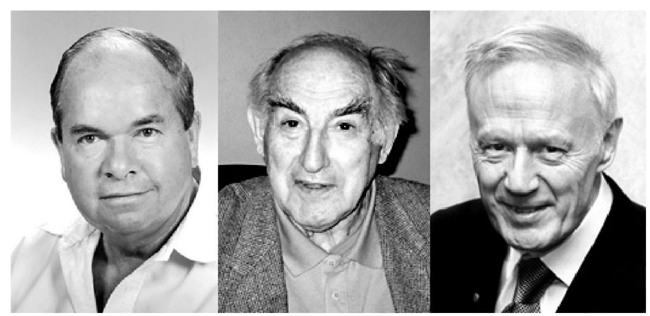
John Bardeen Leon Neil Cooper
John Robert Schrieffer



Leo Esaki Ivar Giaever
Brian David Josephson



J. Georg Bednorz
K. Alexander Müller



Alexei A. Abrikosov Vitaly L. Ginzburg Anthony J. Leggett

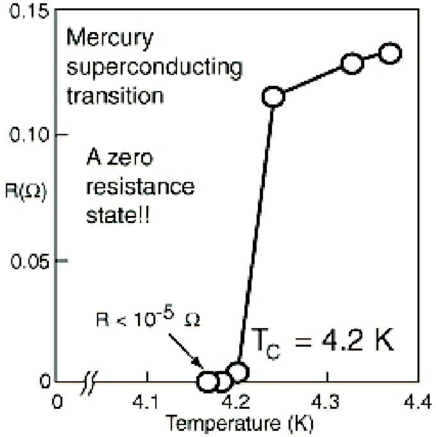
What's superconductivity?

- **Basic Phenomena:**

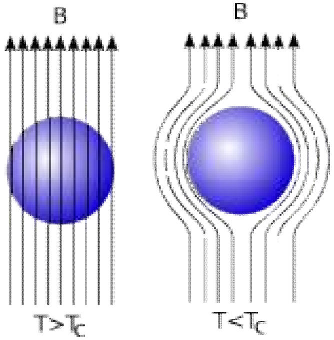
(i) Disappearance of resistance

(ii) Perfect Diamagnetism (Meissner Effect)

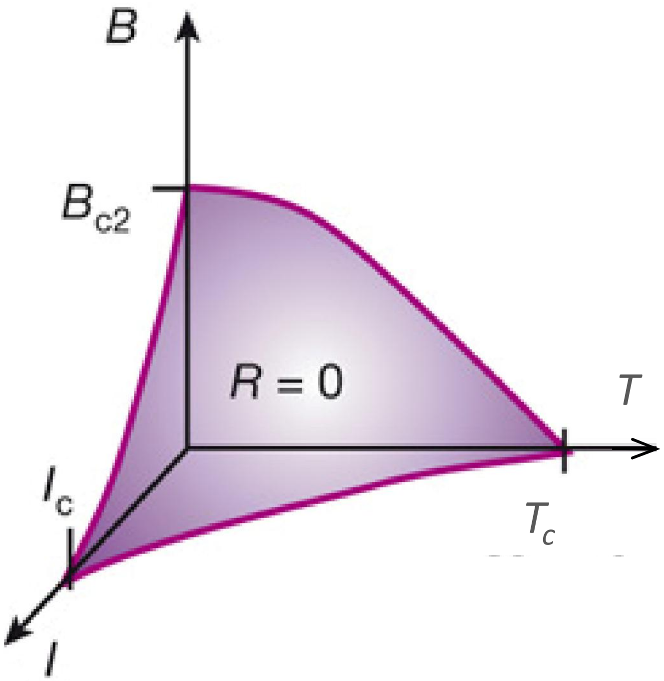
Kamerlingh-Onnes (1911)



H. K. Onnes, Commun. Phys. Lab.12,120, (1911)



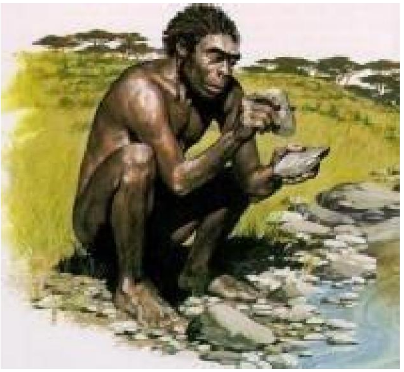
Meissner effect (wikipedia)



Superconducting Phase Diagram

Why superconductor important?
Human's History

Stone Age (Insulator Age)



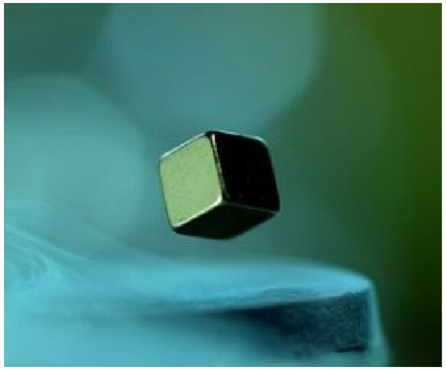
Iron Age (Conductor Age)

Today's Mankind

Information/Semiconductor Age

Our Tomorrow: Superconductor Age?

Superconductor

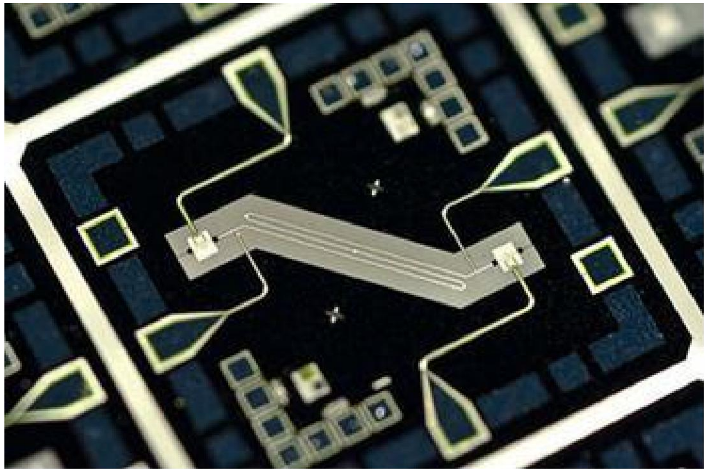


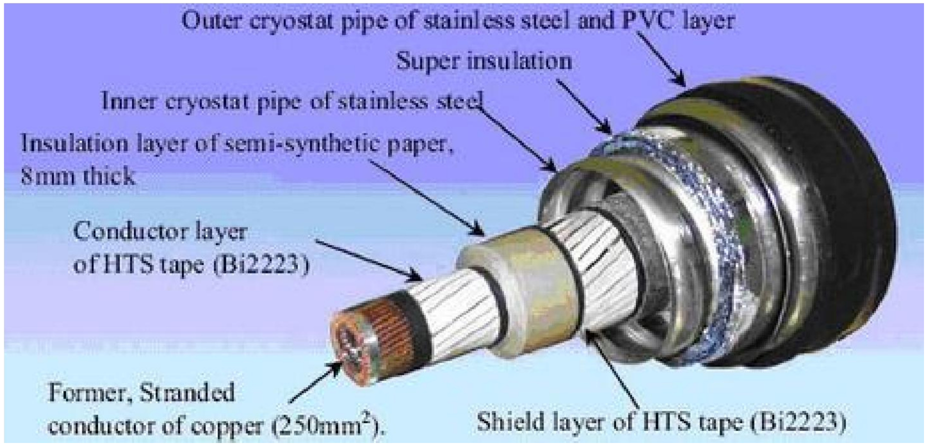
Dream and Aim

Room Temperature Superconductor?

Avatar

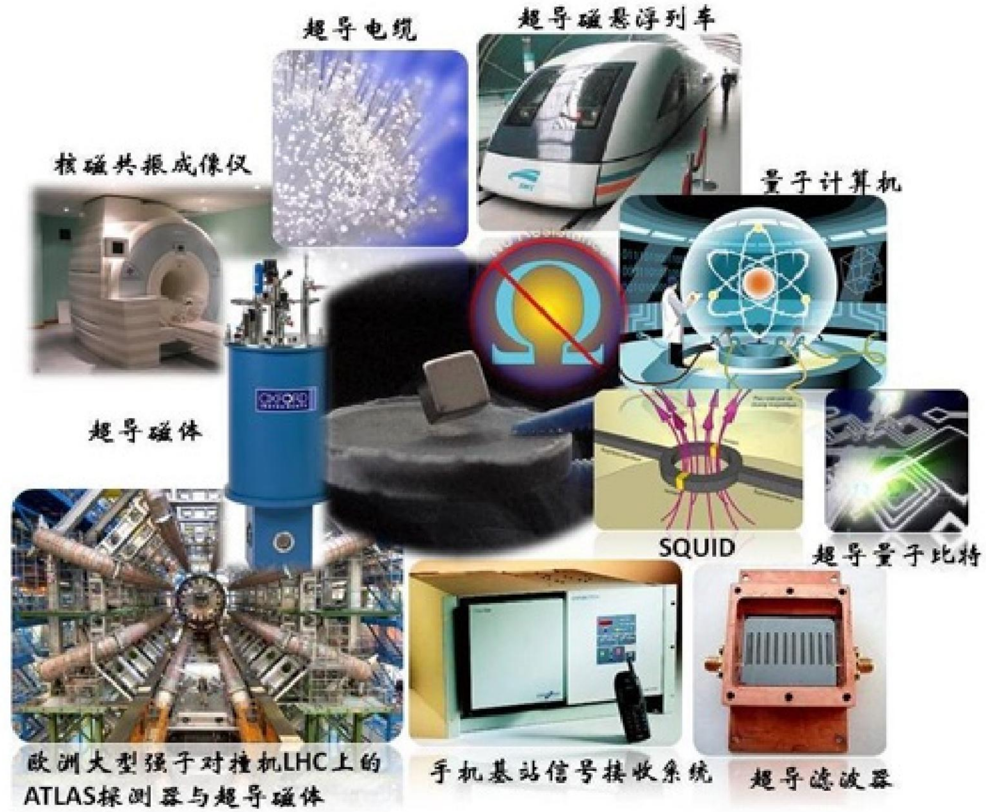
Applications in electronics and electricity:





Our Tomorrow: Superconductor Age?

Cable



Next generation of technology revolution?

Two-dimensional superconductivity

Let us begin by introducing the specific scales involved and systems of interest. A superconductor with one, two or three dimensions smaller than ξ is in the quasi-two-dimensional (2D), quasi-one-dimensional (1D) or quasi zero dimensional (0D) regime respectively. For most conventional superconductors, ξ is of the order of microns. Therefore, systems falling in the 2D, 1D or 0D category are nanoscale systems. According to Hohenberg-Mermin-Wagner theorem (Hohenberg, 1967; Mermin & Wagner 1966), in these reduced dimensionality systems, fluctuations should destroy superconducting order even at low temperature. In 2D samples, the Berezinski-Kosterlitz-Thousless transition occurs, enabling superconducting order to exist at low temperature. However, the existence, limits

*Meenakshi Singh, Yi Sun , **Jian Wang**,"Superconductivity in nanoscale systems", Book chapter of "Superconductors-Properties,Technology, and Applications", ISBN 979-953-307-233-2, InTech - open science | open minds*

Why 2D important?

Our present information technology is based on the “in-plane” fabrication technique.

Previous achievements in 2D superconductors
1. Superconductivity in amorphous films (superconductor insulator transition)

Films Grown on a-Ge Substrates-Homogeneous?(amorphous)

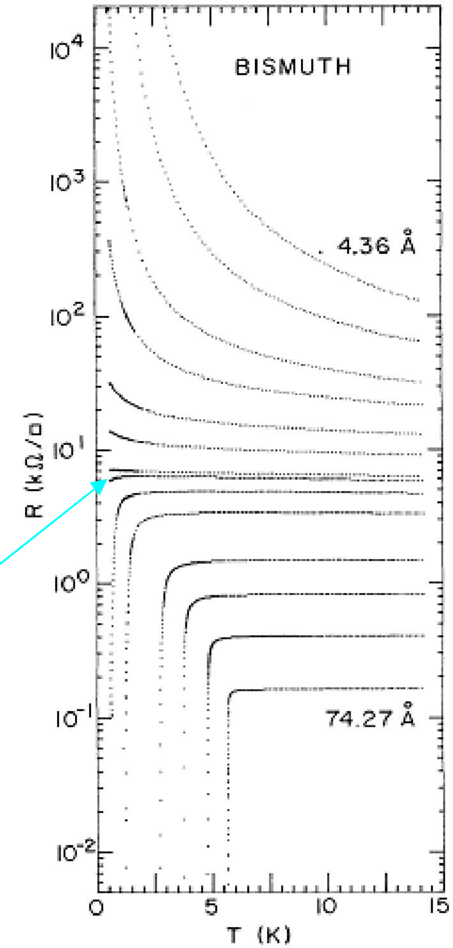
However, no information for morphology and quality of the films due to the technical limitation at that time.

Cyclic evaporation leads to evolution of superconductivity with thickness.

Apparent separation between superconducting and insulating behavior.

Critical resistance close to $h/4e^2 = 6450\ \Omega$

Bi film deposited on Ge. Film thicknesses shown range from 4.36 to 74.27 Å



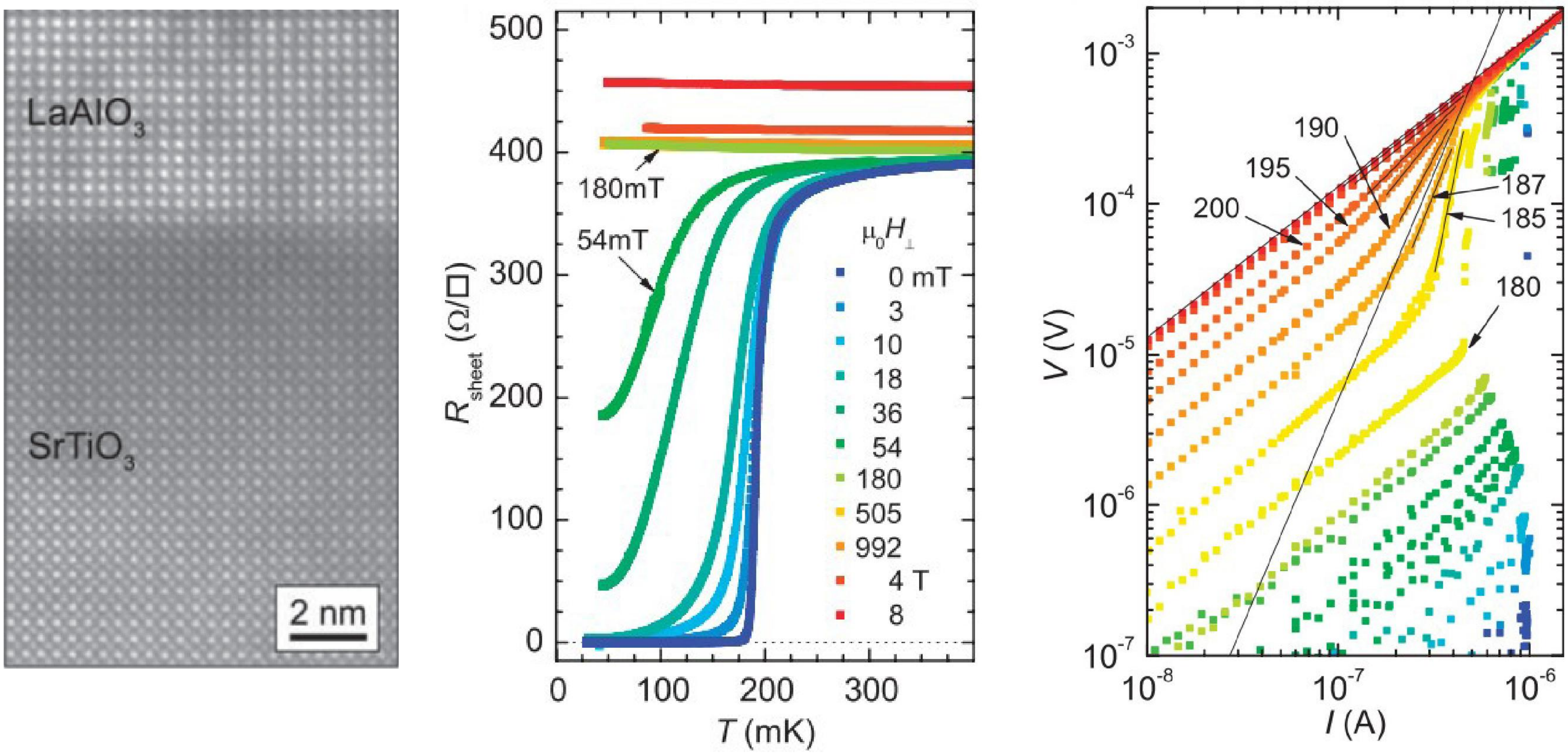
Haviland,Liu, and Goldman Phys.Rev.Lett.62,2180(1989)

The existence of an unstable fixed point at T=0 separating insulating and superconducting behavior

2015 Oliver E. Buckley Condensed Matter Physics Prize Recipient(s):

Aharon Kapitulnik
Stanford University
Allen Goldman
University of Minnesota
Arthur Hebard
University of Florida
Matthew Fisher
University of California, Santa Barbara

2. Interface superconductivity

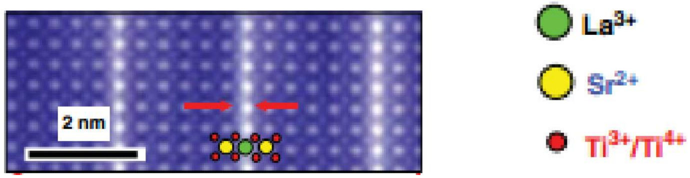


- ➢ **The electron system at the interface is that of a two-dimensional superconductor;**
- ➢ **The superconducting transition temperature is of 200 mK;**
- ➢ **A clear signature of the BKT transition is found in V-I curves.**

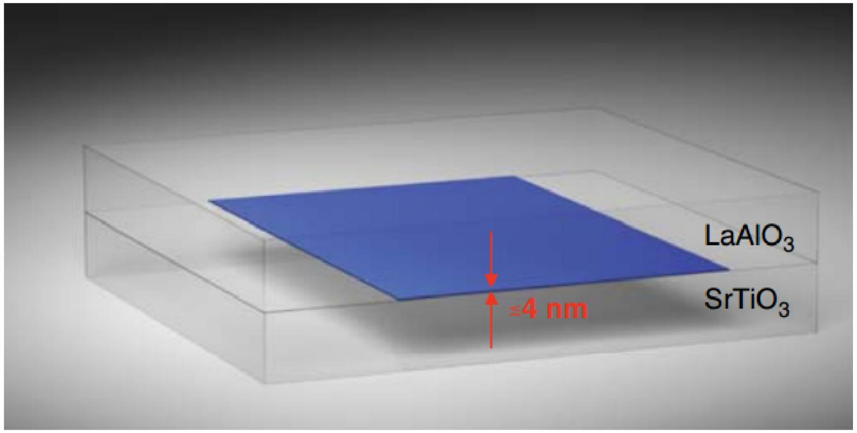
Superconductivity at $LaAlO_3/SrTiO_3$ interface

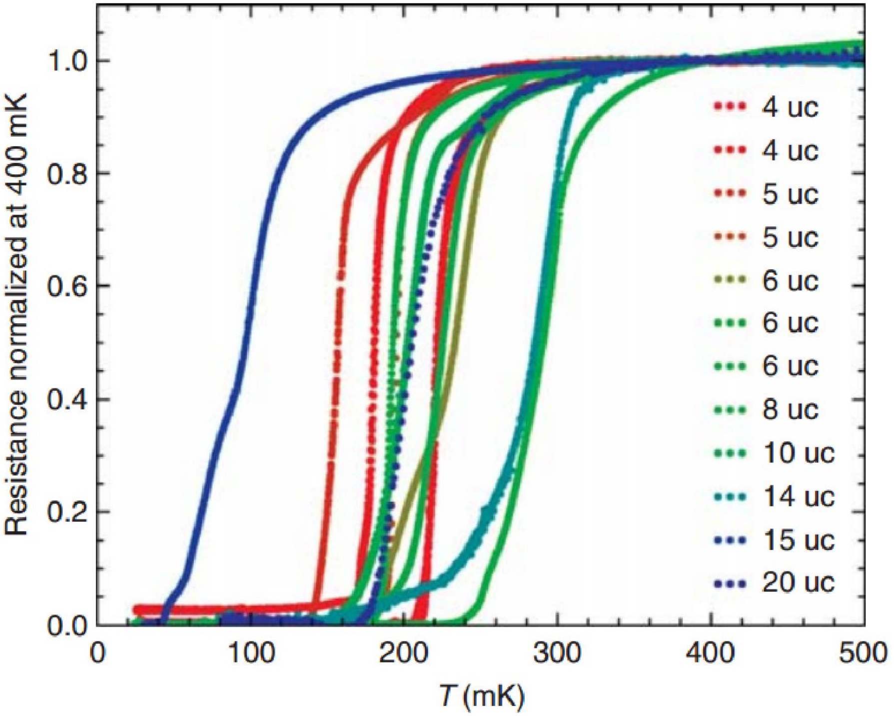
N. Reyren et al. Science 317, 1196 (2007)

Superconductivity at $LaAlO_3/SrTiO_3$ interface



- The thickness of the superconducting sheet is estimated to be less than ~4 nm.





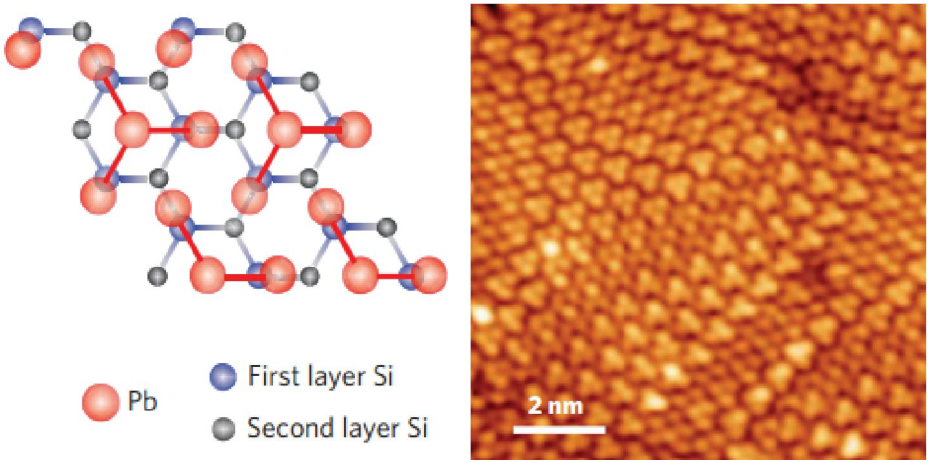
- In such samples, a superconducting transition with a critical temperature of ~ 200 mK is commonly observed.

Tc is too low and the thickness of superconducting layer is 4 nm, which may be beyond 2D limit.

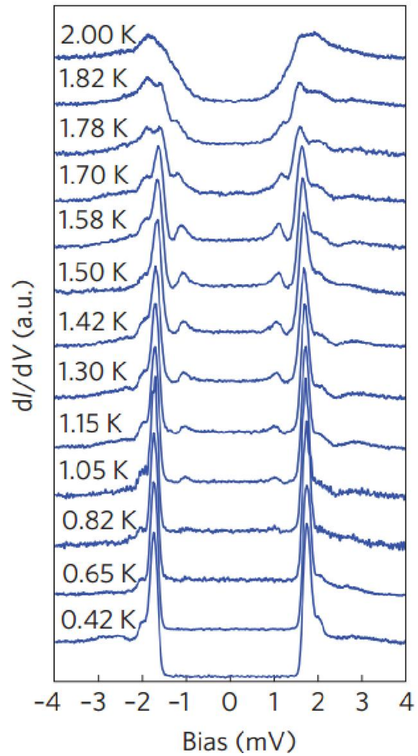
J. Mannhart, et al. MRS Bulletin 33,1027(2011)

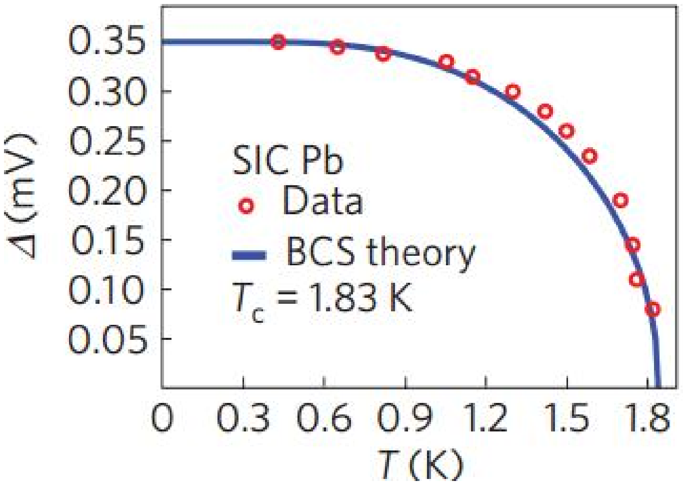
3. Superconductivity in the thinnest single crystalline films

Superconductivity in one-atomic-layer Pb film



Atomic structural model and High-resolution STM images of the striped incommensurate -Pb





- **The film shows a superconducting transition temperature of 1.83 K for an atom areal density n_s= 10.44 Pb atoms nm^{-2}. (Tc of bulk Pb is 7.2 K)**

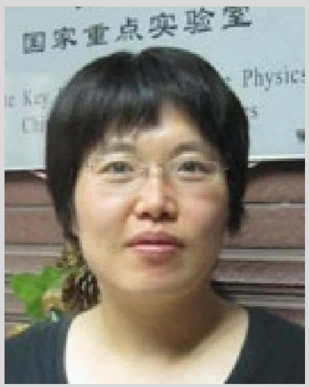
Zhang *et al.*, Nature Physics 6, 104 (2010)

Part I: Direct evidence of high Tc in 0.55 nm thick FeSe film

Major Collaborators:

Tsinghua University


Prof. Qi-Kun Xue

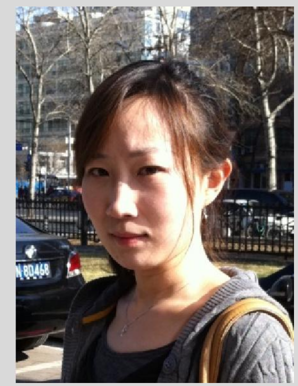


Prof. Lili Wang


Prof. Xucun Ma


Dr. W. Zhang

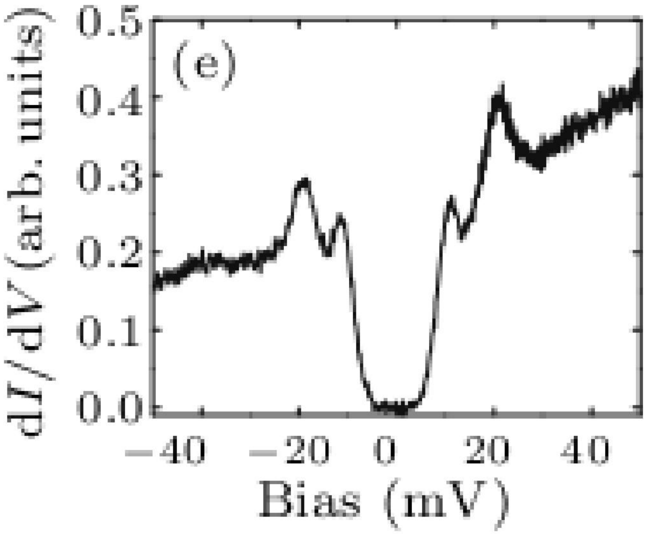
Peking University


Dr. Yi Sun

Other collaborators: **ZHANG Jin-Song, LI Fang-Sen, GUO Ming-Hua, ZHAO Yan-Fei, ZHANG Hui-Min, PENG Jun-Ping, XING Ying, WANG Hui-Chao, FUJITA Takeshi, HIRATA Akihiko, LI Zhi, DING Hao, TANG Chen-Jia, WANG Meng, WANG Qing-Yan, HE Ke, JI Shuai-Hua, CHEN Xi, WANG Jun-Feng, XIA Zheng-Cai, LI Liang, WANG Ya-Yu, CHEN Ming-Wei**

Previous studies in one unit cell (1UC) FeSe film on STO substrate:

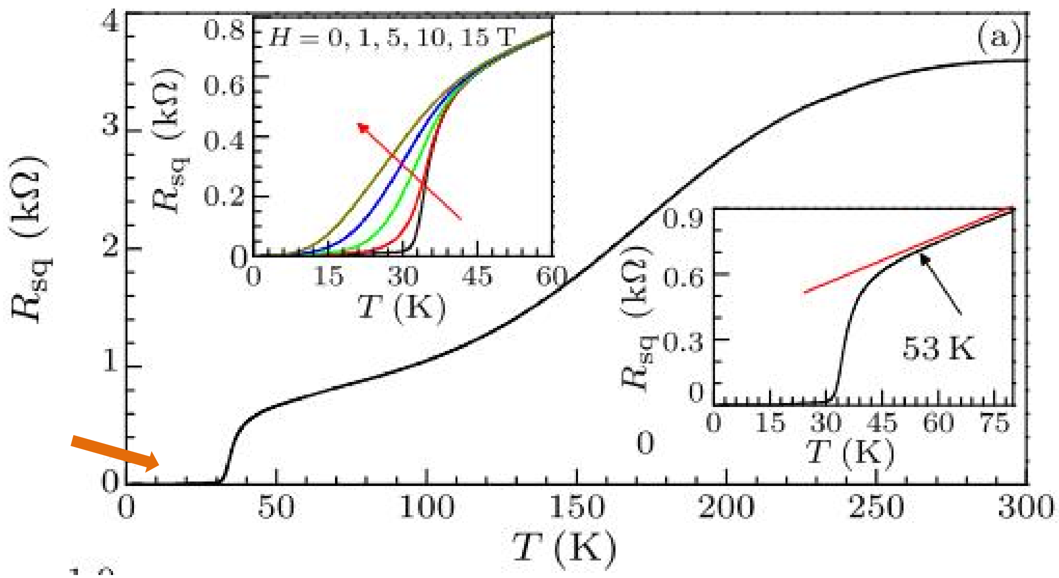
Qi-Kun Xue Team: Chin. Phys. Lett. 29, 037402 (2012)



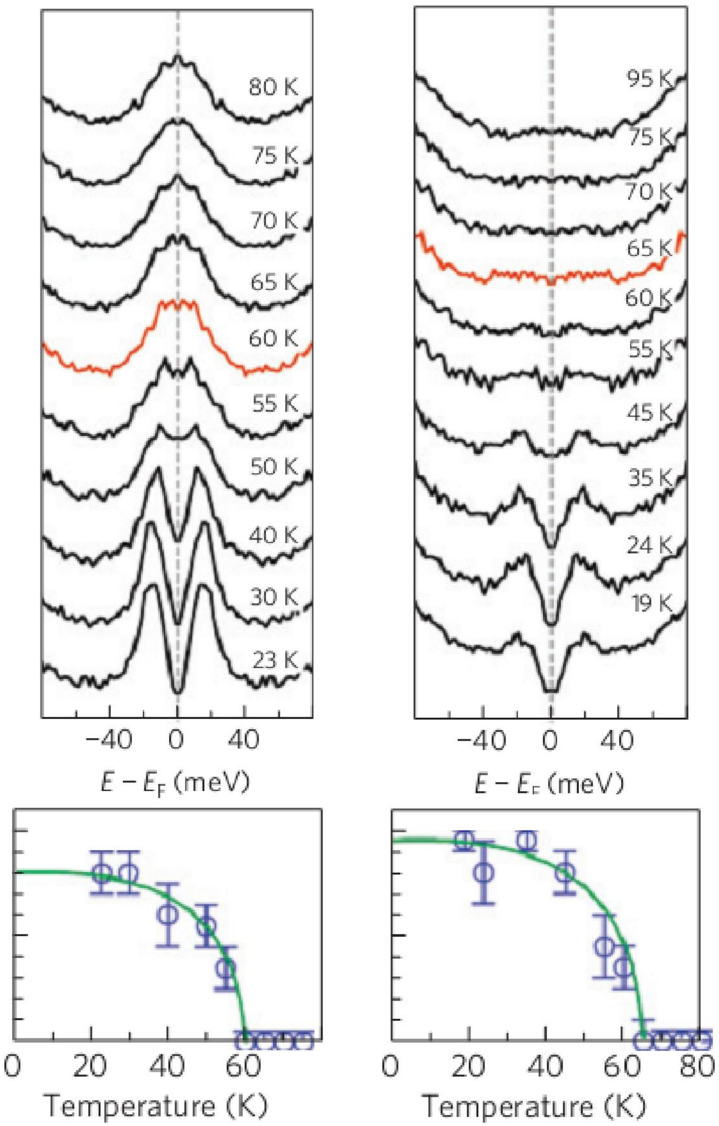
1UC-FeSe film on Nb-doped STO substrate

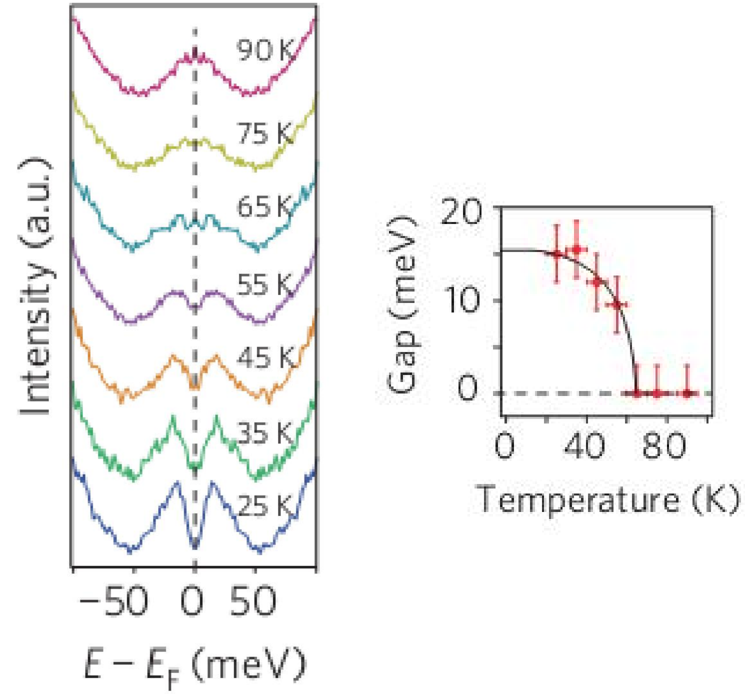
The large superconducting-like gap Δ=20.1 meV by STM

5UC-FeSe film with Si capping layer



Small residual resistance





Single-layer FeSe films grown on $SrTiO_3$ substrates by ARPES:

Estimated $T_c \sim$ 65 K ± 5K

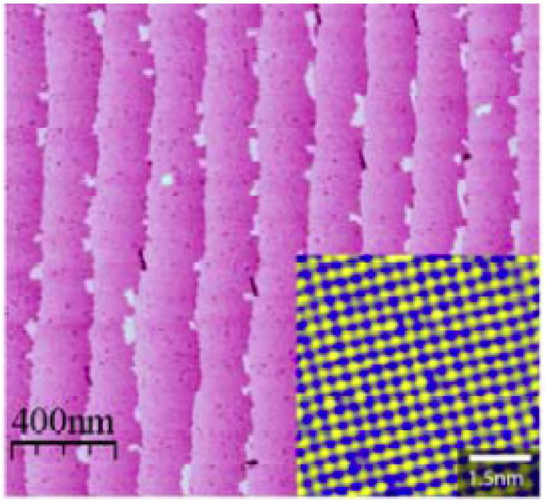
Is the gap real superconducting gap?

X. J. Zhou: Nature Mater. 12, 605 (2013).
D. L. Feng: Nature Mater. 12, 634 (2013).

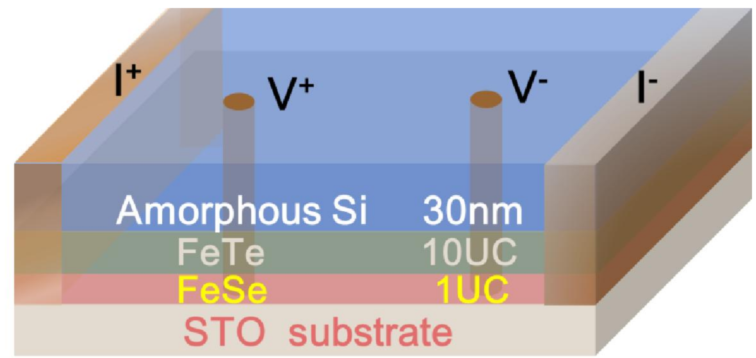
The Greatest Challenge: direct transport and Meissner effect evidences for high T_c in 1 UC (0.55nm) thick FeSe films!

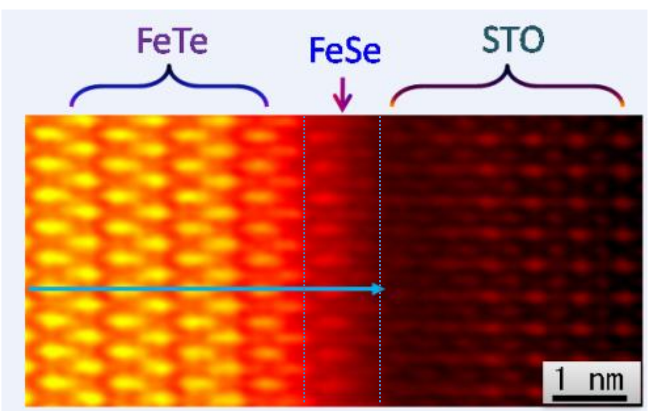
Our work was to achieve direct transport and Meissner effect evidences for high Tc 1 UC (0.55nm) thick FeSe films!

Is it possible to measure 1UC FeSe by *ex situ* measurements?



STM image of atomic flat FeSe film grown in ultrahigh vacuum (UHV) chamber





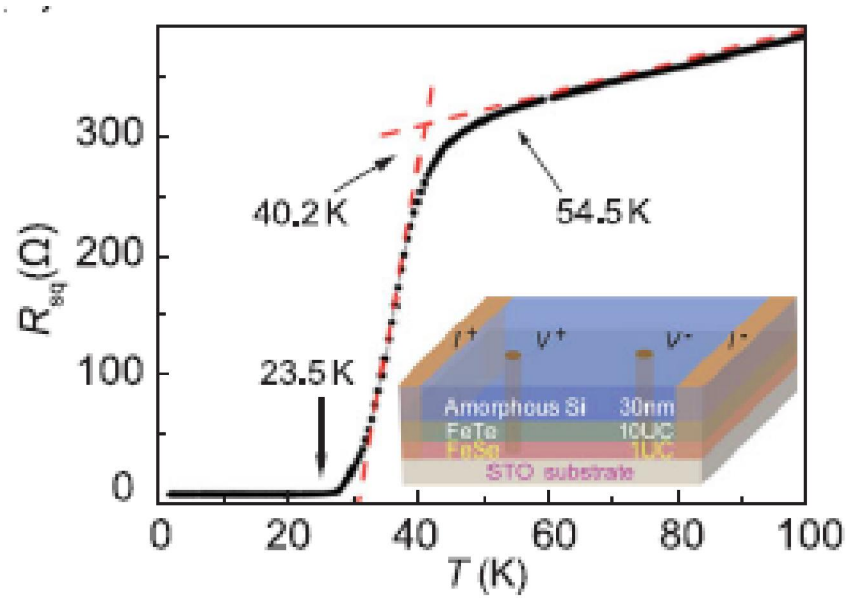
TEM image of 0.55 nm thick FeSe film with FeTe protection layer

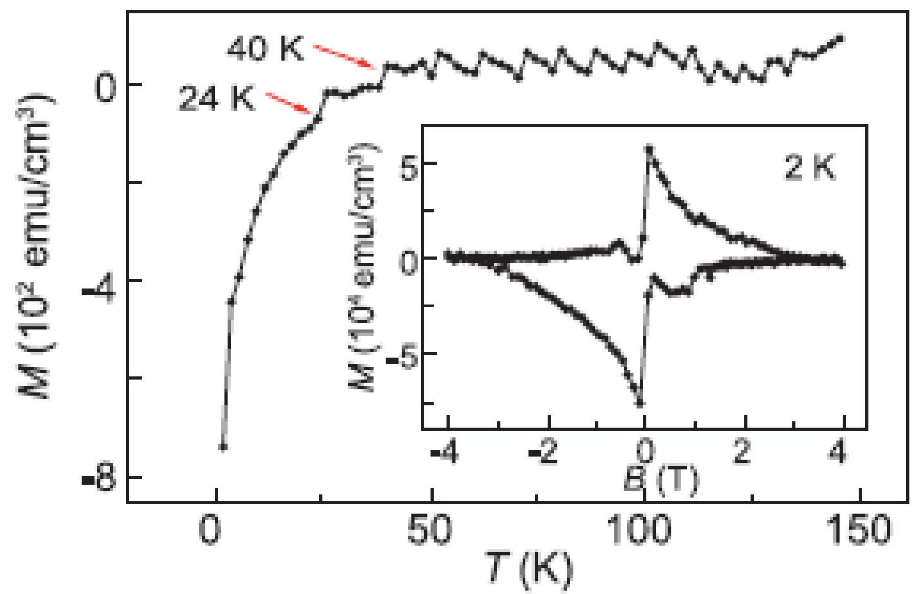
A schematic structure for *ex situ* measurements

CHIN. PHYS. LETT. 31, 017401(2014); arXiv:1311.5370

First direct evidence of superconductivity in 0.55nm thick FeSe films on insulating STO: extremely interface enhanced superconductivity

We might be first group to obtain Meissner effect in such thin superconducting films!



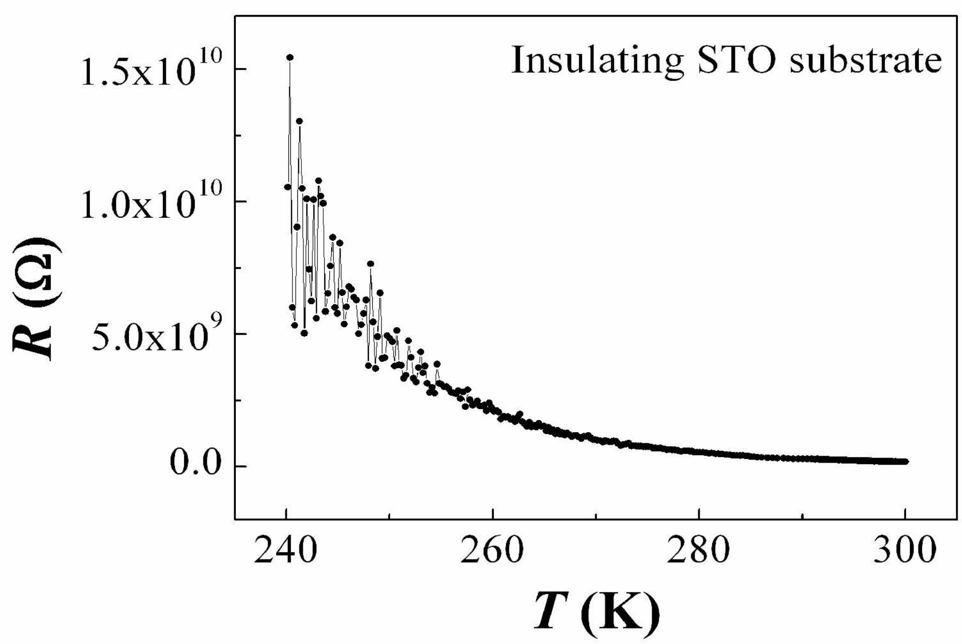


The onset Tc of 0.55 nm FeSe is above 40 K (high Tc), which is five times larger than that of bulk FeSe.

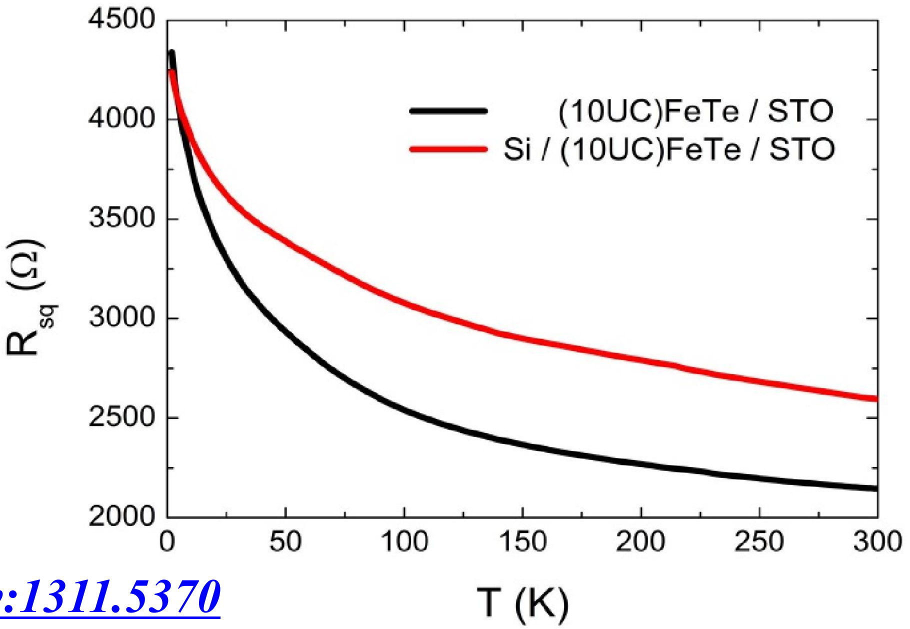
Transport and Magnetization measurements show the zero resistance and Meissner effect, which are direct evidences of superconductivity.

CHIN. PHYS. LETT. 31, 017401(2014); arXiv:1311.5370

The superconducting layer is limited in 0.55 nm thick FeSe film.

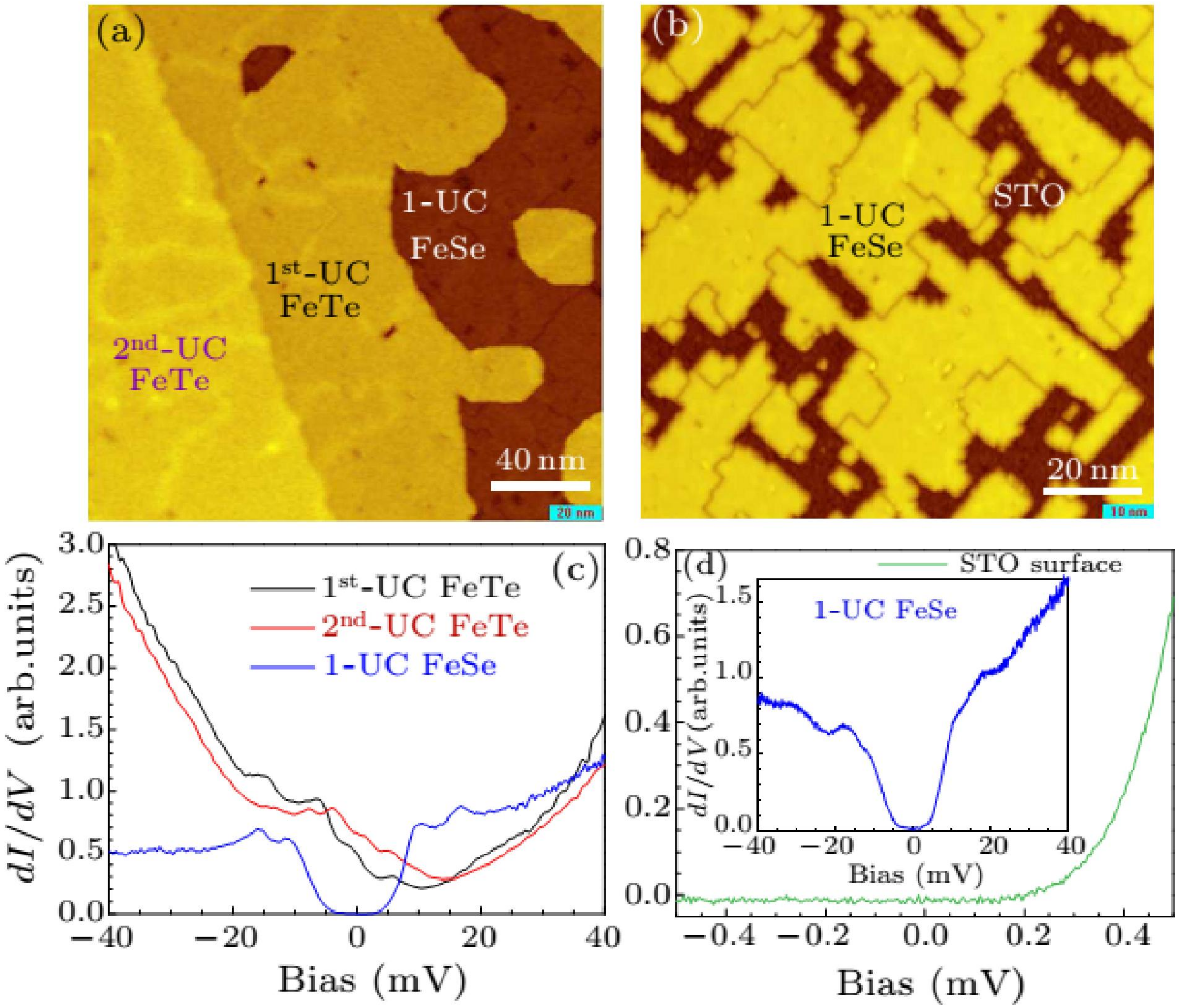


FeTe/Si protection layer



CHIN. PHYS. LETT. 31, 017401(2014); arXiv:1311.5370

Proximity effect cannot make the FeTe layer and STO top surface superconducting.

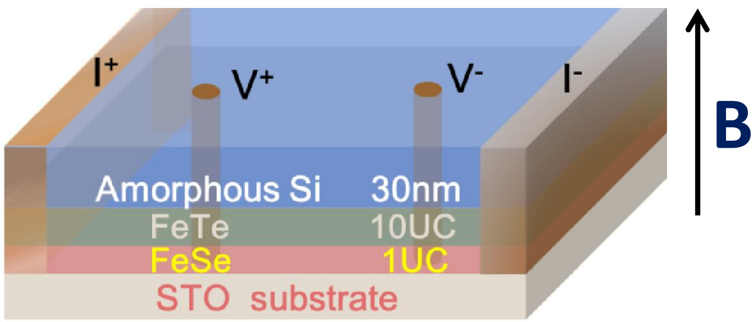


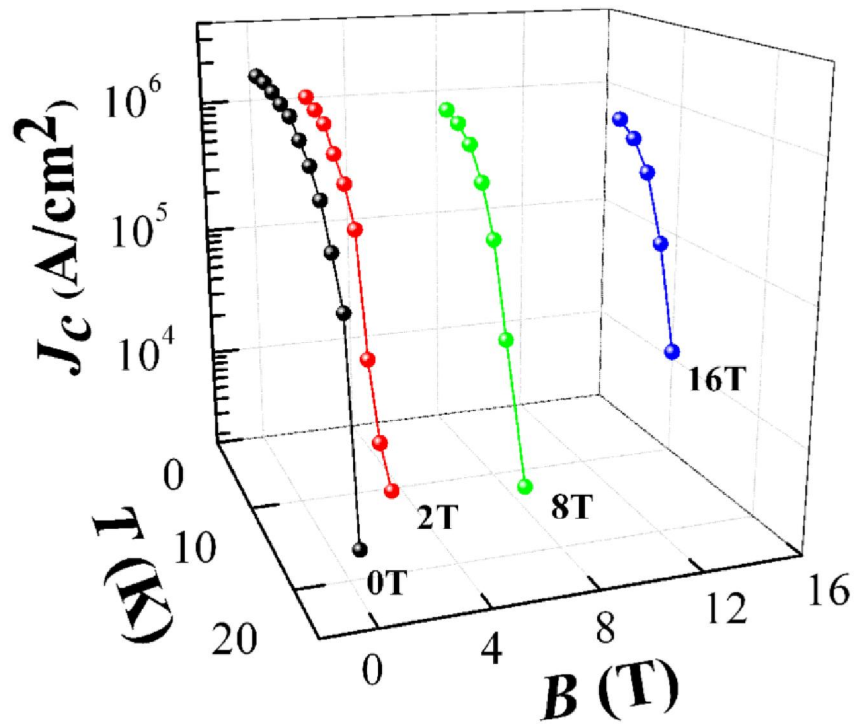
The evidence of charge transfer?

CHIN. PHYS. LETT. 31, 017401(2014); arXiv:1311.5370

0.55 nm thick FeSe superconducting layer: the thinnest high Tc superconductor

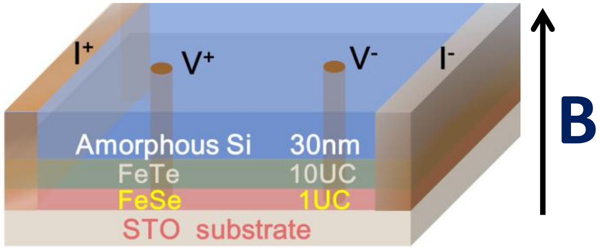
We demonstrated the superconducting layer is limited in 1 UC FeSe, i.e. 0.55nm thick layer.





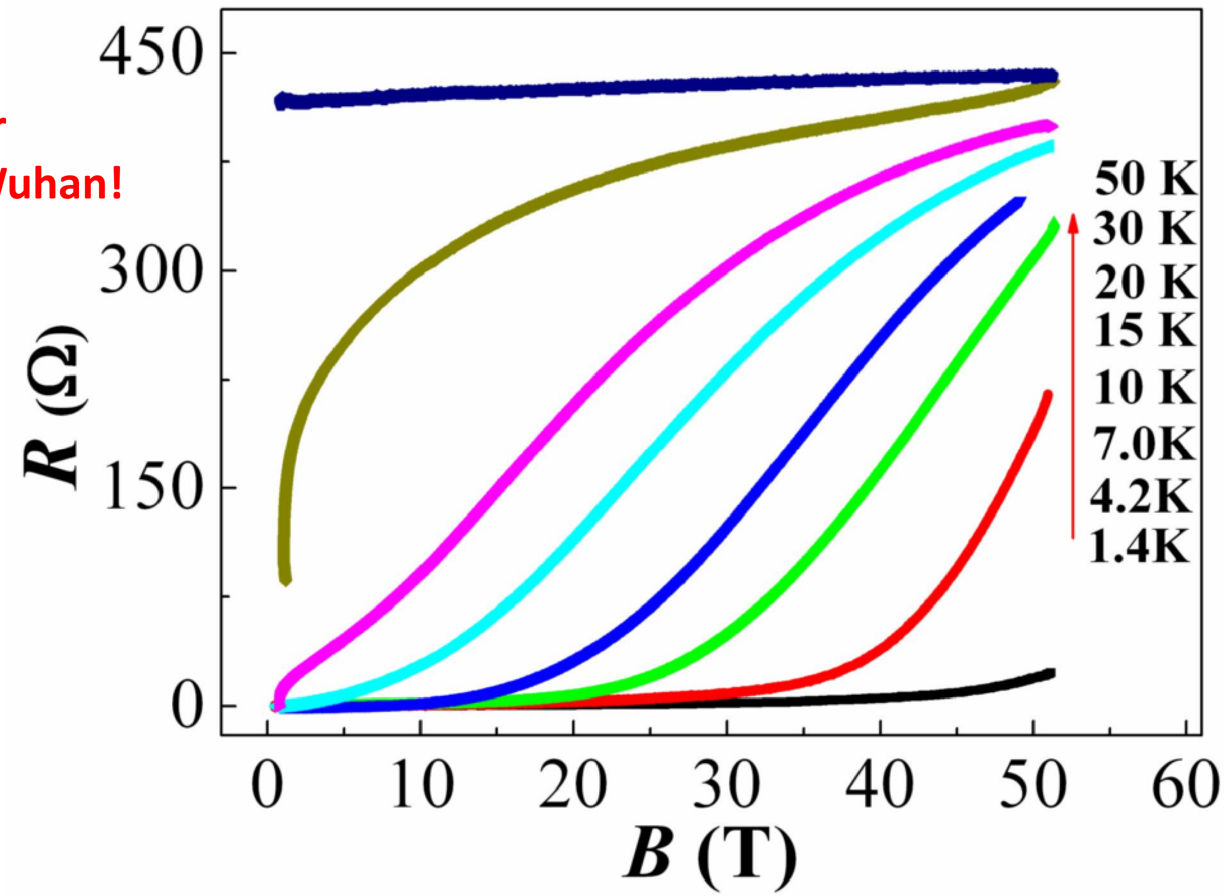
Below 12 K, the critical current density J_c of the film is always larger than 1×10^6 A/cm^2, which is two orders of magnitude higher than that of bulk FeSe (10^4 A/cm^2 at 1.8 K)

CHIN. PHYS. LETT. 31, 017401(2014); arXiv:1311.5370

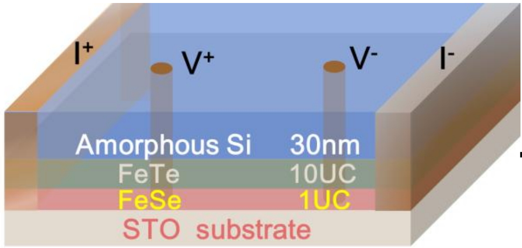


Pulsed Magnetic Field @Wuhan

We are the first user
of high field lab @Wuhan!

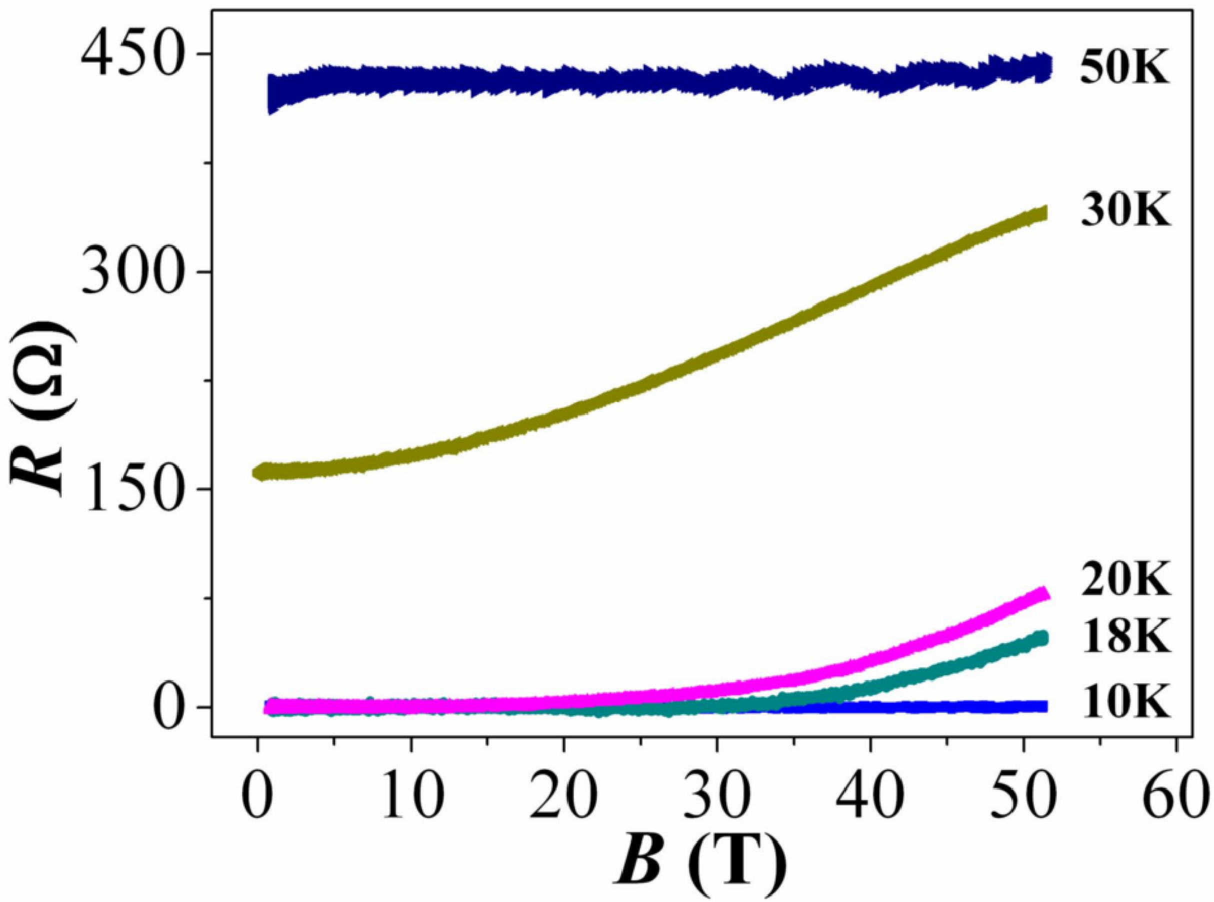


The resistance is significantly lower than the normal state value even at 52 T unless for temperatures close to Tc.
At 1.4 K, the resistance maintains zero up to 40 T.



B

Pulsed Magnetic Field

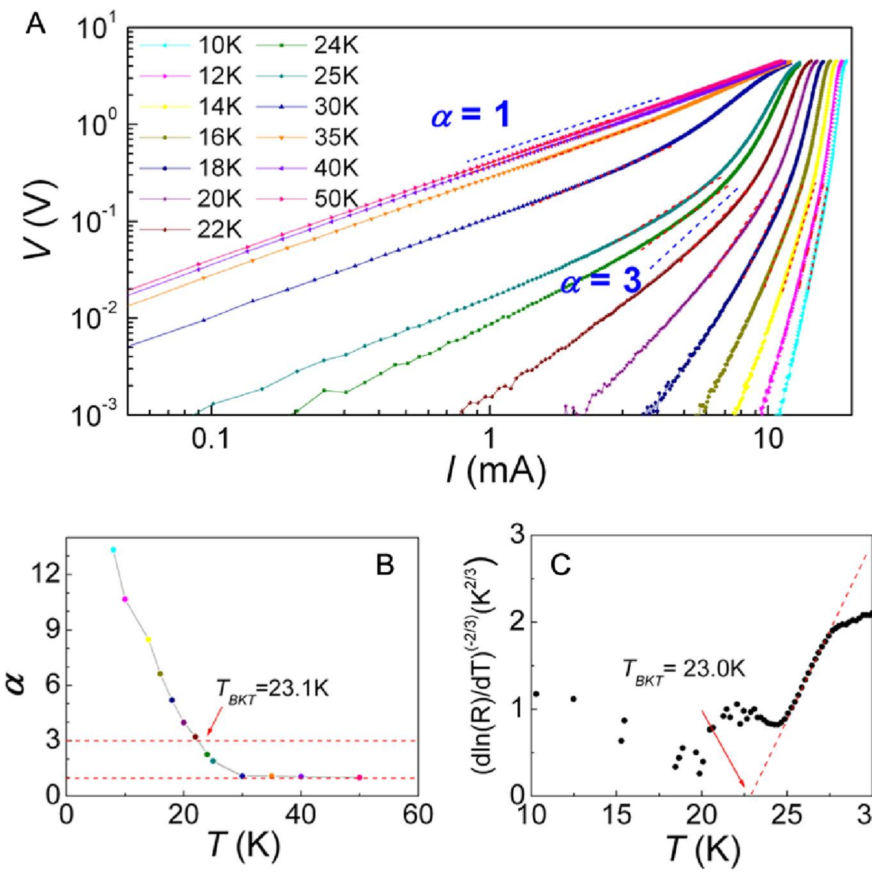


A signature of
2D Superconductivity

In parallel field, the zero resistance state persists at a magnetic field up to 52 T and a temperature of 10 K.

BKT-like phase transition was observed, which may show another signature of 2D superconductivity

At the BKT transition, the current-induced Lorentz force results in a $V \sim I^{\alpha}$ behavior, with $\alpha(T_{BKT}) = 3$

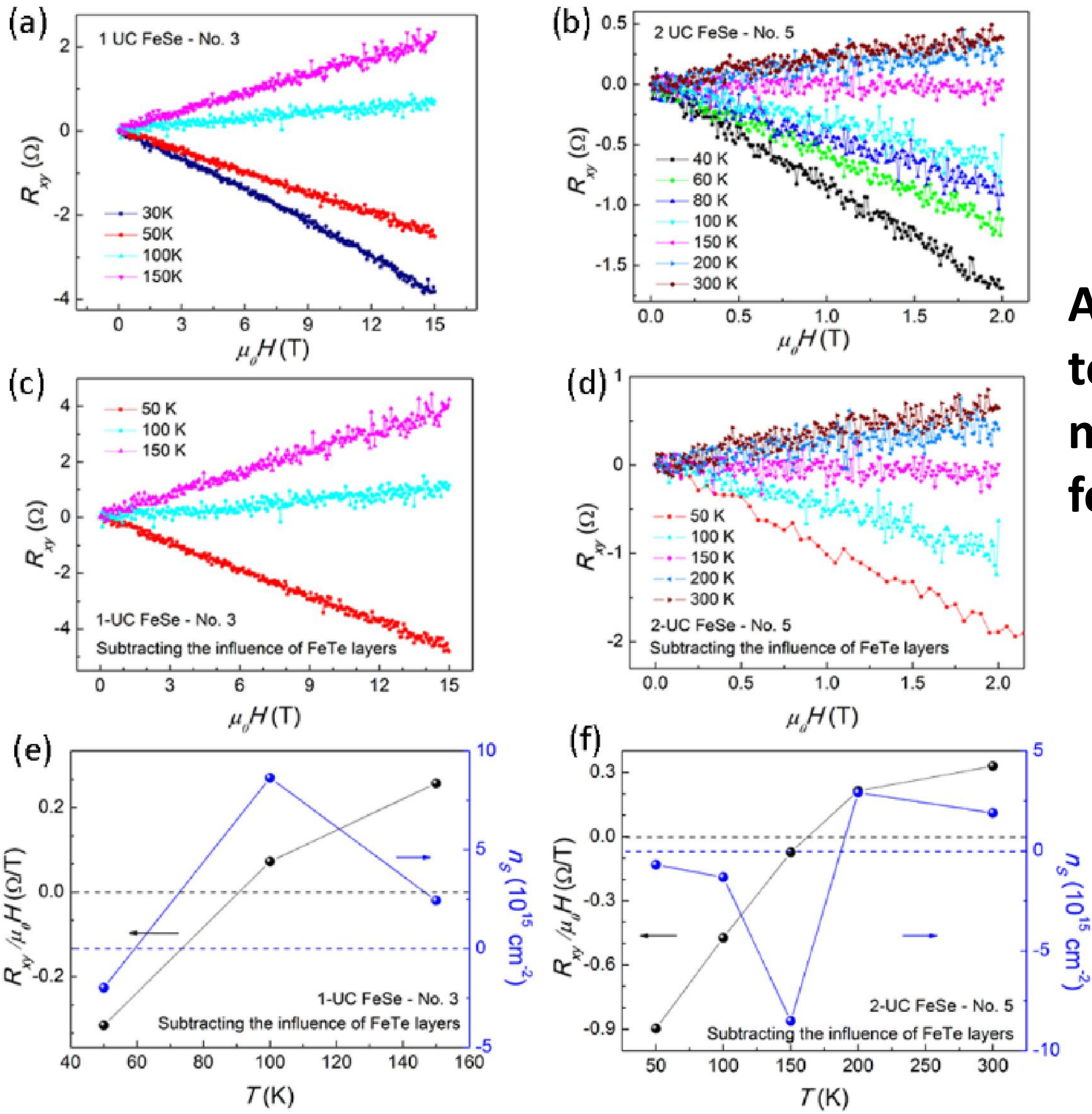


It was predicted that if the superconducting transition of a 2D film is governed by the BKT process, the resistance near the transition temperature T_{BKT} will show a temperature dependence of the form,

$$R(T) = R_0 \exp[-b(T / T_{BKT} - 1)^{-1/2}]$$

CHIN. PHYS. LETT. 31, 017401(2014); arXiv:1311.5370

For 1-UC and 2-UC FeSe films on insulating STO substrates,
the information of carrier density above Tc can be obtained by Hall measurement:



A crossover from p type to n type is observed, which might be a necessary transform for observed high Tc.

More parameters and detailed information, please see:

Y. Sun *et al.*, Scientific Reports, 4, 6040 (2014)

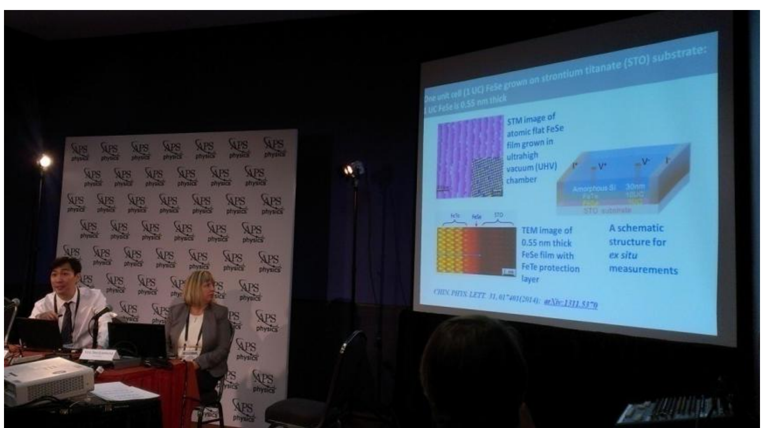
arXiv:1404.3464

CHIN. PHYS. LETT. Vol. 31, No. 1 (2014) 017401 Express Letter

Direct Observation of High-Temperature Superconductivity in One-Unit-Cell FeSe Films *

Our first transport and Meissner effect evidences of high Tc superconductivity in 1 UC FeSe film were published in CHIN. PHYS. LETT. 31, 017401(2014) arXiv:1311.5370

A press conference at 2015 March Meeting



Environmental Protection Agency Air Quality System for 1999–2008, Meng *et al.* investigated the relationship between PbA and PbB since the phase-out of leaded gasoline. They found that the emission sources for lead have changed,

leading to a shift from a fine to a coarse PbA particle size distribution, and show that PbA in coarse airborne particles is a statistically significant predictor of PbB. The PbB levels of children are more sensitive to changes in PbA concentrations than are those of adults. — JFU

Environ. Sci. Technol. 10.1021/es4039825 (2013).

PHYSICS

A Very Thin Superconductor

Manipulating the dimensionality of materials can lead to profound changes in their electronic properties. The iron-based superconductor FeSe has a relatively low superconducting transition temperature T_c of about 8 K in the bulk; however, spectroscopic measurements have suggested that a single-unit-cell layer of this material has a much higher T_c. Transport measurements needed to confirm this finding proved challenging; now, Zhang *et al.* overcome these difficulties by growing the FeSe layer on a $SrTiO_3$ substrate and capping it with FeTe, with an additional layer of Si deposited on top of the FeTe to prevent its exposure to air. By measuring the electrical resistance as a function of temperature, they detected the onset of superconductivity at a temperature higher than 40 K; the critical current density, important for practical applications, was much higher than in the bulk. Because neither the substrate nor the capping layer exhibited superconductivity, and the transport characteristics power laws were consistent with the Berezinskii-Kosterlitz-Thouless transition, the superconductivity appears to be a genuine property of the FeSe layer and has a two-dimensional nature. Because of its relative simplicity, the system presents a good testing ground for unconventional superconductivity. — JS

Chin. Phys. Lett. **31**, 017401 (2014).

Highlighted in Editors' Choice: Science 343, 230 (2014)

Published by AAAS

美国物理学会的《物理》介绍的2015 March Meeting看点

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spotlighting exceptional research

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Notes from the Editors: Snapshots from the 2015 APS March Meeting

Published March 19, 2015 | Physics 8, 25 (2015) | DOI: 10.1103/Physics.8.25

Researchers from industry, universities, and major labs gathered at the annual APS March meeting held in San Antonio, Texas. Here's a selection of this year's presentations.

Hints to High-T_c Superconductivity from a Thin Material?

Researchers still don't know why superconductivity occurs in iron-based compounds—materials that, like cuprates, superconduct at a relatively high temperature. Perhaps answers will come from the recent, and surprising, finding that a single unit cell of FeSe, grown on the insulator $SrTiO_3$, superconducts at a temperature five times higher than its bulk form does. Speaking at a session on superconductivity in two-dimensional materials, Jian Wang of Peking University gave an overview of his measurements, first reported in 2014, showing that a 0.55-nanometer-thick layer of FeSe has an onset of superconductivity around 50 kelvin (K), compared to 8 K for bulk FeSe.

A huge and expensive research effort—almost entirely based in China—is underway to make new samples and explain the effect, which was first seen in surface spectroscopy measurements. In November, researchers at Jiao Tong University in Shanghai reported that they had seen the resistivity of FeSe on $SrTiO_3$ plunge to zero at 109 K. If it can be reproduced by other groups, the result would "change our entire view" of high-temperature superconductivity, said Ivan Bozovic of Brookhaven National Laboratory in a phone call. He said the result is important because the electronic structure of FeSe on $SrTiO_3$ is so much simpler than it is in bulk iron compounds or in the cuprates. If one mechanism explains all three systems—and Bozovic hopes it does—it would suggest that the complex electronic structure of the cuprates and iron compounds isn't essential for high-temperature superconductivity. (See this commentary in *Nature Physics* from Bozovic and Charles Ahn of Yale University).)

–Jessica Thomas and Katherine Wright

Previous Editorial | Next Editorial

Summary

- **We identified high Tc in 1 UC FeSe on STO, which reveals the way that by interface engineering, the superconductivity in ultrathin layer can be extremely enhanced. Our discovery also offers an aspect to understand high Tc superconductivity based on two dimensional or interface superconductors.**
- **The macroscopic area of ultrathin high Tc superconducting FeSe film on gating easily substrate STO shows great potential for application in superconducting nanoelectronics or electronic devices, such as FET and SQUID.**

For more details:

CHIN. PHYS. LETT. 31, 017401 (2014) (arXiv:1311.5370)

Highlighted in Editors' Choice: Science 343, 230 (2014)

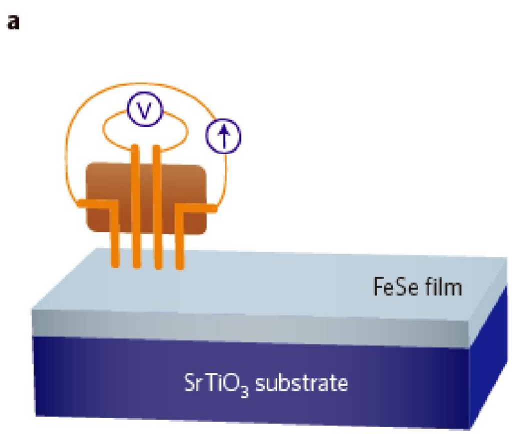
A new frontier for superconductivity

Ivan Bozovic and Charles Ahn **A brief review for 1 UC FeSe: Nature Physics 10, 892 (2014)**

Monolayer films of iron selenide deposited on strontium titanate display signatures of superconductivity at temperatures as high as 109 K. These recent developments may herald a flurry of exciting findings concerning superconductivity at interfaces.

Two indications of Tc above nitrogen temperature in 1 UC FeSe are reviewed in this paper.

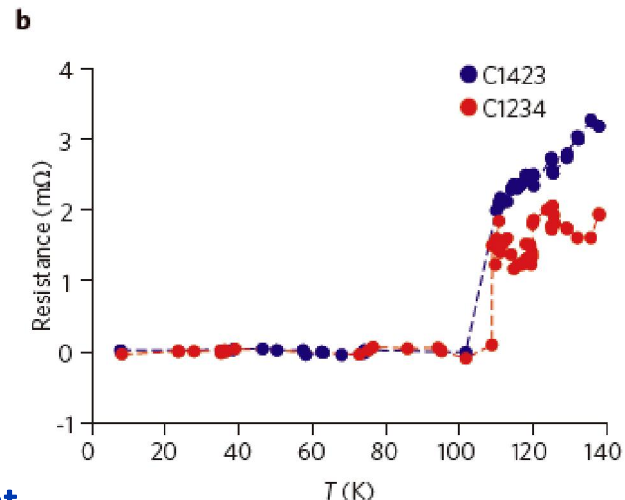
a



Local four-tip measurement

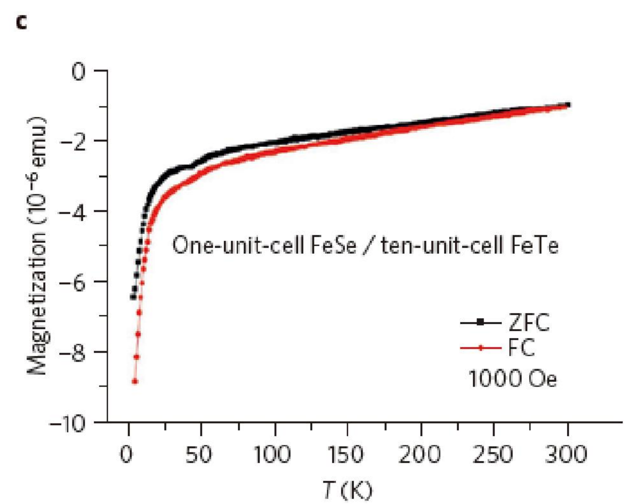
Shanghai Jiaotong University

b



DOI:10.1038/NMAT4153

c



Scientific Reports 4, 6040 (2014) (arXiv:1404.3464)

More reliable experiments are necessary!

Future Research Direction and Perspective

- **Is 1 UC FeSe the other superconducting system above liquid nitrogen temperature besides cuprates? We need further increase the quality of 1 UC FeSe film, try different substrates and develop better protection layer to detect if Tc of 1 UC FeSe can be higher than 77 K by *in situ* and *ex situ* transport and Meissner effect measurements.**
- **Stimulated by the observation of high Tc in 1 UC FeSe, we can try various one unit cell metallic or superconducting films on different ceramic or semiconducting substrates to search for new extremely interface enhanced 2D superconductors, especially for high Tc and even for long-term pursuit room temperature superconductors.**

北京大學 PEKING UNIVERSITY

Part II: Detection of a new superconducting phase in 2D limit: a two-atom layer Ga film grown on semiconducting GaN(0001)

Physical Review Letters 114, 107003 (2015) (Editors' Suggestion)

Acknowledgments

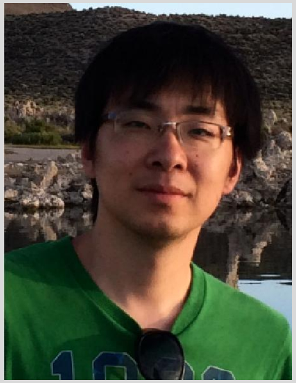
Major Collaborators:

Tsinghua University and Institute of Physics

Prof. Qi-Kun Xue

Prof. Xucun Ma

Huimin Zhang



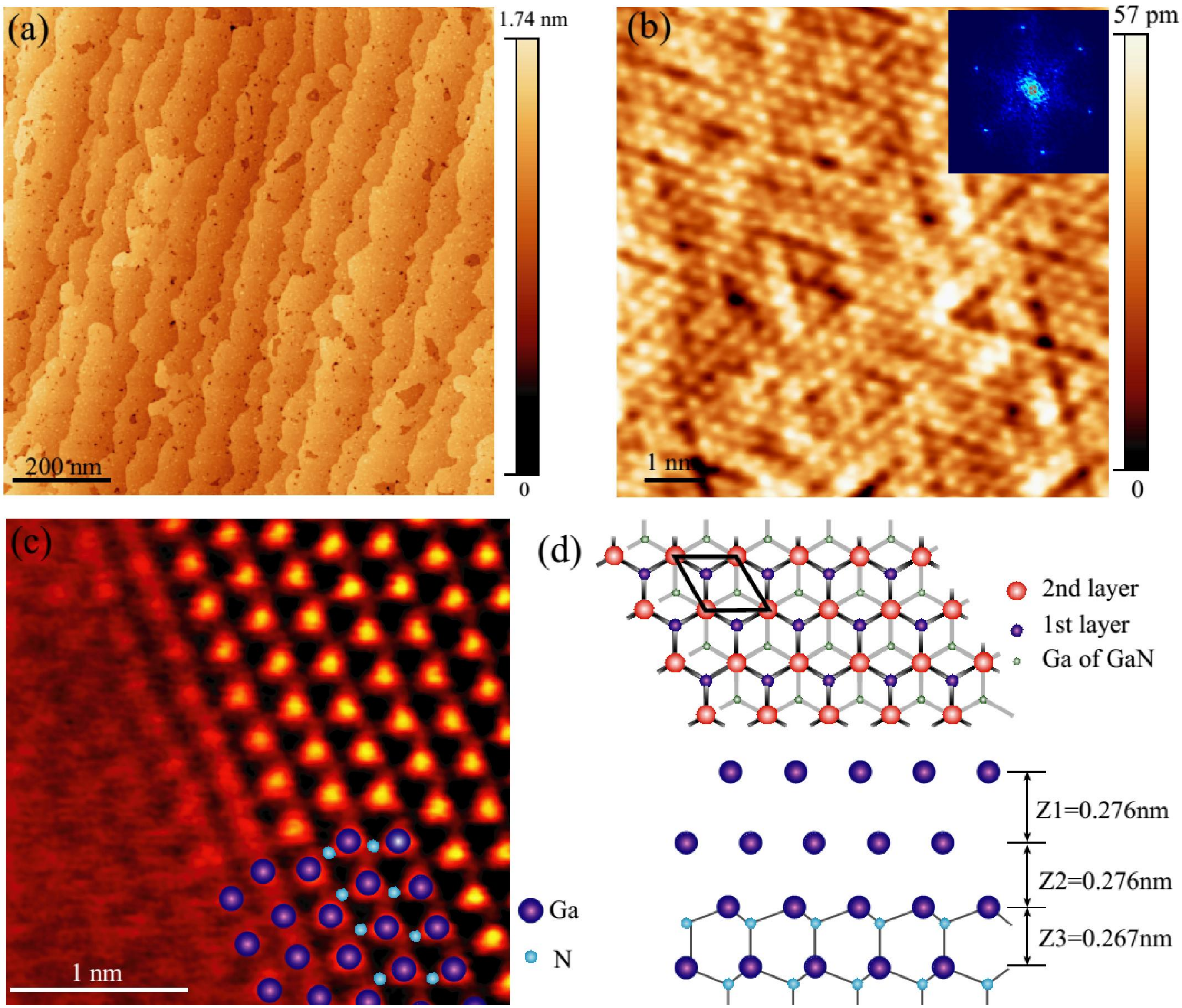
Dr. Wei Li

Peking University

Dr. Yi Sun

Other collaborators: Jun-Ping Peng, Can-Li Song, Ying Xing, Qinghua Zhang, Jiaqi Guan, Zhi Li, Yanfei Zhao, Shuaihua Ji, Lili Wang, Ke He, Xi Chen, Lin Gu, Langsheng Ling, Mingliang Tian, Lian Li, X. C. Xie, Jianping Liu, Hui Yang

Two-atom layer Ga film grown on GaN(0001) by MBE

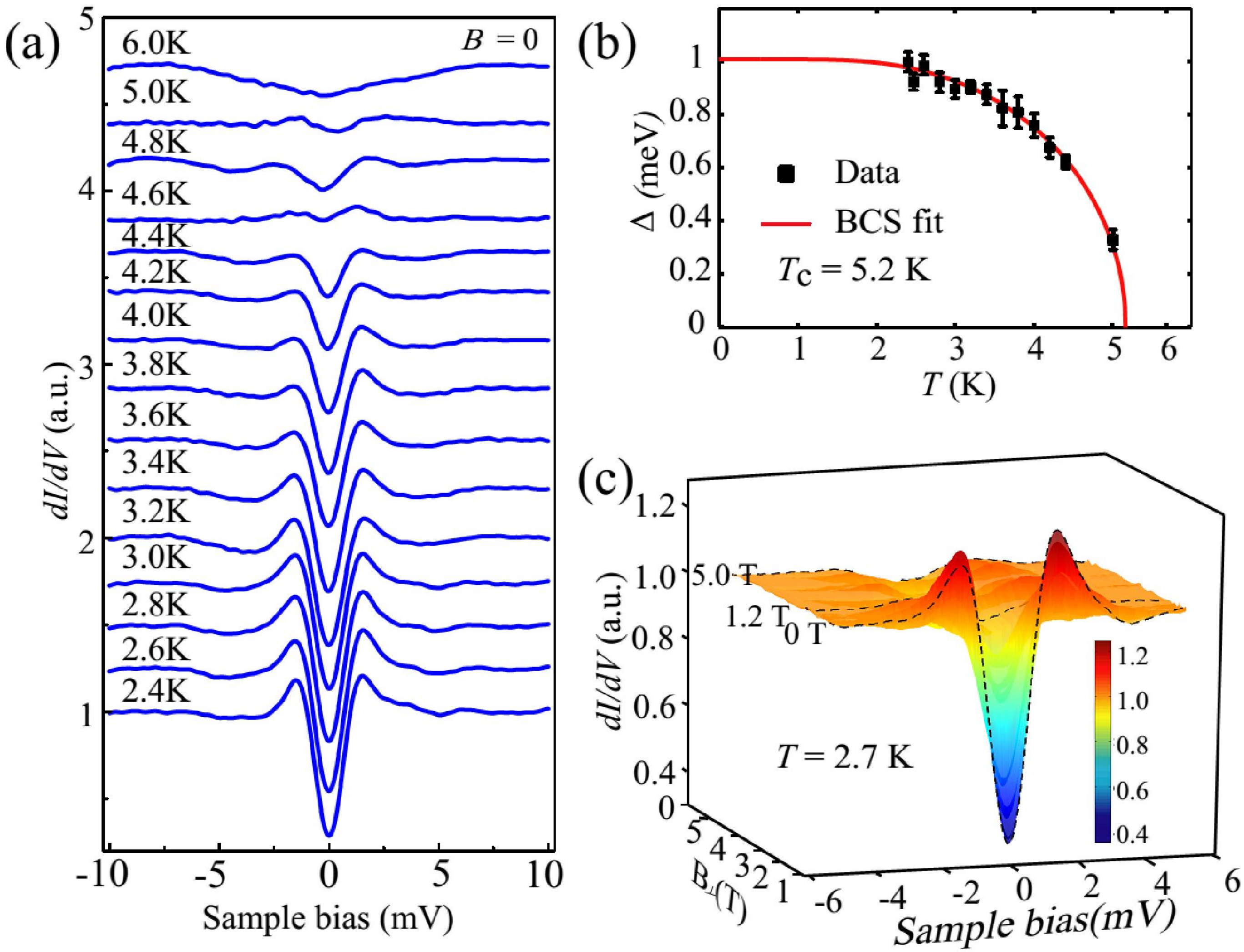


The thickness of the Ga film is 0.552 nm.

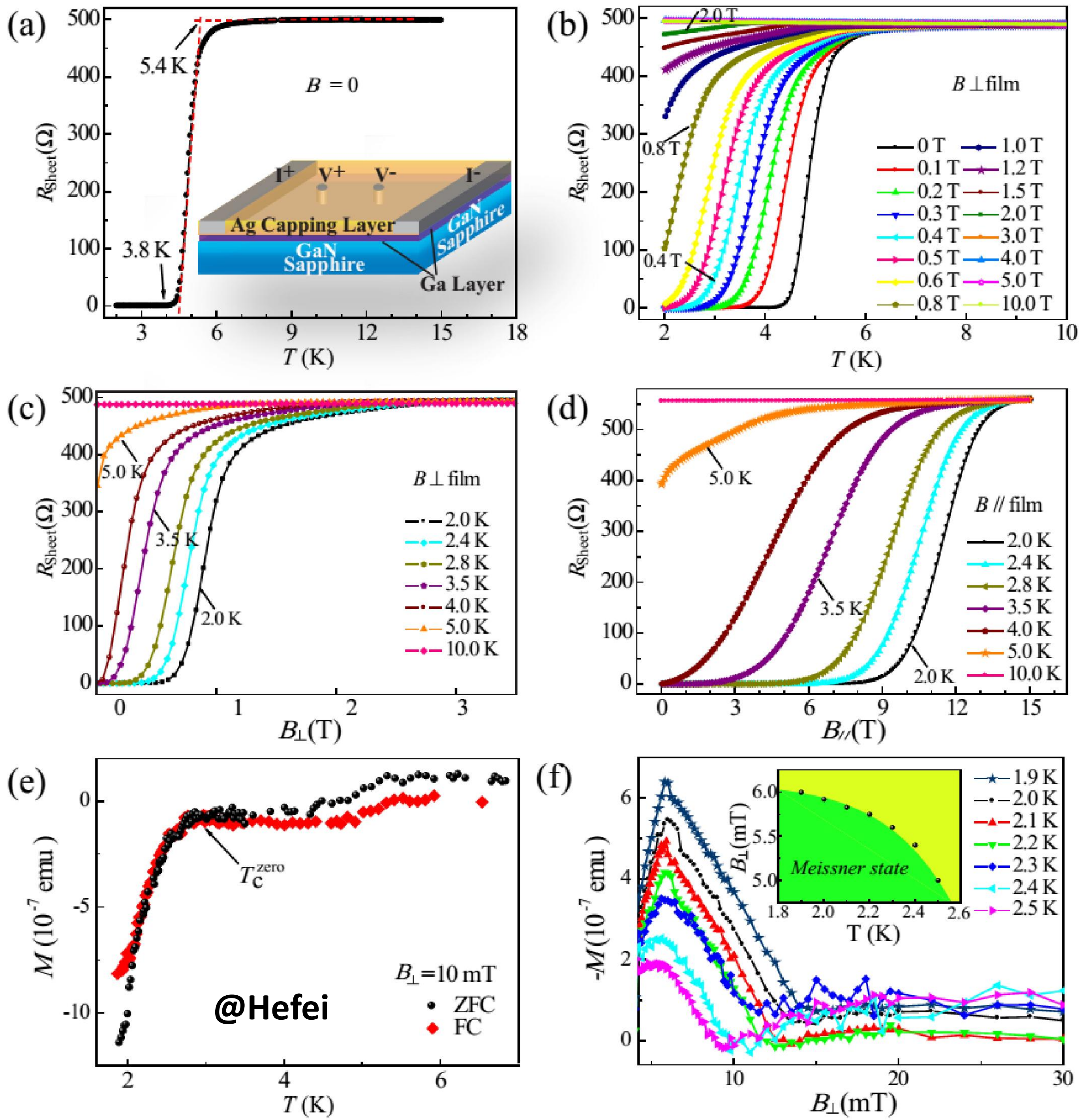
The hexagonal structure and lattice constant (a=b=0.318 nm and c = 0.276 nm)

Graphene and Silicene like Structure!?

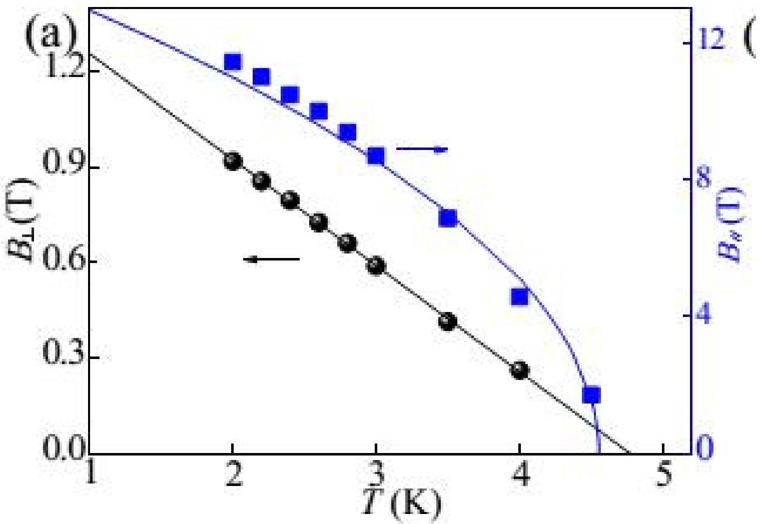
The superconductivity of two-atom layer Ga film on GaN(0001) detected by *in situ* STM



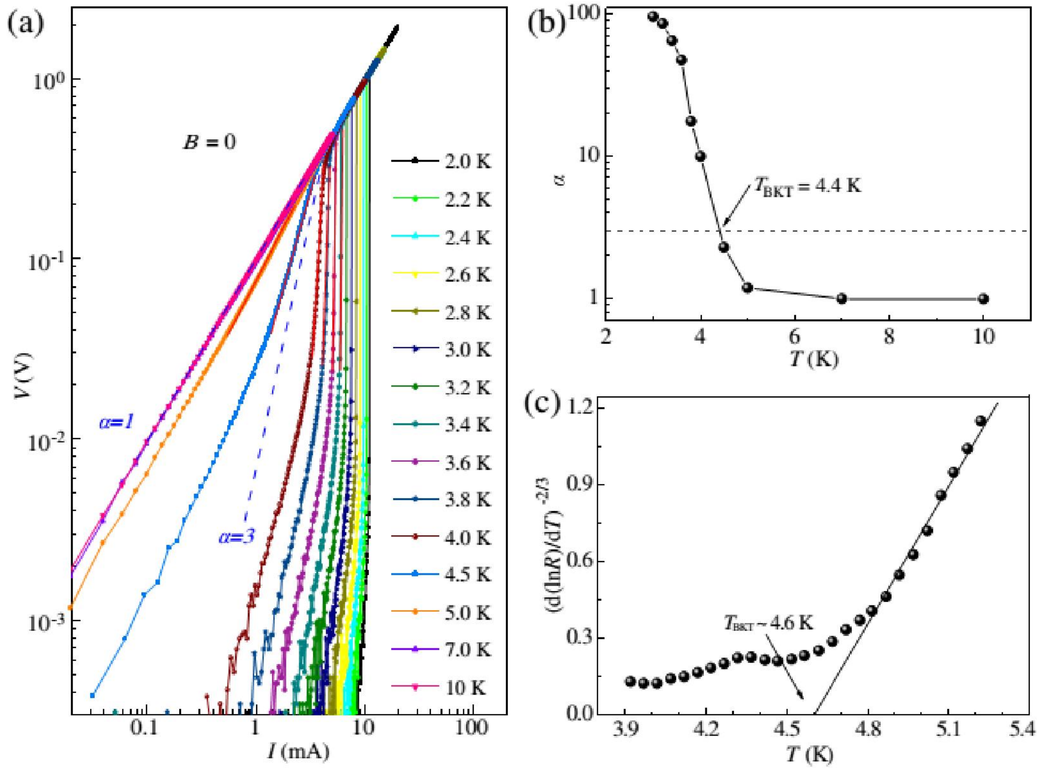
The superconductivity of two-atom layer Ga film on GaN(0001) detected by *ex situ* transport and magnetization measurements.



Evidences for "ideal" 2D superconductivity:



We observed typical critical field behavior for 2D superconductor.



BKT-like behavior

PEKING UNIVERSITY

Therefore, a new superconducting phase in 2D limit is discovered.

Two-atom layer Ga on GaN vs. stable bulk α phase Ga:

1. Tc: 5.4 K vs. 1.08 k
2. Hc: 3.26 T vs. 58.3 Oe
3. Hexagonal vs. orthorhombic (completely different lattice constant)

Physical Review Letters 114, 107003 (2015) (Editors' Suggestion)

Summary

北京大学
PEKING UNIVERSITY

1. **By *in situ* STM/STS and *ex situ* transport and magnetization measurements, we discover a new 2D superconducting phase with a transition temperature up to 5.4 K in 2 ML (0.552nm) crystalline Ga films grown on wide band-gap semiconductor GaN.**

2. **It is the first conventional crystalline superconductor in 2D limit showing Tc enhancement and *ex situ* superconductivity. The observed superconductivity in atomic-scale thin films with relatively high T_C and H_C demonstrates the feasibility in developing dissipationless quantum electronic devices based on wide band-gap semiconductors.**

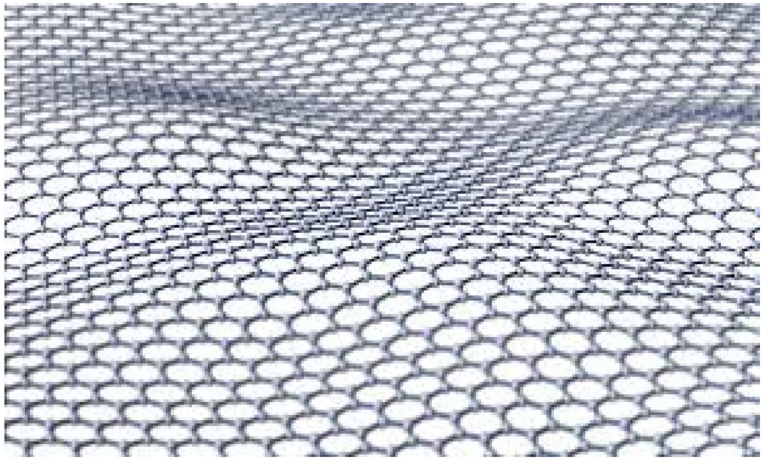
3. **Our result demonstrates a pathway for exploring atomic-scale 2D superconductors by surface and interface engineering in a broad range of metal-semiconductor heterostructures, which benefit from present semiconductor technology and ultrathin film fabrication technique.**

Physical Review Letters 114, 107003 (2015) (Editors' Suggestion)

Perspective

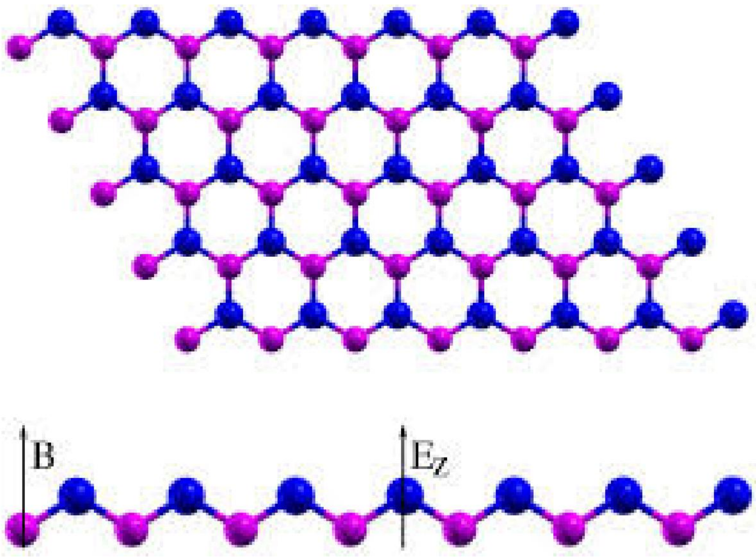
The two-atom Ga layer shows graphene and silicene like structure!

Graphene



www.wearable-technologies.com

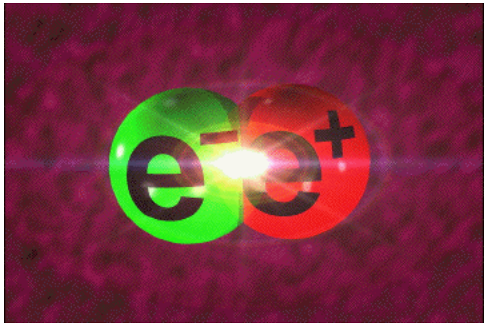
Silicene



www.nature.com

Does two-atom layer Ga show topological property?
Can it be a candidate of topological superconductors?
More experiments, calculations, and theories are necessary!

镓烯？**"Made in China"**



Majorana Fermion

Part III: Potential to topological superconductivity in 3D Dirac semimetal

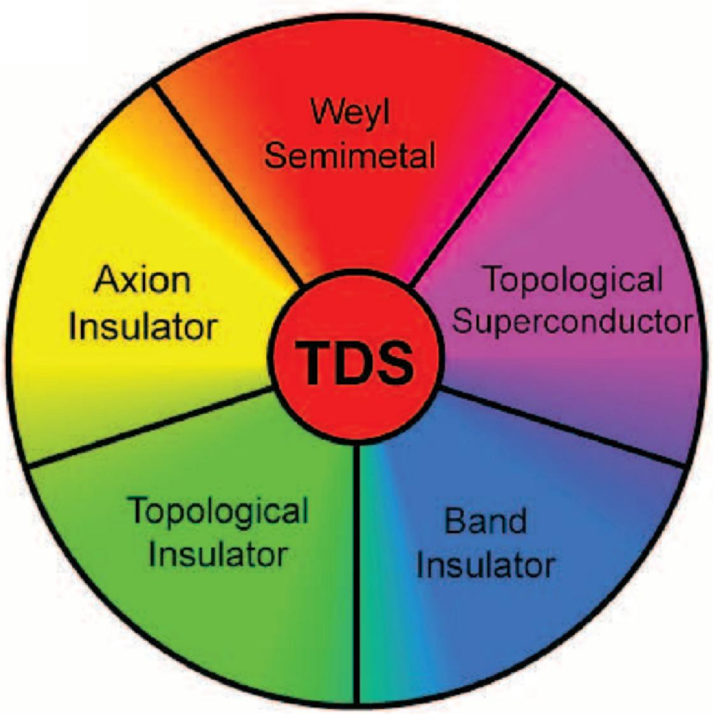
arXiv:1412.0330

arXiv:1501.00418

Background: 3D Topological Dirac Semimetal

"3D graphene"

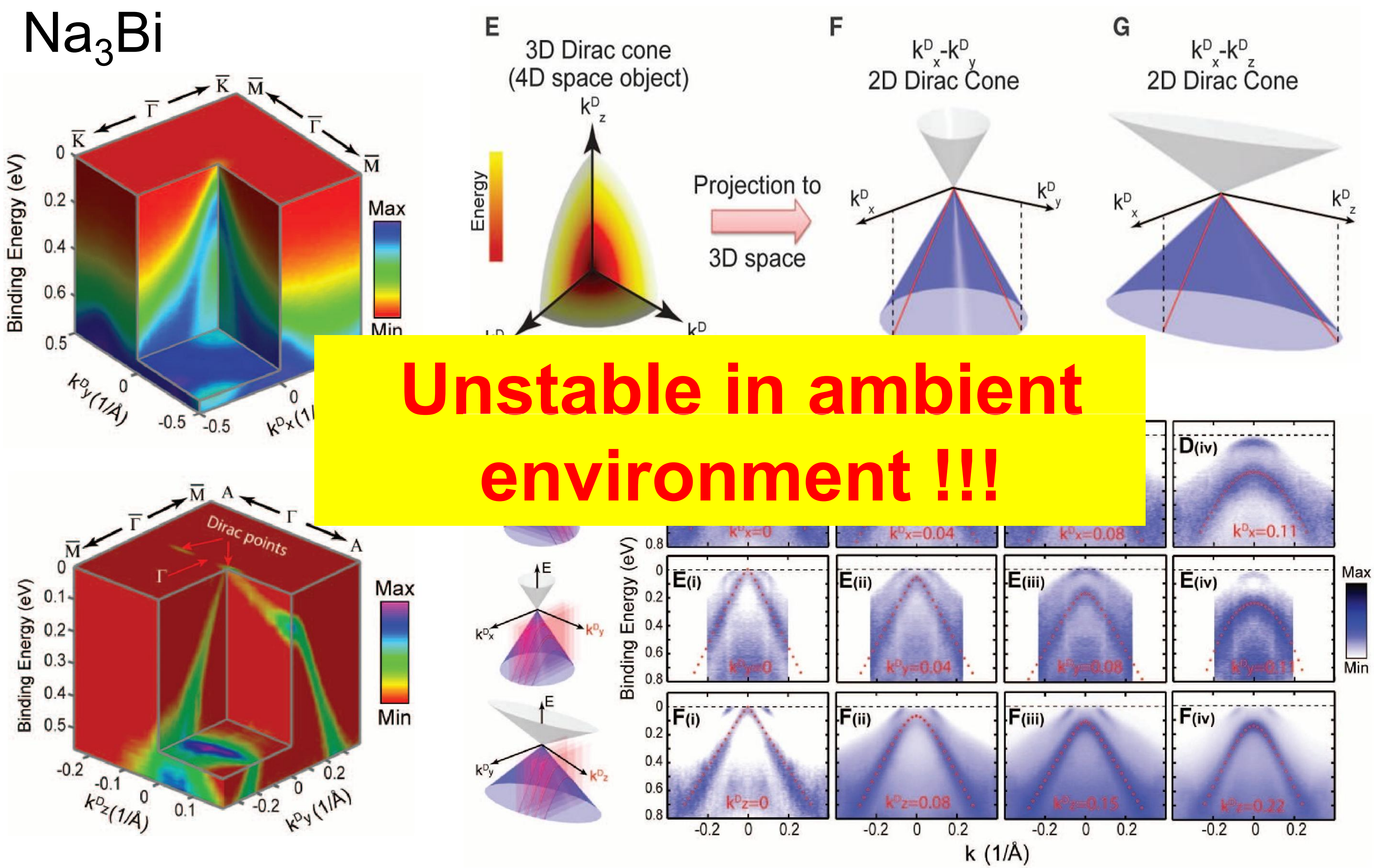
Rich Novel States



Z. K. Liu et al, Science 343, 864 (**2014**)

3D Topological Dirac Semimetal

Na_3Bi

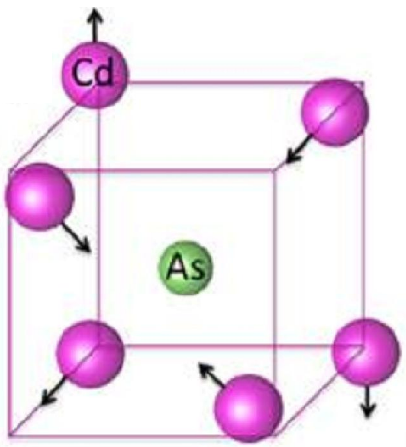


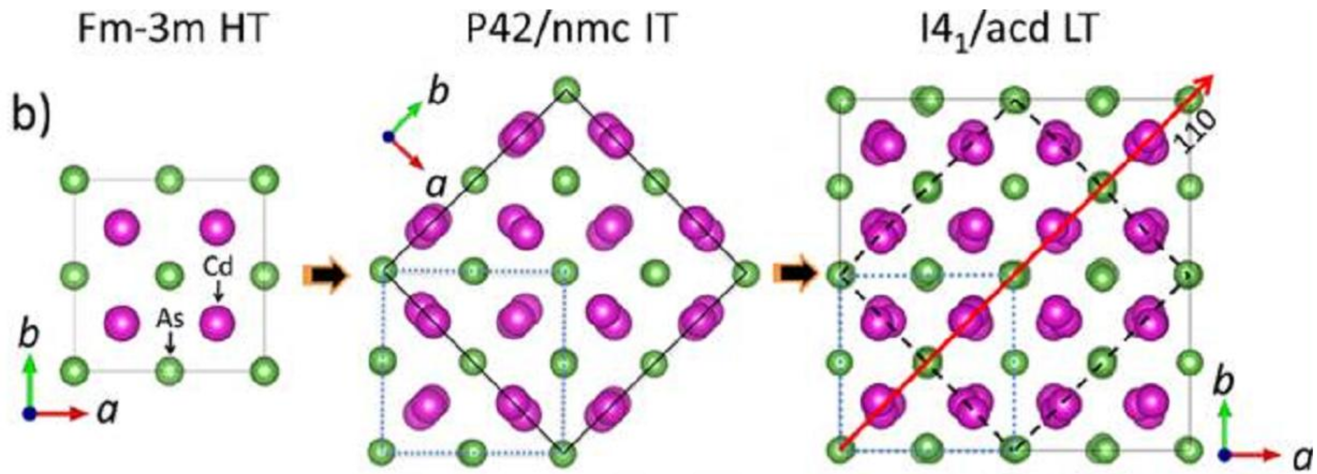
Unstable in ambient environment !!!

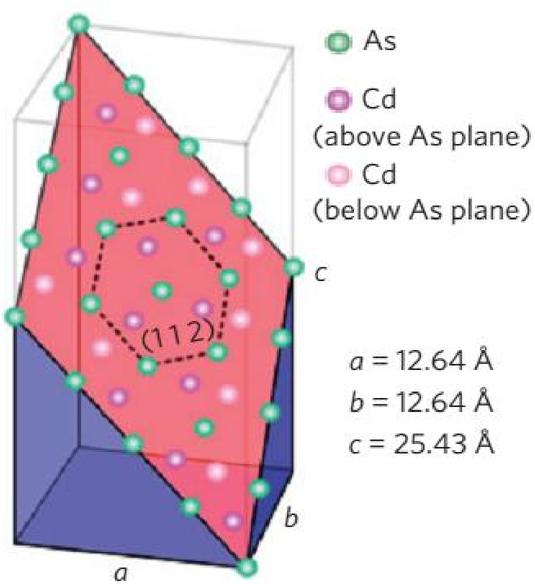
Z. K. Liu et al, Science 343, 864 (**2014**)

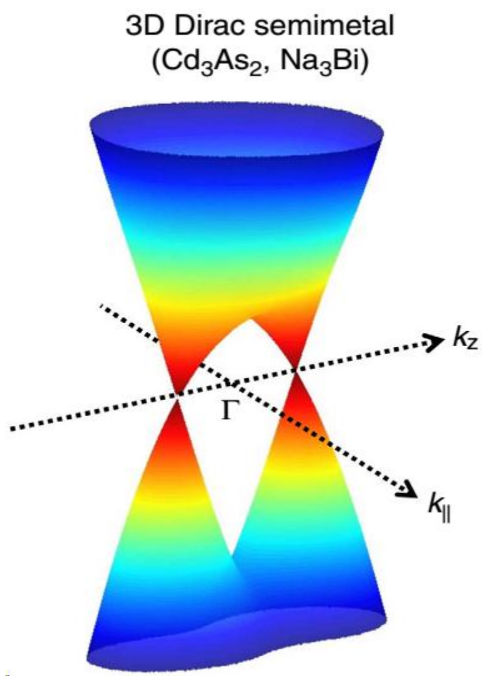
3D Topological Dirac Semimetal

Cd_3As_2









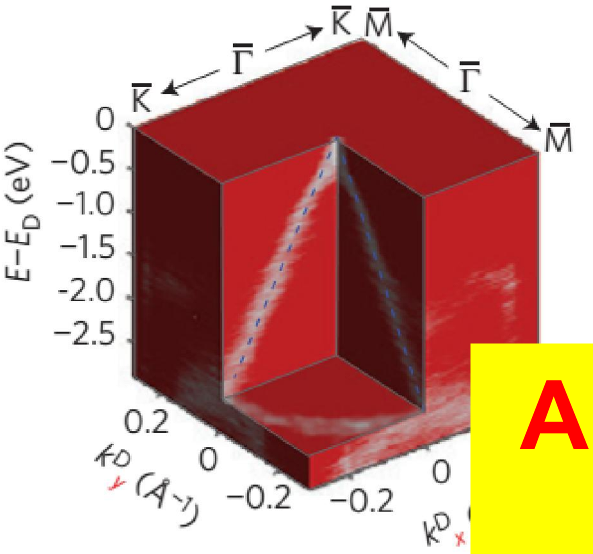
M. N. Ali, et al, Inorg. Chem. 53, 4062 (**2014**)

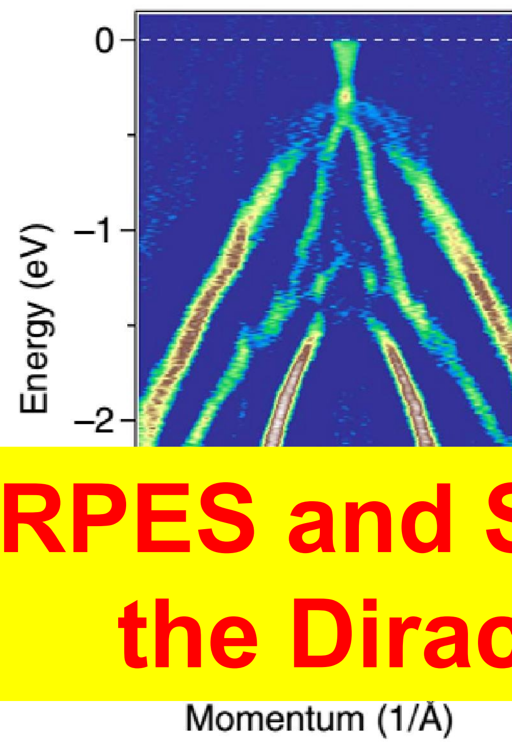
S. Jeon, et al, Nat. Mater. 13, 851 (**2014**)

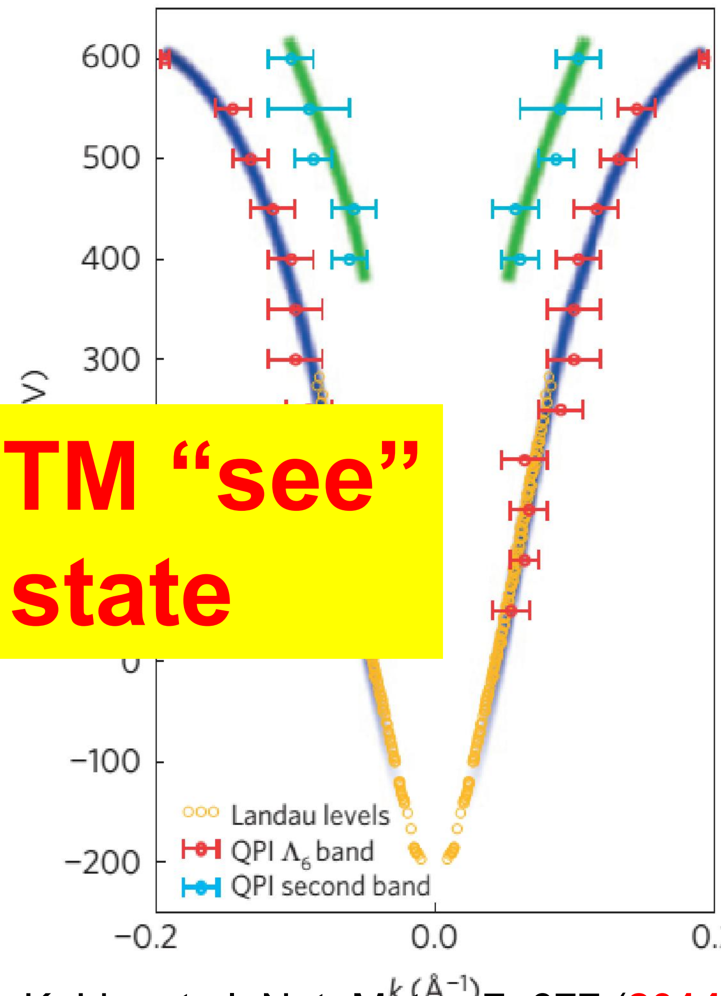
M. Neupane, et al, Nat. Commum 5, 3786 (**2014**)

3D Topological Dirac Semimetal

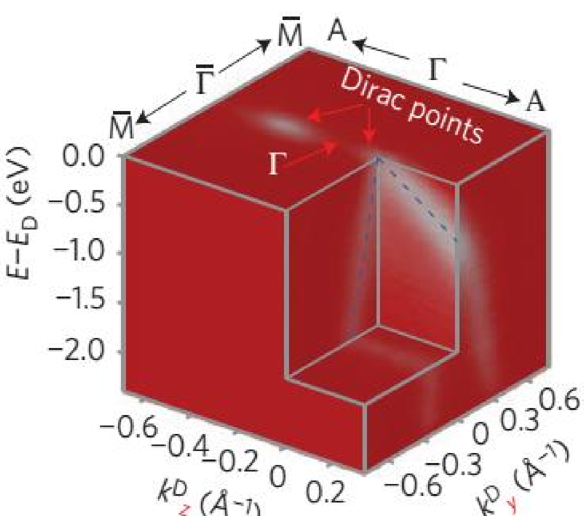
Cd_3As_2

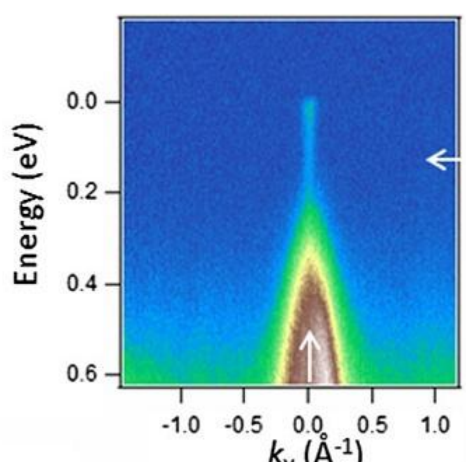






ARPES and STM "see" the Dirac state





Z. K. Liu, et al, Nat. Mater. 7, 677 (**2014**)

S. Jeon, et al, Nat. Mater. 13, 851 (**2014**)

M. Neupane, et al, Nat. Commum 5, 3786 (**2014**), PRL 113,027603 (**2014**)

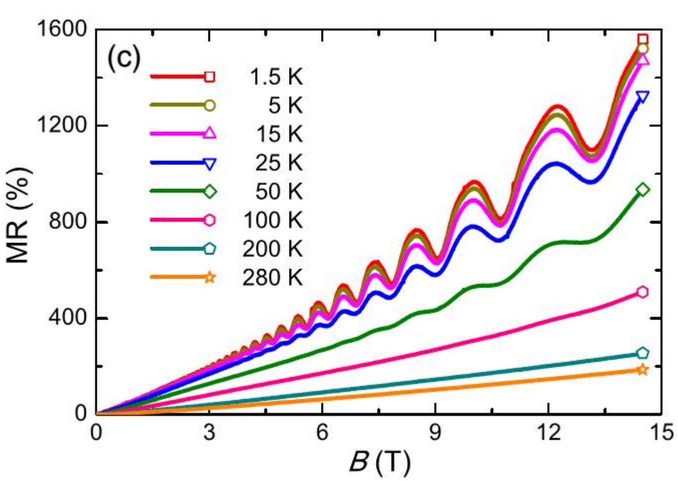
3D Topological Dirac Semimetal

Cd_3As_2

Table 1 | Parameters of the seven samples investigated.

Sample	ρ_1 (nΩ cm)	γ	RRR	μ_1 ($cm^2 V^{-1} s^{-1}$)	MR (9 T)	n_H (9 T) ($10^{18} cm^{-3}$)
A1	32	32.7	781	$\sim 3\times10^6$∗	582	9.1
A4	14,600	2.72	21.4	40×10^3	34.5	4.4
A5	21	18.7	4,100	8.7×10^6	1,336	7.4
A6	4,000	22.6	32.2	320×10^3	112	12.0
A8	110	12.8	118	4.0×10^6	404	13.3
B1	46,500	-	5.37	$\sim 10\times10^3$∗	36.9	-
B7	32,200	-	7.26	$\sim 20\times10^3$∗	62.2	15

ρ_1 is the resistivity along $\hat{x}$ at 5 K. The anisotropy γ is ρ_2/ρ_1 at 5 K (γ is undefined in B1 and B7). RRR is the ratio $\rho_1(300)/\rho_1(5)$. The mobilities are determined from σ_{xy} and γ, except in A1, B1 and B7 (∗) where they are estimated from the residual resistivity. MR is the ratio $\rho_{xx}(9\,T)/\rho_{xx}(0)$ at 5 K. The Hall density n_H (9 T) equals $B/e\rho_{yx}$ measured at 9 T (all n-type).



Ultrahigh mobility

LMR

SdH Oscillations

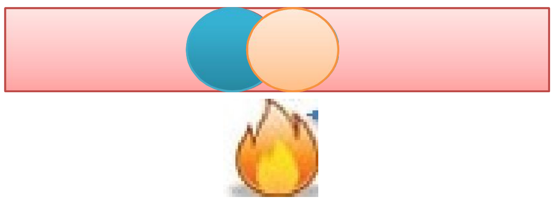
Nat. Mater. 14, 280 (**2015**)

Phys. Rev. Lett. 113, 246402 (**2014**)

Sample Growth

- **Flux crystal growth**

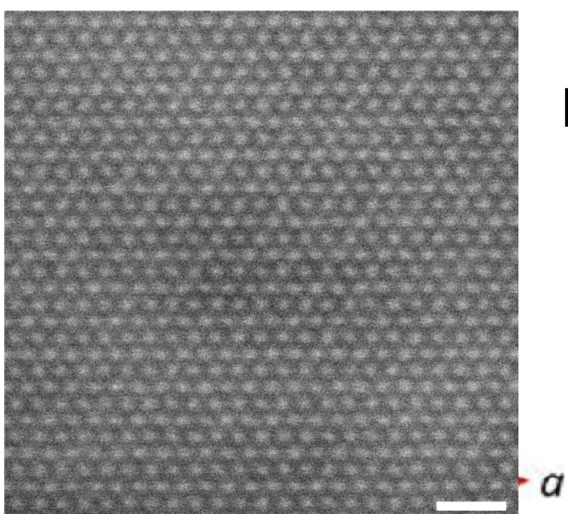
Cd:As=85:15 → **T = 825°C Keep 48 hours** → (**Rate 6°C/h**) **Cool down to 425°C**

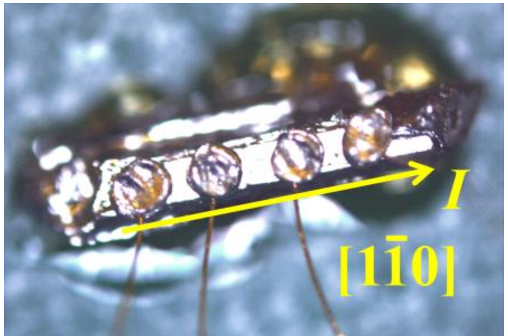


Heat up to 825°C

↓

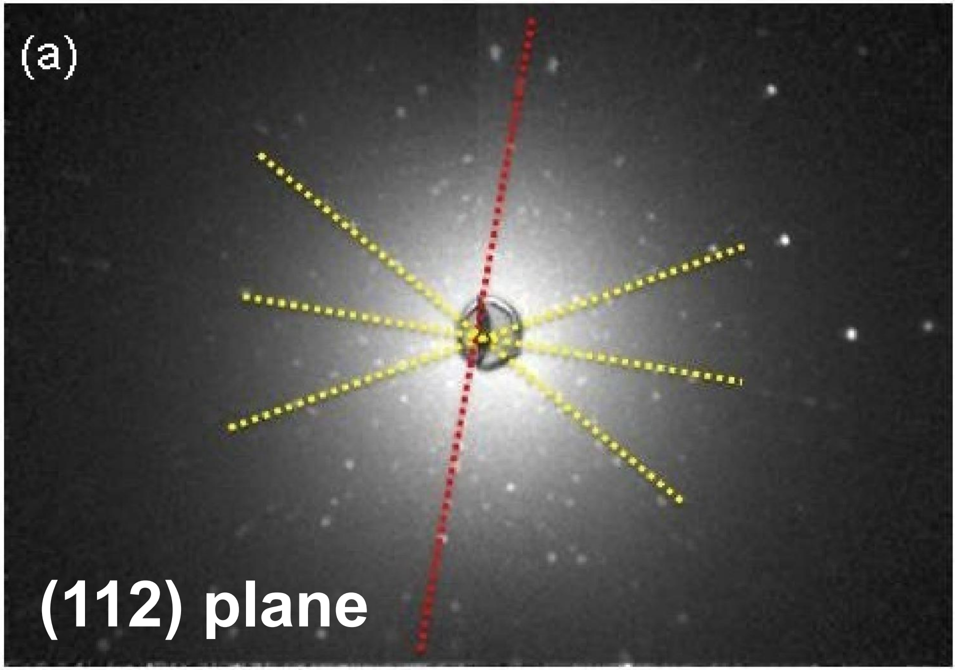
Cd_3As_2 Single Crystal → **Decant the remaining liquid**

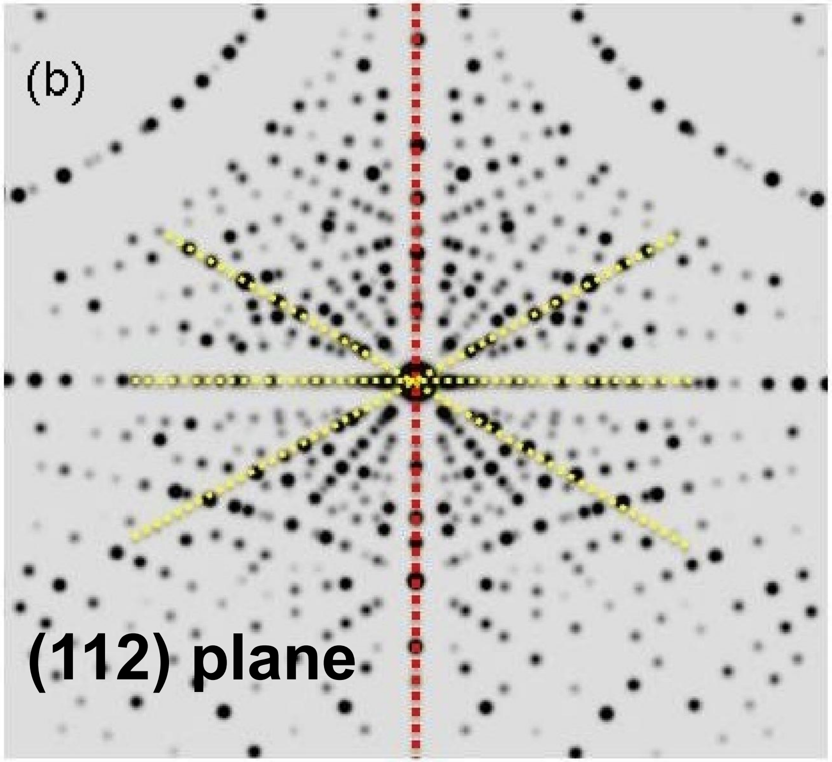


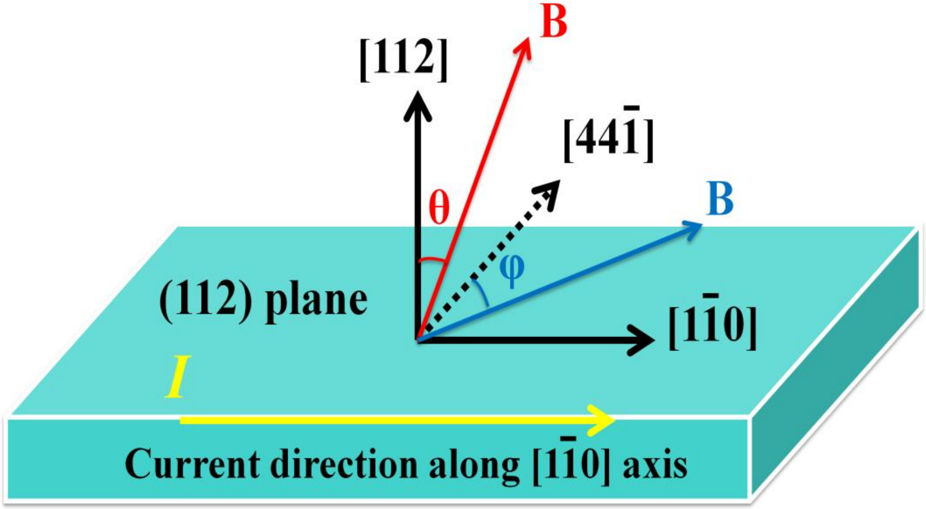


Inorg. Chem. **53,** 4062-4067 (2014)

Laue Image

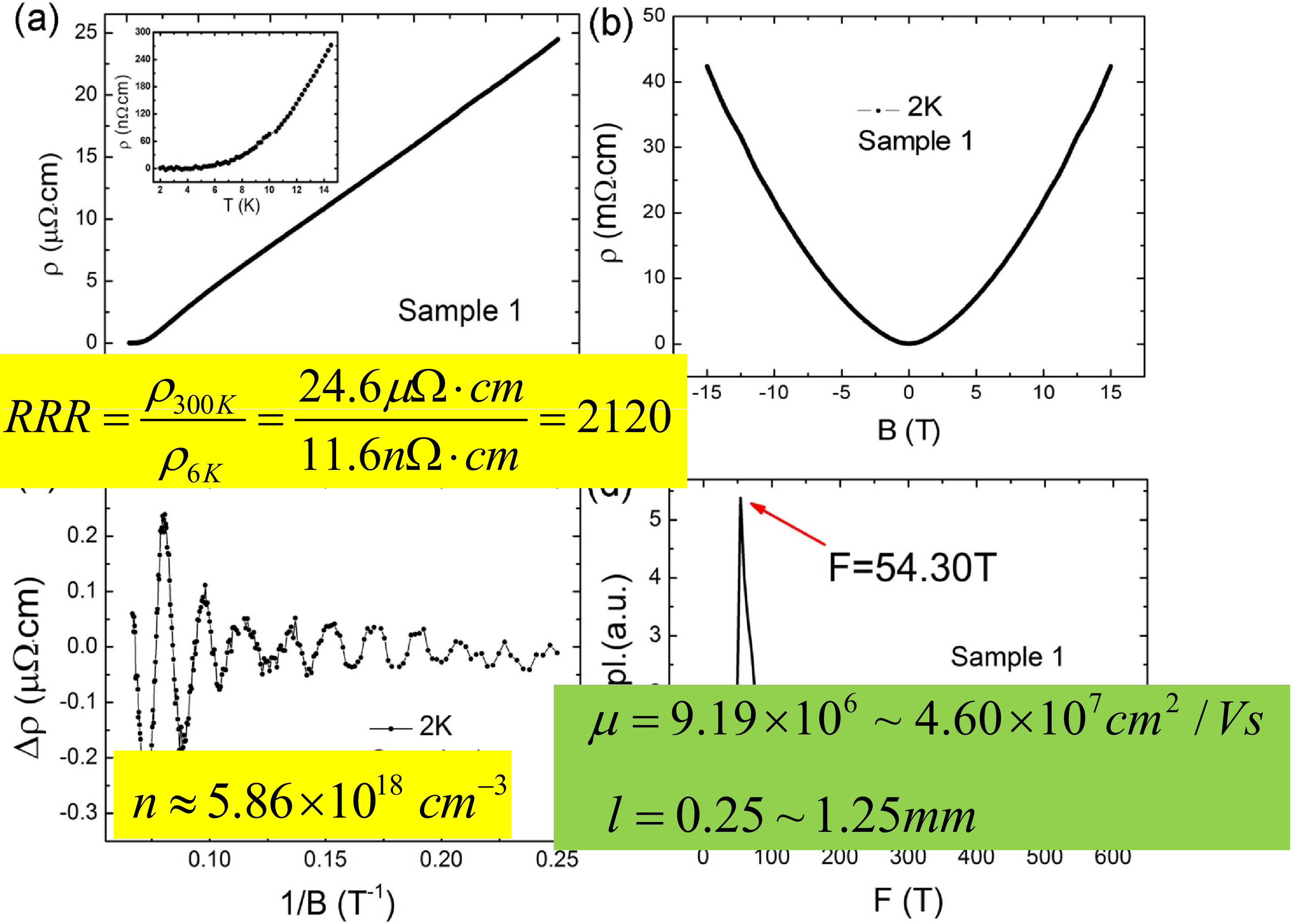






Transport Sketch map

Ultrahigh Mobility



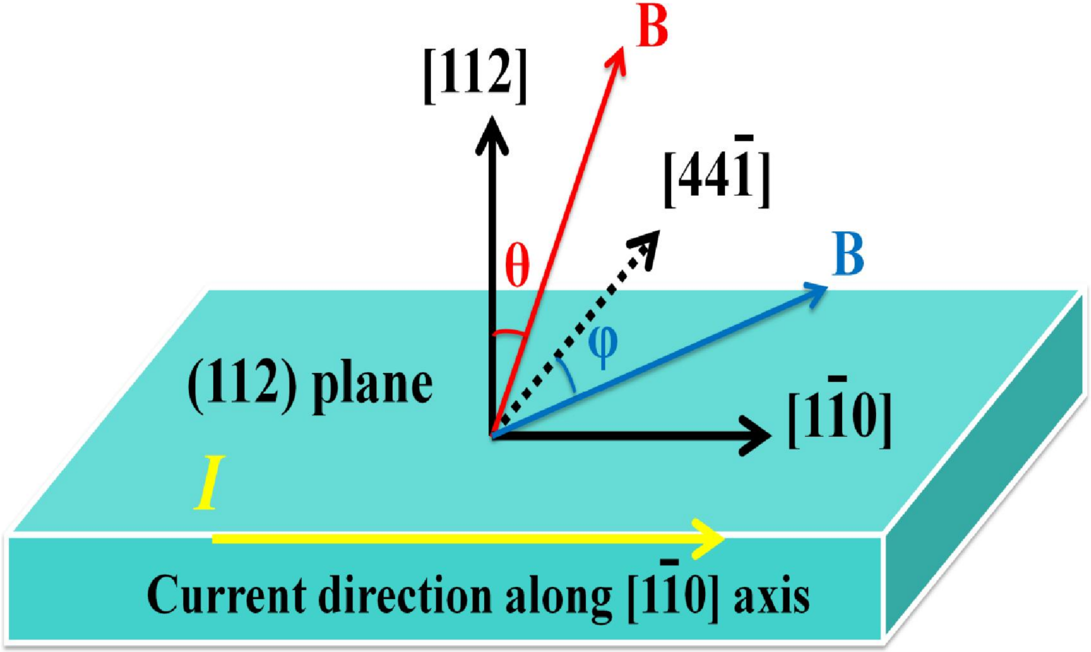
$$RRR = \frac{\rho_{300K}}{\rho_{6K}} = \frac{24.6\mu\Omega\cdot cm}{11.6n\Omega\cdot cm} = 2120$$

$$n \approx 5.86\times10^{18}\ cm^{-3}$$

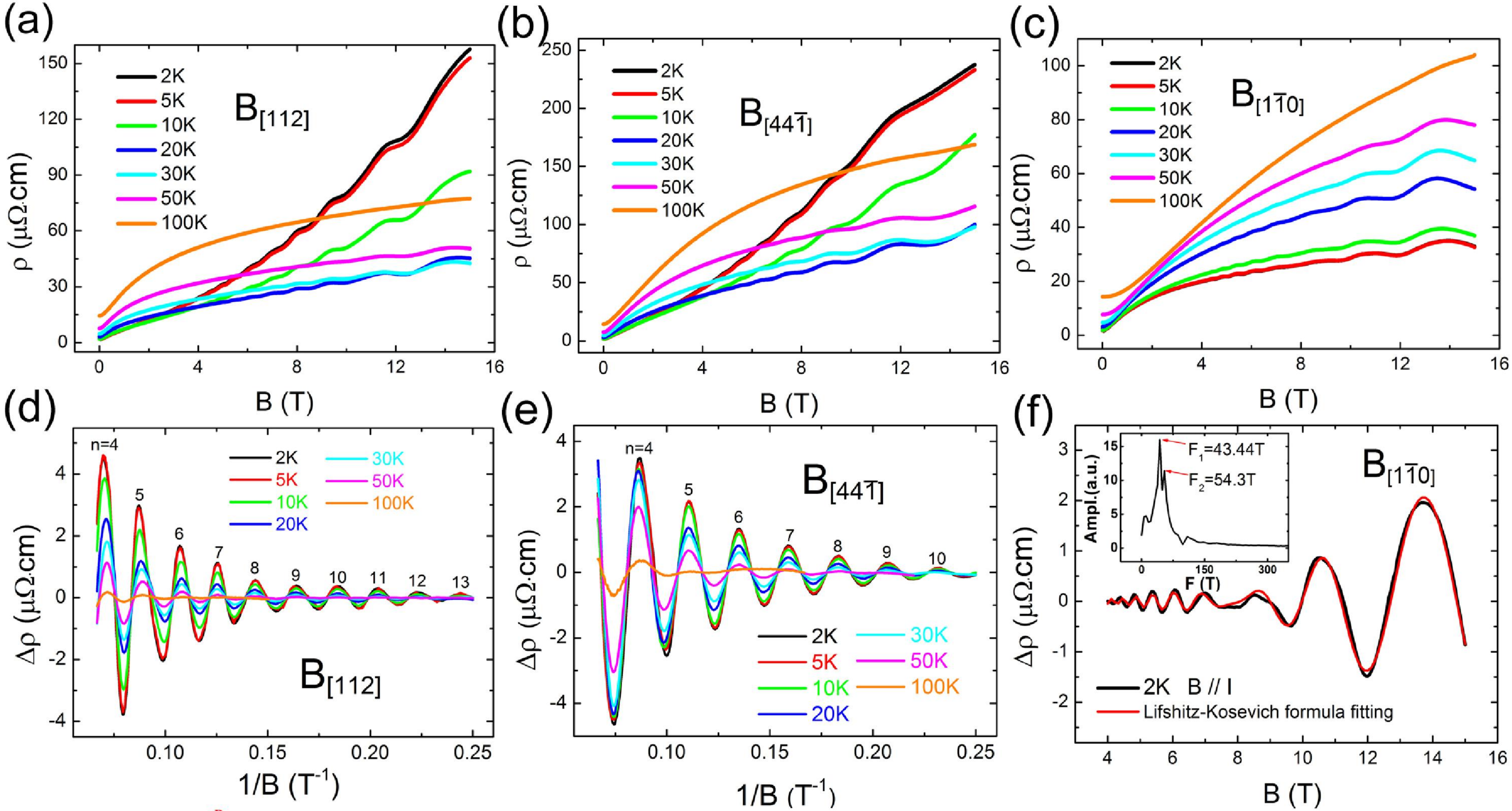
$$\mu = 9.19\times10^{6} \sim 4.60\times10^{7} cm^{2}/Vs$$

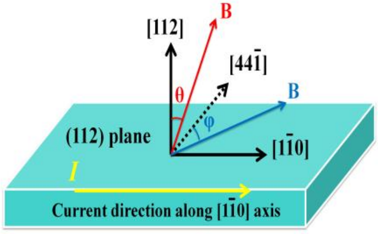
$$l = 0.25 \sim 1.25mm$$

3D Anisotropic Fermi Surface



3D Anisotropic Fermi Surface

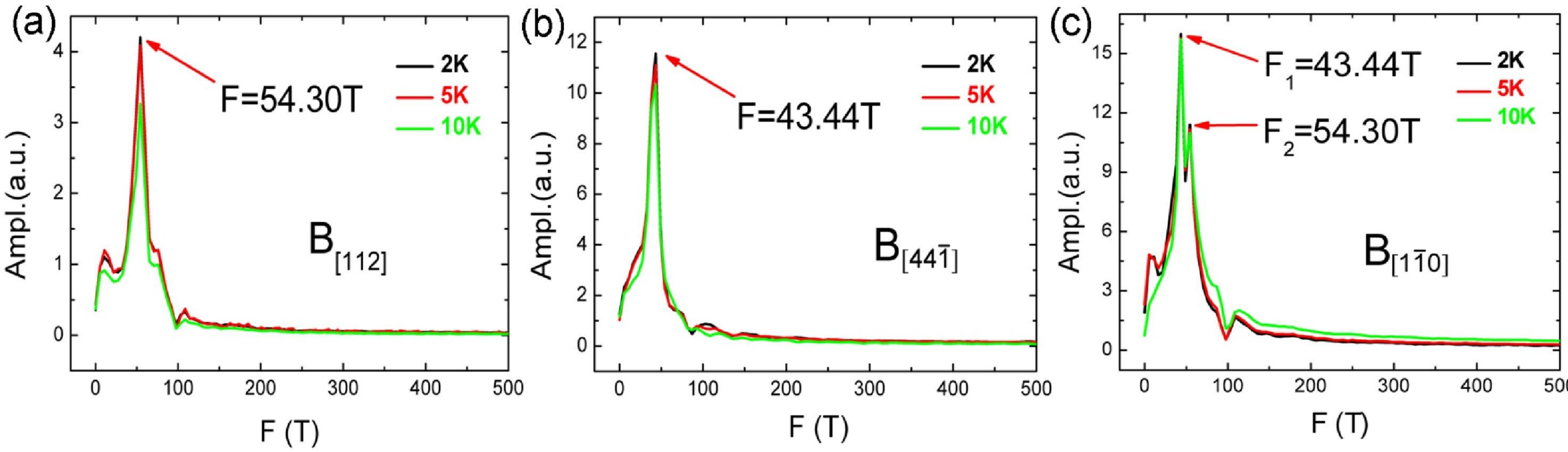


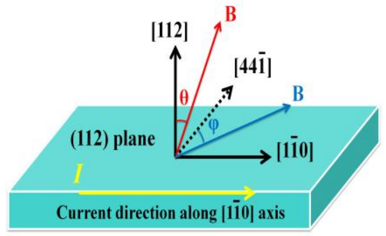


[112] and [44$\bar{1}$] single period SdHO

[1$\bar{1}$0] two periods SdHO

3D Anisotropic Fermi Surface



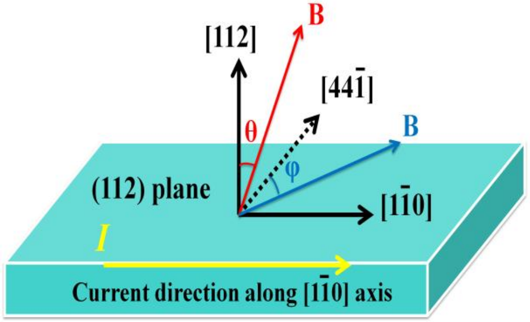


Anisotropic Fermi surface

[112] and [44$\bar{1}$] single period SdHO

[1$\bar{1}$0] two periods SdHO

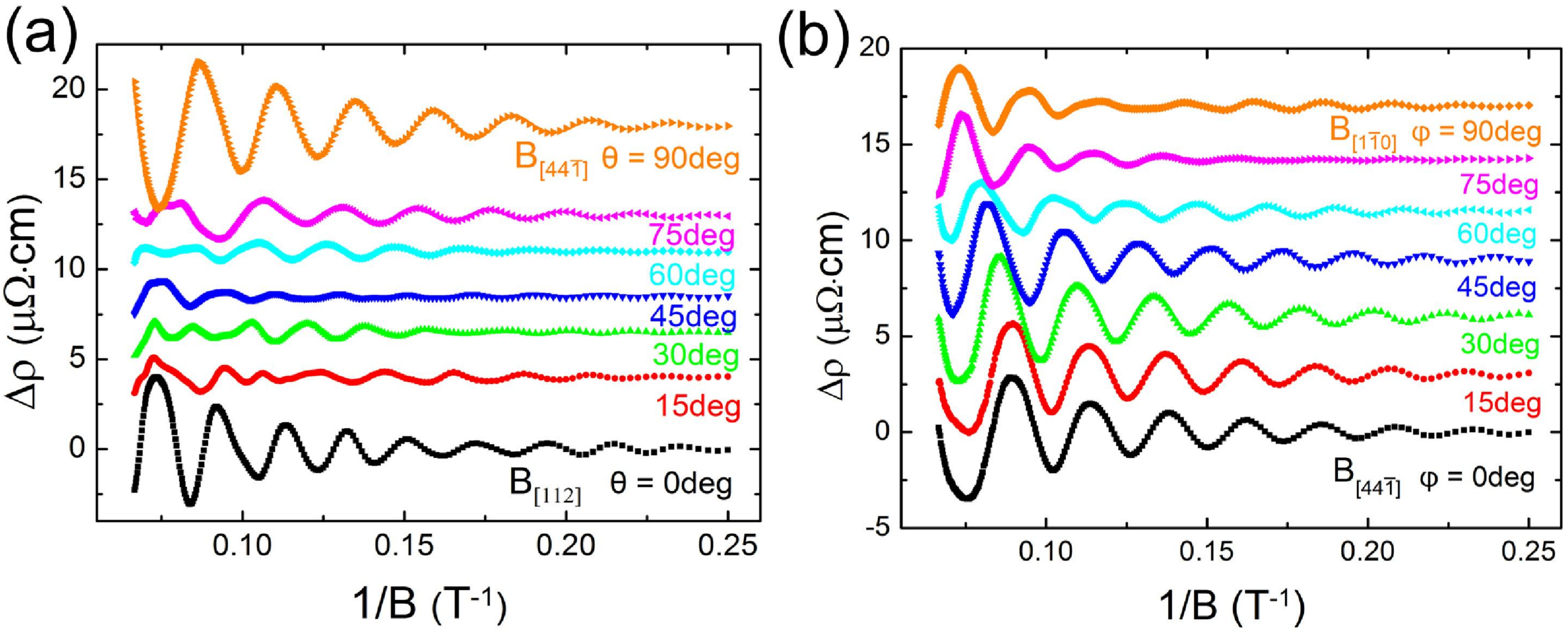
3D Anisotropic Fermi Surface



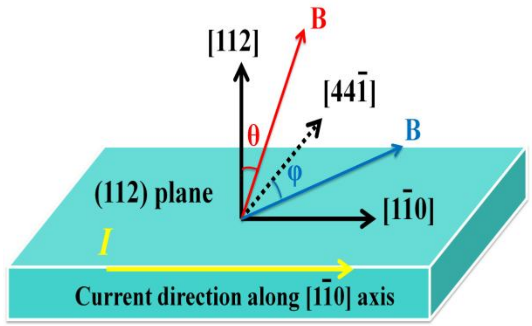
[112] and [44$\bar{1}$] single period SdHO

[1$\bar{1}$0] two periods SdHO

Anisotropic Fermi surface



3D Anisotropic Fermi Surface



[112] and [44$\bar{1}$] single period SdHO

[1$\bar{1}$0] two periods SdHO

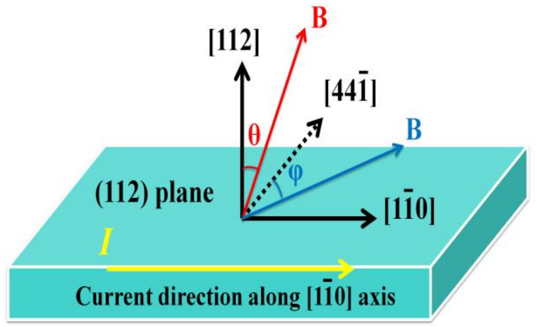
Anisotropic Fermi surface

TABLE I: FFT analysis of SdH oscillations in various magnetic field directions.

Rotation angle	0 *deg*	15 *deg*	30 *deg*	45 *deg*	60 *deg*	75 *deg*	90 *deg*
$B_{[112]}$ rotate	54.30 *T*	43.44 T	48.87 T	54.30 *T*	48.87 T	43.44 T	43.44 T
to $B_{[44\bar{1}]}$	–	54.3 T	59.73 T	–	–	–	–
$B_{[44\bar{1}]}$ rotate	43.44 T	43.44 T	43.44 T	43.44 T	43.44 T	48.87 T	43.44 T
to $B_{[1\bar{1}0]}$	–	–	–	–	48.87 T	43.44 T	54.30 T

When changing the magnetic field angle θ and φ, two periods oscillations also present

3D Anisotropic Fermi Surface

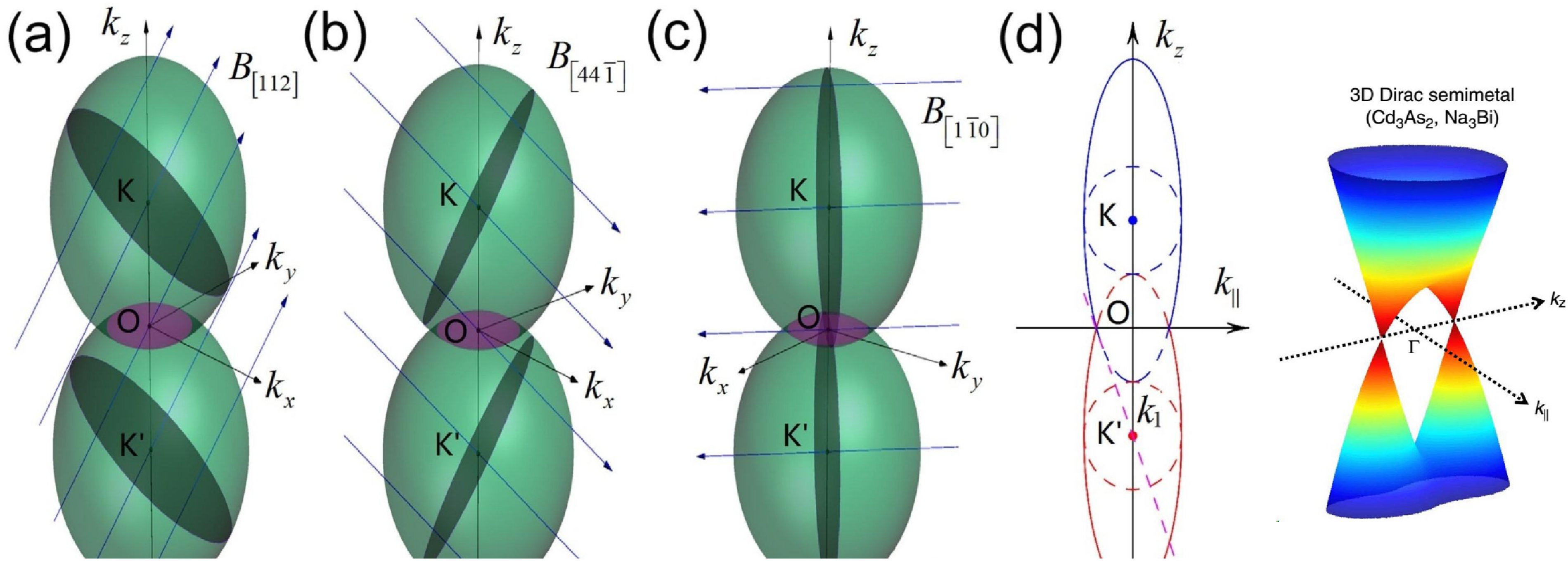


[112] and [44$\bar{1}$] single period SdHO

[1$\bar{1}$0] two periods SdHO

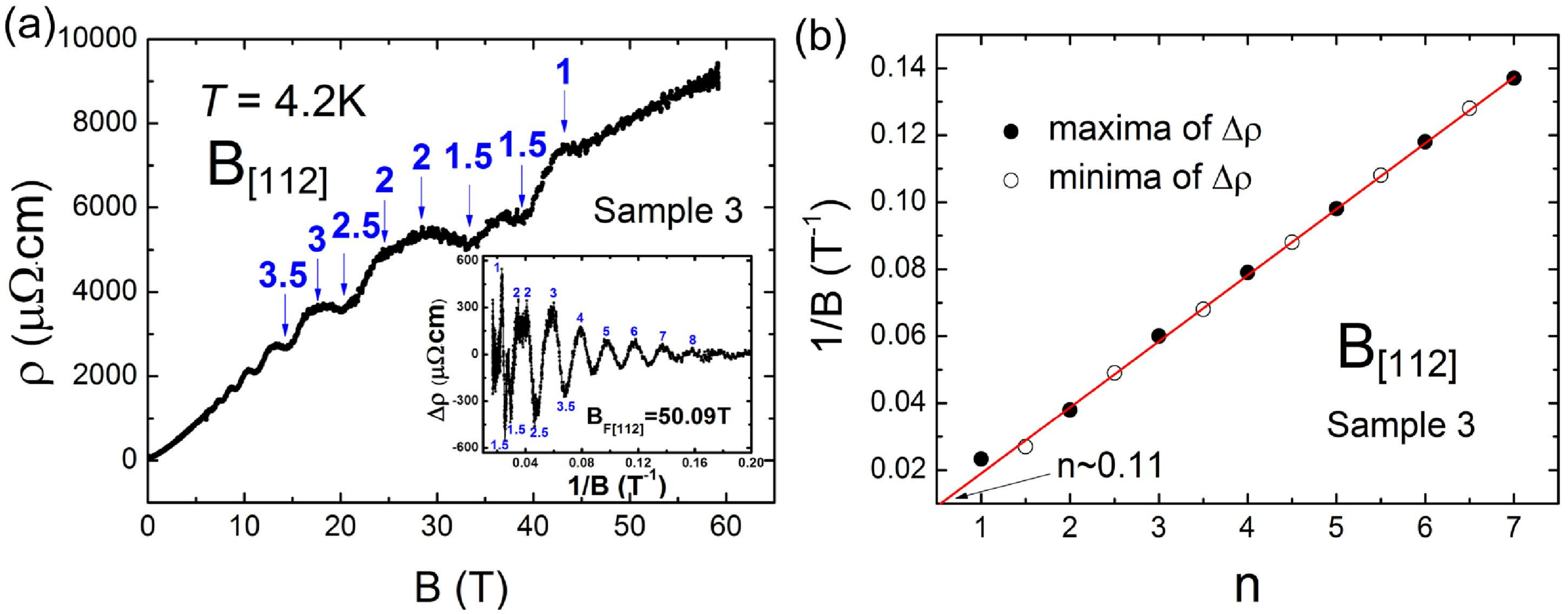
Anisotropic Fermi surface

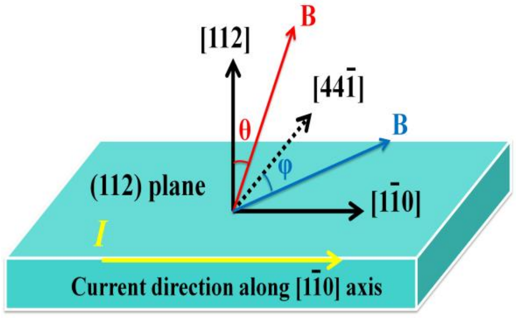
At certain angle: two periods SdHO



Two nested ellipsoid Fermi surface beyond the Lifshitz point

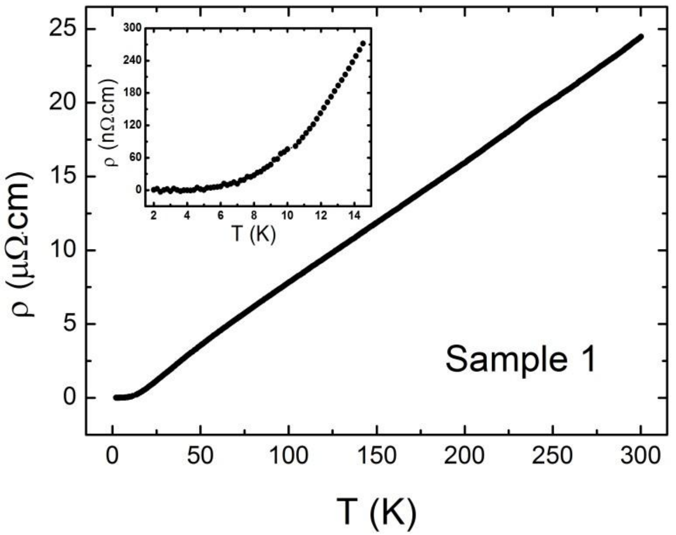
Quantum Limit

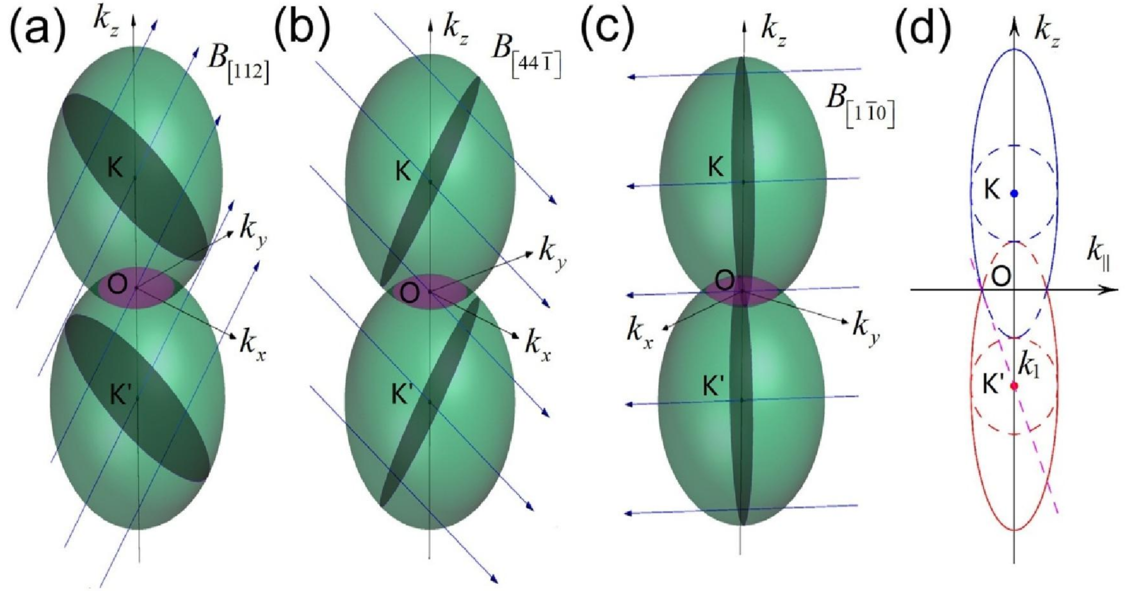




- Quantum limit: n = 1
- SdH Oscillation with Zeeman Splitting
- Linear MR behavior
- LL fan diviate from linear fitting: Quantum limit

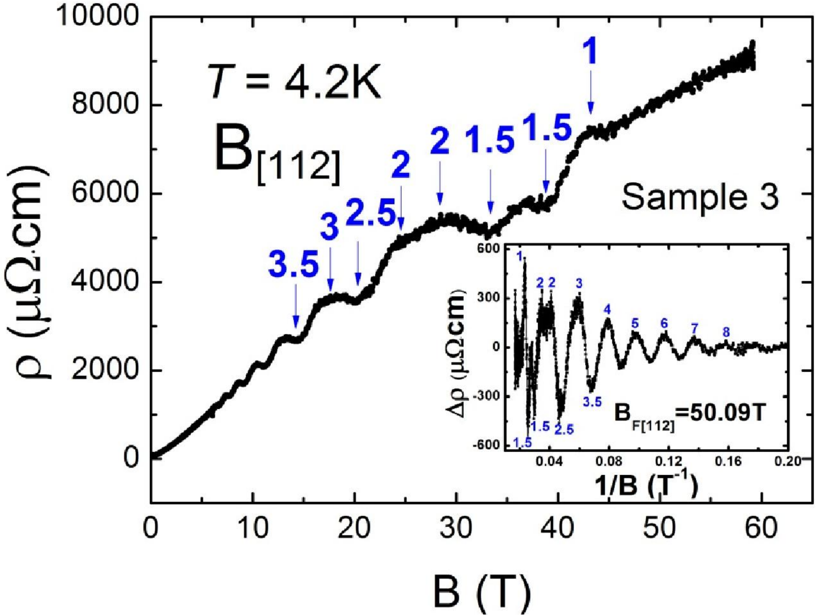
Transport property – Cd_3As_2



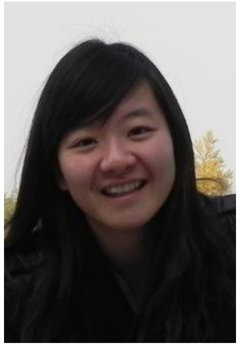


Ultrahigh mobility

Two nested Anisotropic Fermi surface



Quantum Limit



Yanfei Zhao

Yanfei Zhao *et al.* arXiv: 1412.0330

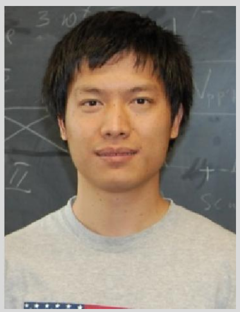
Observation of superconductivity induced by point contact in 3D Dirac semimetal Cd3As2 crystal

arXiv:1501.00418

Major Collaborators:

Peking University

Prof. Jian Wei



Prof. Xiong-Jun Liu

Prof. X. C. Xie

Prof. Shuang Jia

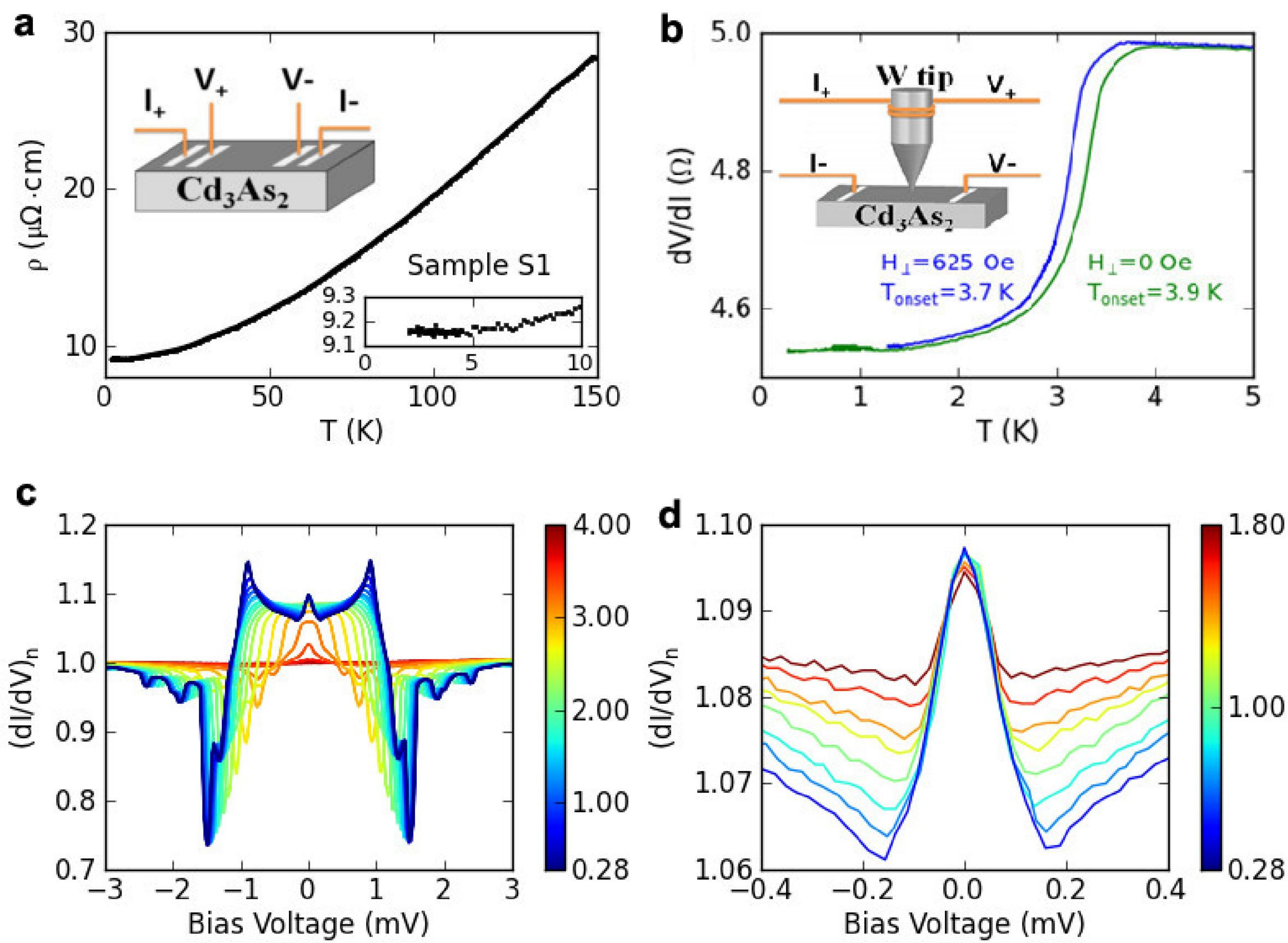
He Wang

Huichao Wang

Haiwen Liu

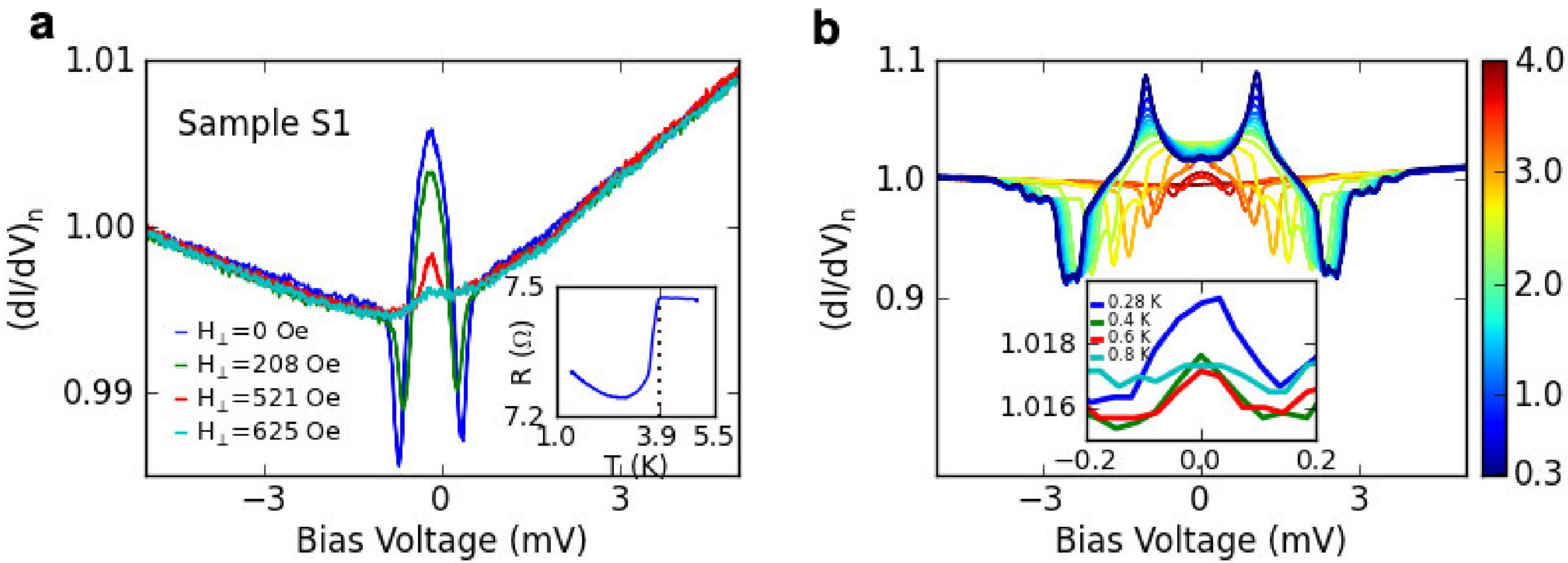
All authors: He Wang, Huichao Wang, Haiwen Liu, Hong Lu, Wuhao Yang, Shuang Jia, Xiong-Jun Liu, X. C. Xie, Jian Wei, and Jian Wang

The data from Sample 1: the observation of superconductivity



arXiv:1501.00418

The data from Sample 1 on another site:

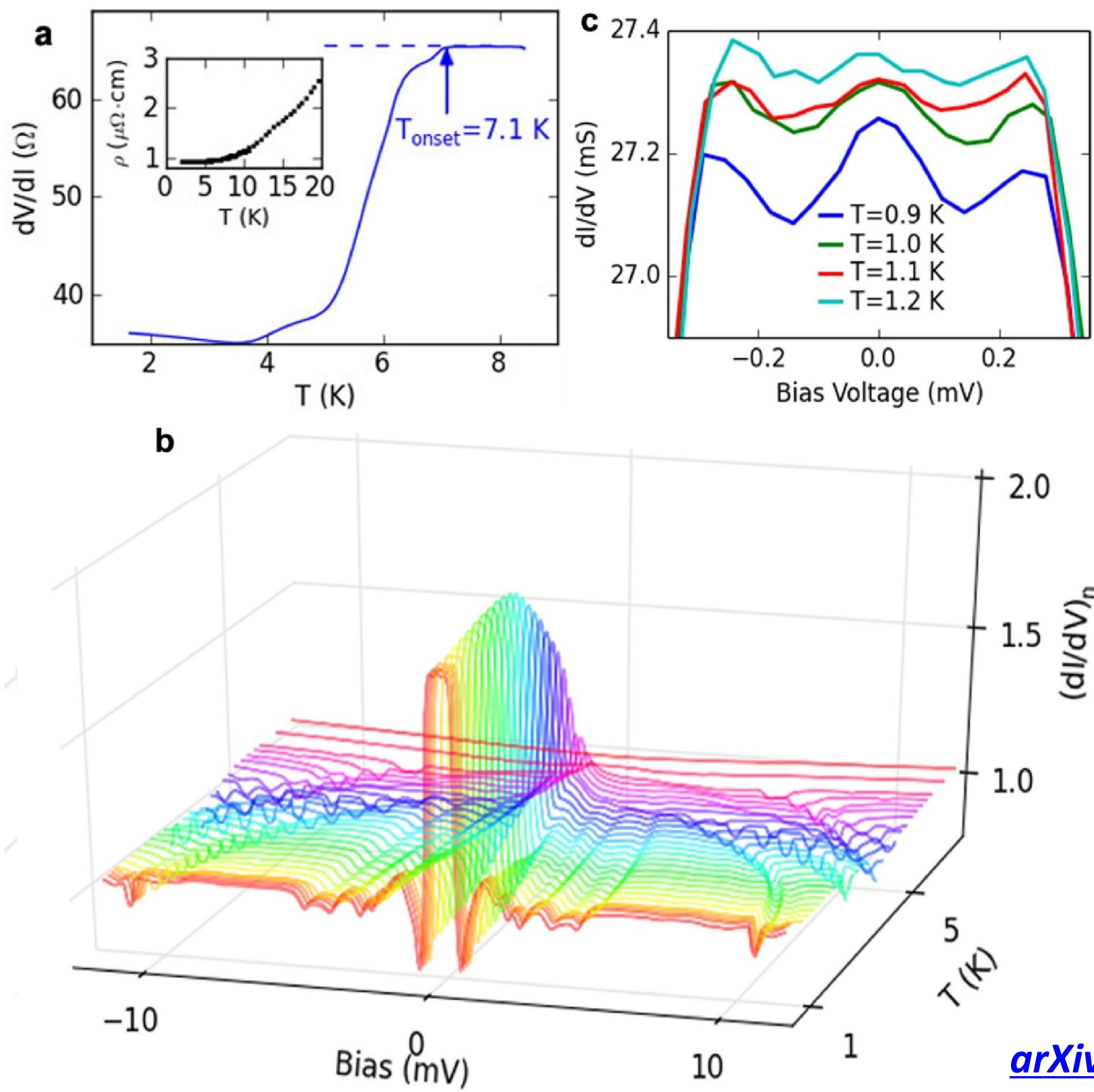


The applied magnetic field can suppress the observed gap.

Similar structure

arXiv:1501.00418

The data from Sample 2:



[arXiv:1501.00418]

Summary

1. By point contact measurement using "needle-anvil" configuration we firstly observe the unexpected superconducting behavior in 3D Dirac semimetal Cd_3As_2 crystal.
2. The observed ZBCP and DCPs features in PCS indicate the superconductivity we found is unconventional.
3. Our further theoretical analyses reveal that the exotic features may originate from topological superconductivity in the surface FAS and bulk states.
4. So far, most experiments are still focused on demonstrating or exploring the existence of topological superconductors. Our discovery of superconductivity in 3D Dirac semimetal which is of ultrahigh mobility may offer an ideal candidate or platform for studying topological superconductivity.

arXiv:1501.00418

Welcome to Jian Wang's Lab at Peking University:

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PhD Students:

Yanfei Zhao

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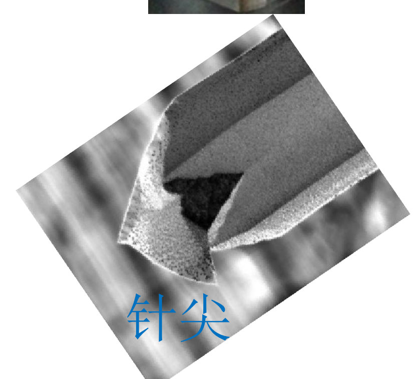
Ying Xing

探头

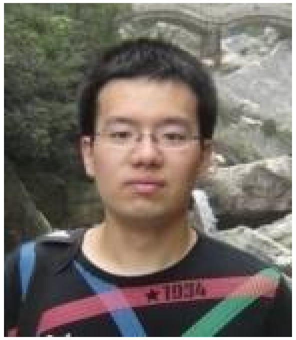


16 T, 50 mK Transport Measurement
+AFM/MFM system
Angle-dependent measurements and ETO

UHV MBE + Low temperature STM system

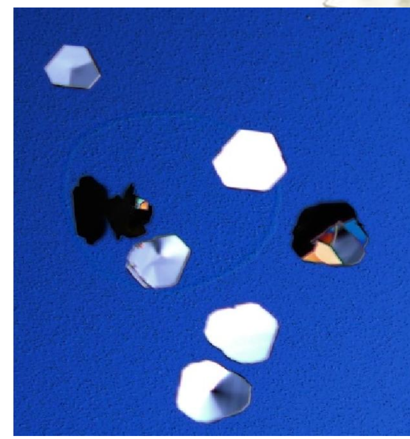
Yangwei Zhang

Yi Liu



Nanostructure sample growth (CVD):

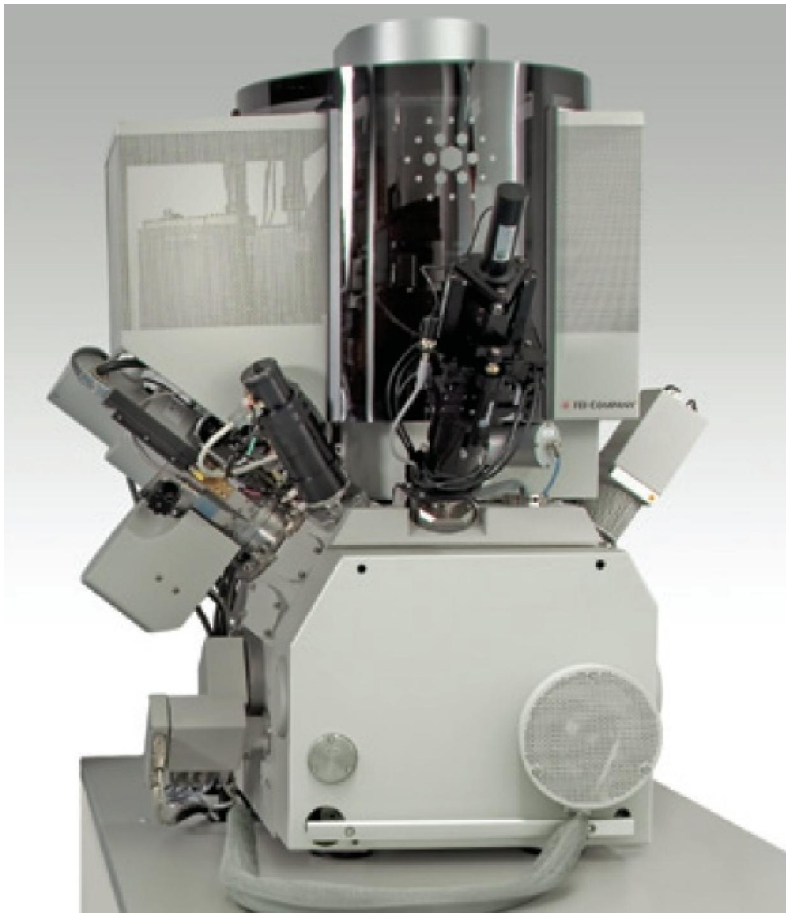
Huichao Wang



Nanostructure sample growth (hydrothermal method):

Yangwei Zhang

Public Clean Room in our Center: Nano Fabrication by Helios 600i (FIB+EBL)



Masters:

Yanfei Zhao

Ying Xing

ICQM PKU

INTERNATIONAL CENTER FOR QUANTUM MATERIALS

北京大學 PEKING UNIVERSITY

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Huichao Wang

Ying Xing

Yangwei Zhang

Yi Liu

THANK YOU !