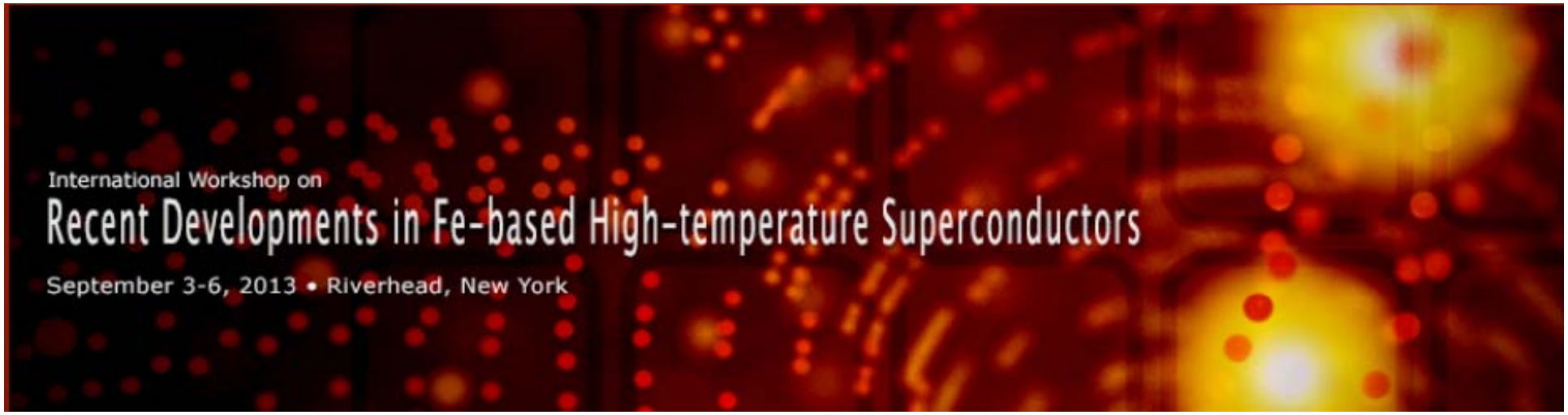

High T_C superconductivity in single unit cell FeSe films on $SrTiO_3$

Lili Wang

Institute of Physics, CAS

4th September, 2013

中国科学院物理研究所
Institute of Physics Chinese Academy of Sciences

清華大學
Tsinghua University

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  Qi-Kun Xue's group @ Tsinghua Univ..
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  Jian Wang's group @ Peking Univ..
- **ARPES Measurements:** Xingjiang Zhou's group @ IOP, CAS
- **TEM observations:** Mingwei Chen's group @ Tohoku Univ. AIMR
- **Pulsed High Magnetic Field:** Liang Li's group @ HUST

CHIN. PHYS. LETT. Vol. 29, No. 3 (2012) 037402

Interface-Induced High-Temperature Superconductivity in Single Unit-Cell FeSe Films on $SrTiO_3$ *

Nb-doped STO → + 1UC FeSe → STM/STS

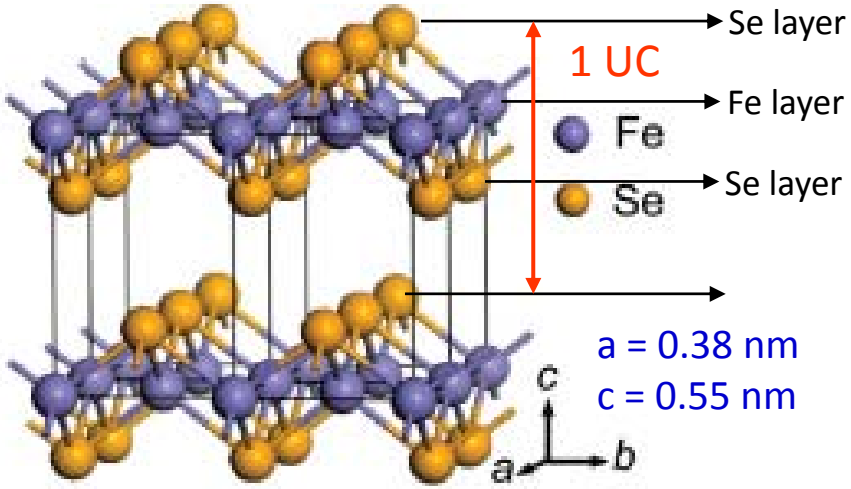
Se-etching

950°C under Se flux for 30 min

Co-evaporating

Se/Fe flux ratio > 10, $T_{Fe} >> T_{STO} > T_{se}$

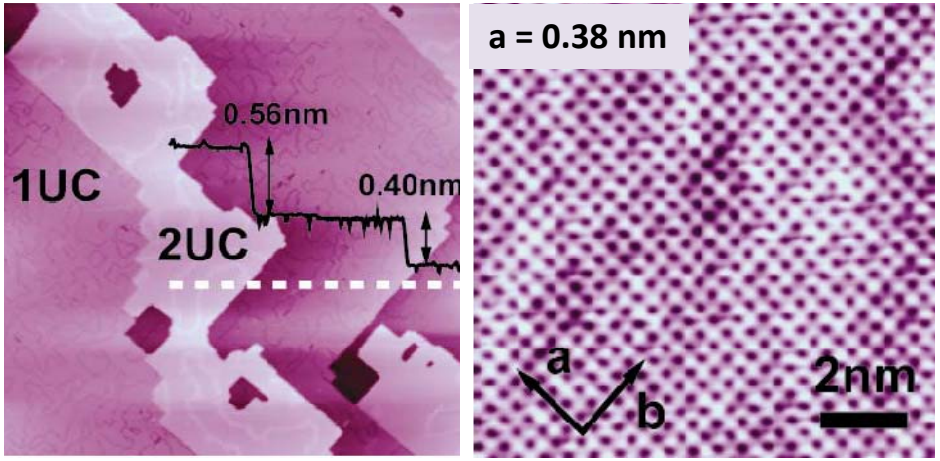
Annealing at 450-500 ℃



$T_{C,\,bulk}$ ~ 8 K

$T_{C,\,8.9GPa}$ ~ 36.7 K

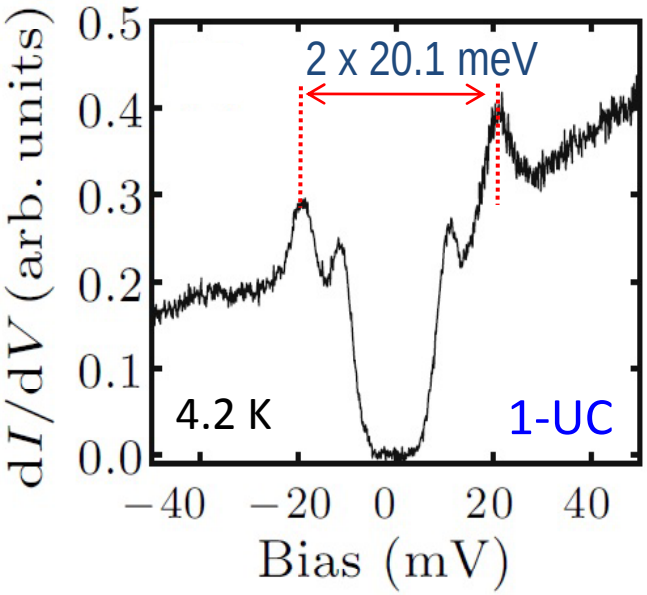
FeSe films

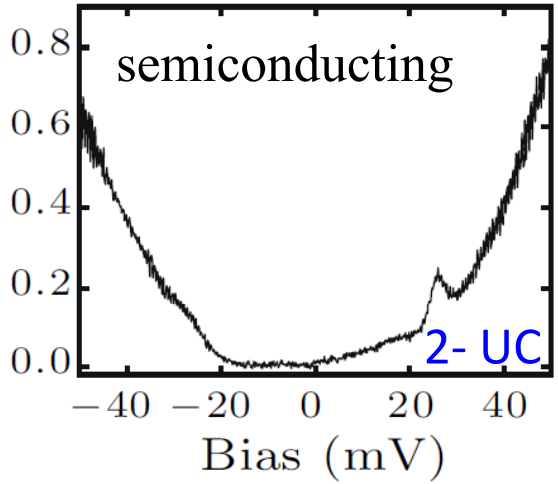


CHIN. PHYS. LETT. Vol. 29, No. 3 (2012) 037402

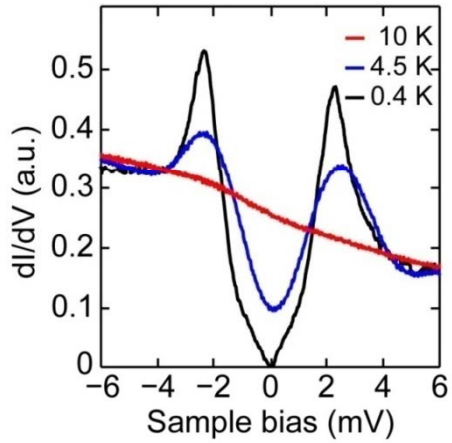
Interface-Induced High-Temperature Superconductivity in Single Unit-Cell FeSe Films on $SrTiO_3$ *

Δ = 20.1 meV

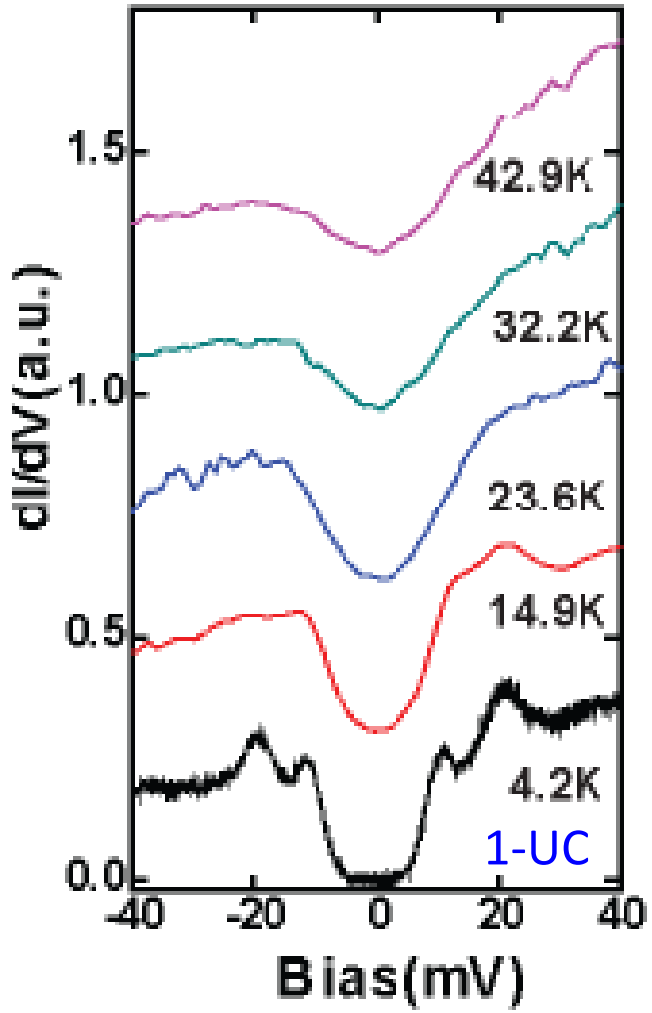




30-UC FeSe on graphene
Δ = 2.2 meV



Science 332, 1410 (2011)



High-temperature superconductivity at the FeSe/SrTiO3 interface
Yuan-Yuan Xiang, Fa wang, DA Wang, Qiang-Hua Wang, and Dong-Hai Lee. *Phys. Rev. B* ***86****, 134508 (2012*)

Atomic and electronic structures of FeSe monolayer and bilayer thin films on SrTiO3(001): First-principles study
Kai Liu, Zhong-Yi Lu, and Tao Xiang. *Phys. Rev. B* ***85****, 235123 (2012)*

Atomic and Electronic Structures of Single-Layer FeSe on $SrTiO_3$(001): The Role of Oxygen Deficiency
Junhyeok Bang, Zhi Li,Y. Y. Sun, Amit Samanta, Yuyang Zhang, Wenhao Zhang, Lili Wang, X. Chen, Xucun Ma, Q.-K. Xue, and S. B. Zhang. Phys. Rev. B ***87****, 220503R (2013)*

Effects of charge doping and constrained magnetization on the electronic structure of an FeSe monolayer
Timur Bazhirov and Marvin L. Cohen. *arXiv: 1208.2260*

Antifferomagnetic FeSe monolayer on SrTiO3: The charge doping and electric field effects
Fawei Zheng, Zhigang Wang, Wei Kang, and Ping Zhang. *arXiv: 1302.2996*

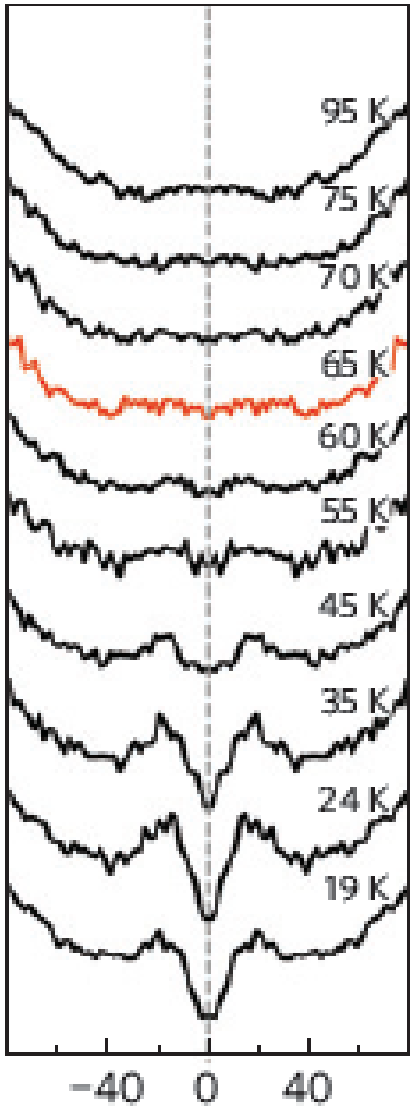
Do Se vacancies electron dope monolayer FeSe?
Tom Berlijn, Hai-Ping Cheng, P. J. Hirsechfeld, and Wei Ku. *arXiv: 1307.0140*

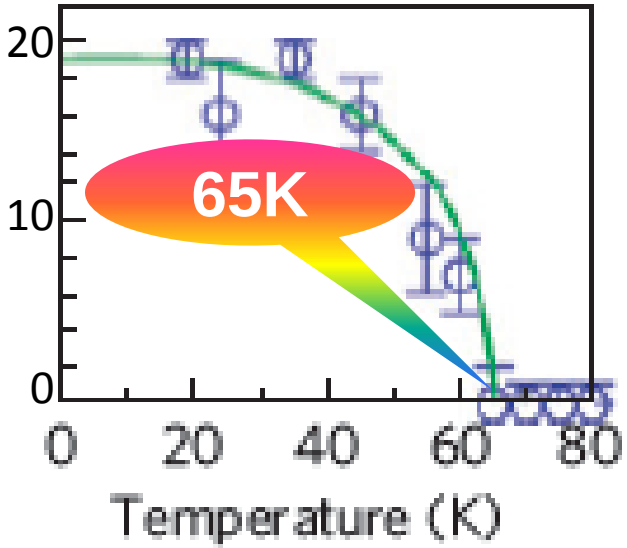
Electronic origin of high-temperature superconductivity in single-layer FeSe superconductor
D.F. Liu et al., *Nat. Commun.* ***3****, 931(2012)*

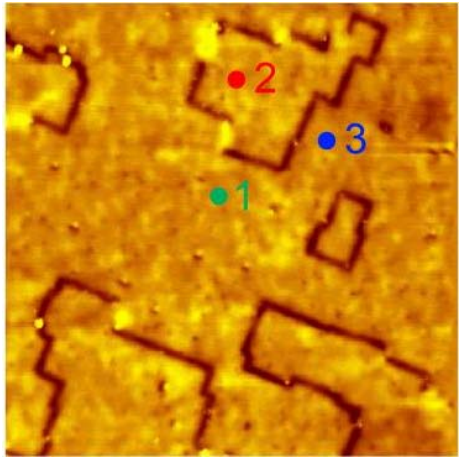
Phase diagram and high temperature superconductivity at 65 K in tuning carrier concentration of single-layer FeSe films
S.L. He et al., *Nature Mater.* ***12****, 605-610 (2013)*

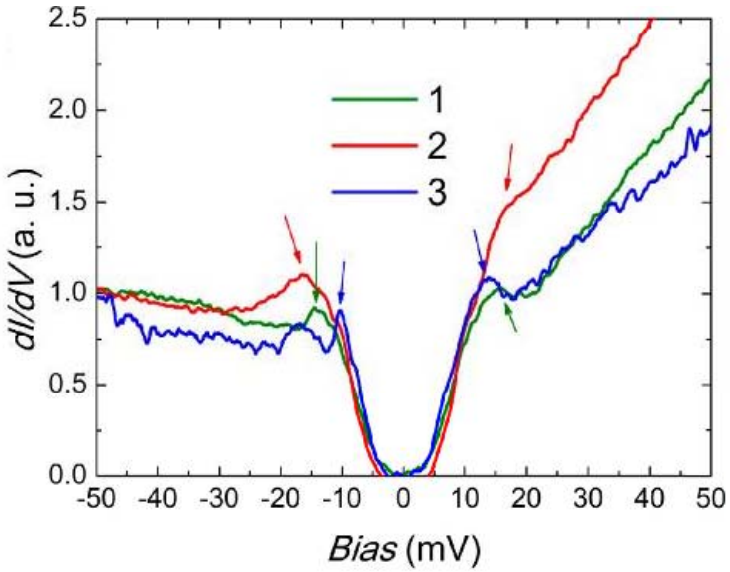
Interface-induced superconductivity and strain-dependent spin density wave in FeSe/SrTiO3 thin films
S. Y. Tan et al., *Nature Mater.* ***12****, 634-640 (2013)*

Superconducting gaps (ARPES)









ARPES: 15-19 meV

Signature of new record T_c in Fe-based superconductors!

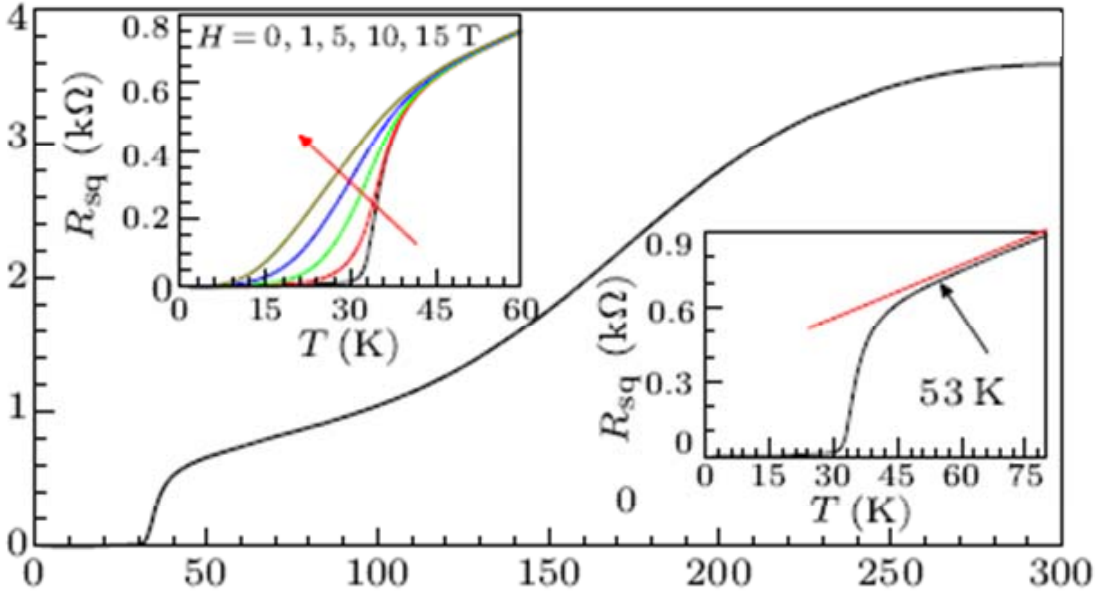
Nature Mater. 12, 605-610 (2013)

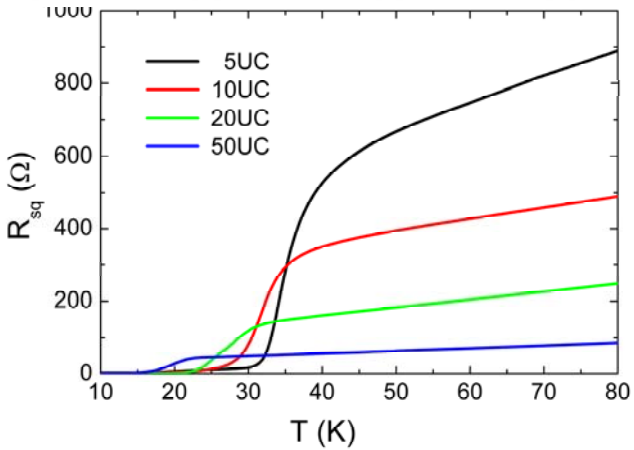
CHIN. PHYS. LETT. Vol. 29, No. 3 (2012) 037402

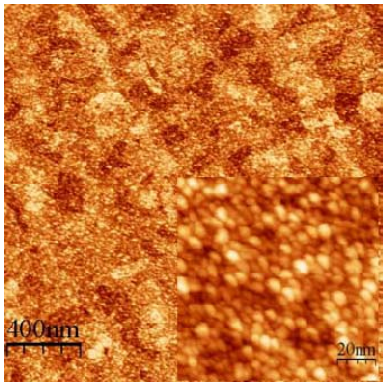
Interface-Induced High-Temperature Superconductivity in Single Unit-Cell FeSe Films on $SrTiO_3$ *

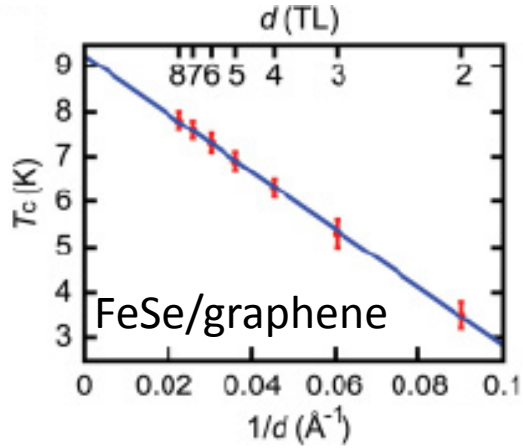
Undoped STO → + 5-UC FeSe → ++amorphous Si → transport

980°C for 10 h under O_2
600°C for 3 h in UHV

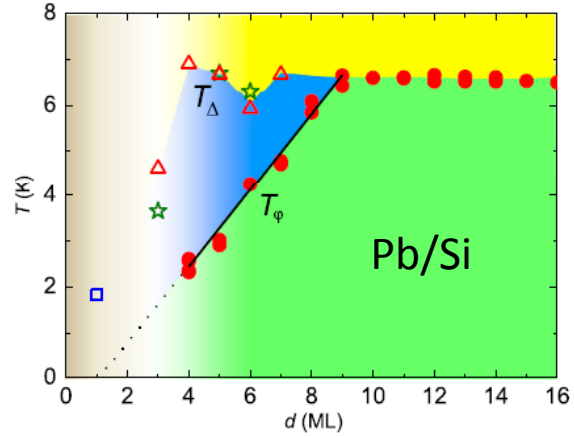








Phys. Rev. B **84**, 020503(2011)

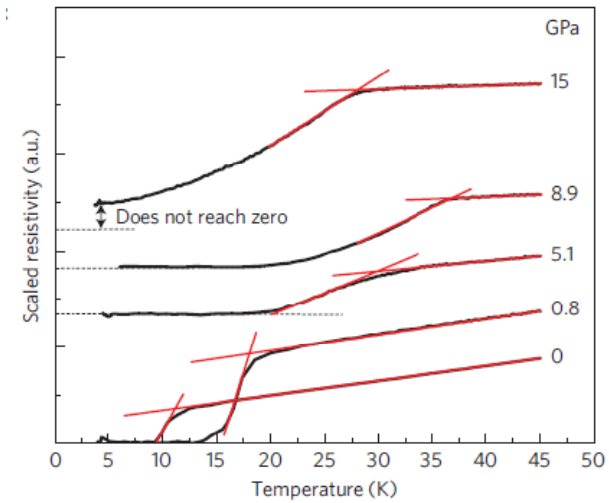


Solid State Commun. ***165****, 59 (2013)*

Why high T_c ?

Strain ?

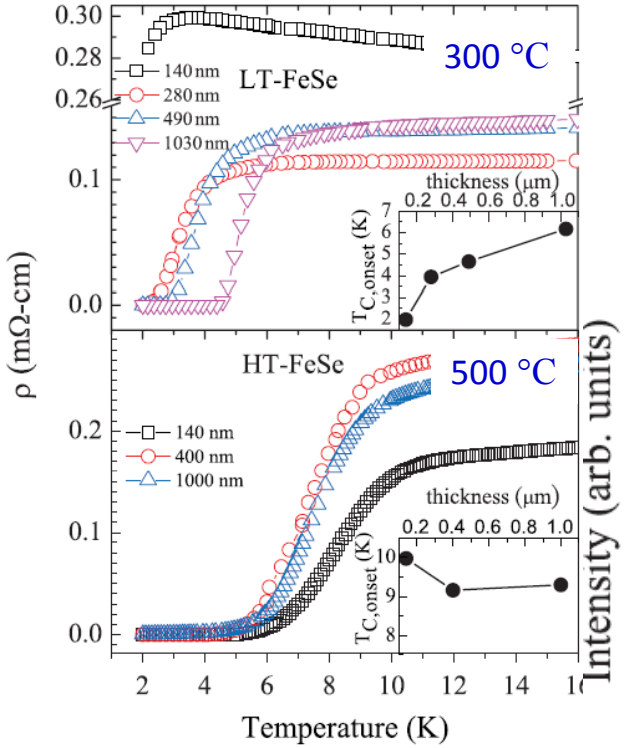
Strain is too weak to enhance T_c.



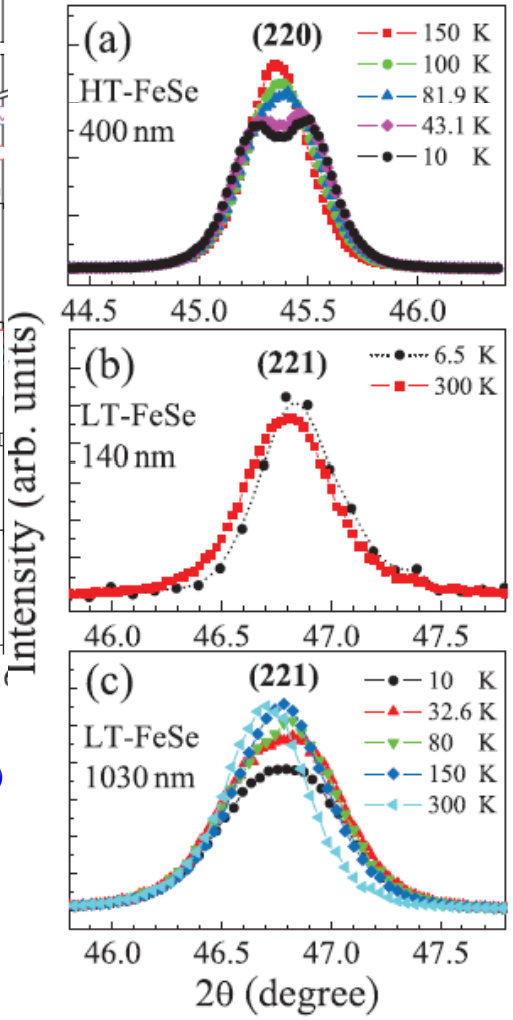
Nature Mater. 8, 630 (2009)

	bulk	8.9GPa	1 UC
a	0.3765	0.357	0.38
c	0.5518	0.50	*0.55*
T_c	12 K	37 K	?

FeSe films on MgO(100)



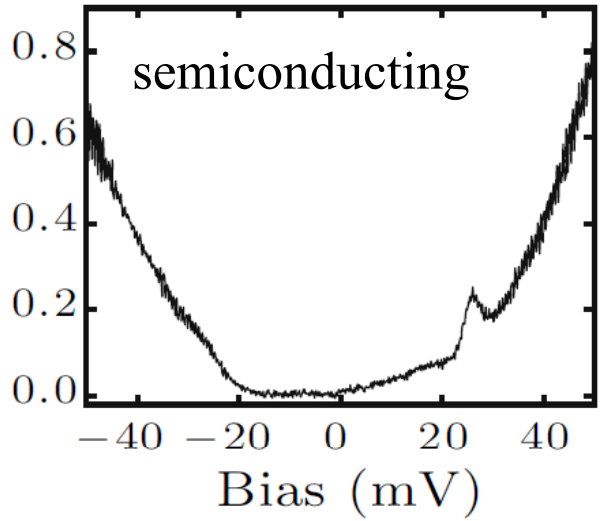
Phys. Rev. Lett. ***103****, 117002 (2009)*



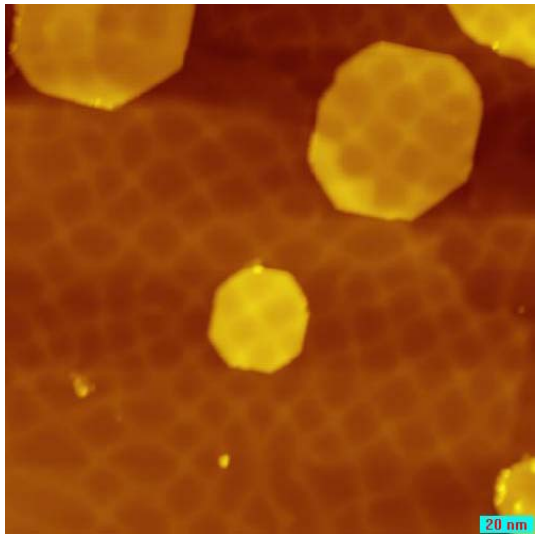
The strain suppresses the lattice distortion from tetragonal to orthorhombic.

Strain suppresses the intrinsic superconductivity in FeSe films?

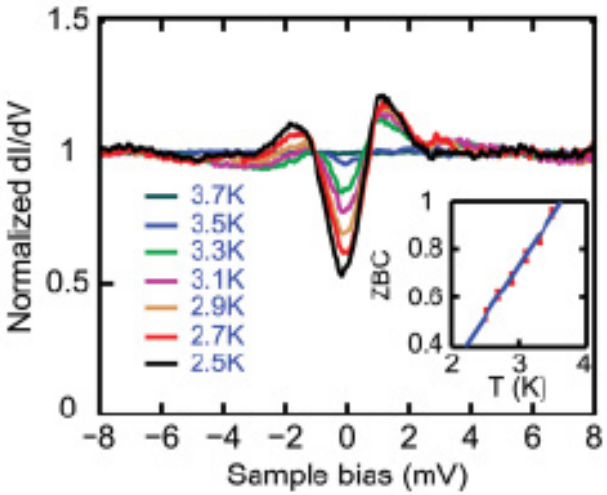
2- UC FeSe on STO

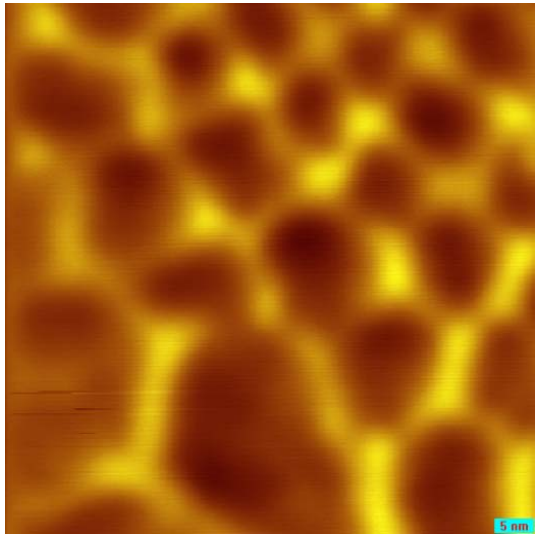


5- UC FeSe on STO



2-UC FeSe on graphene

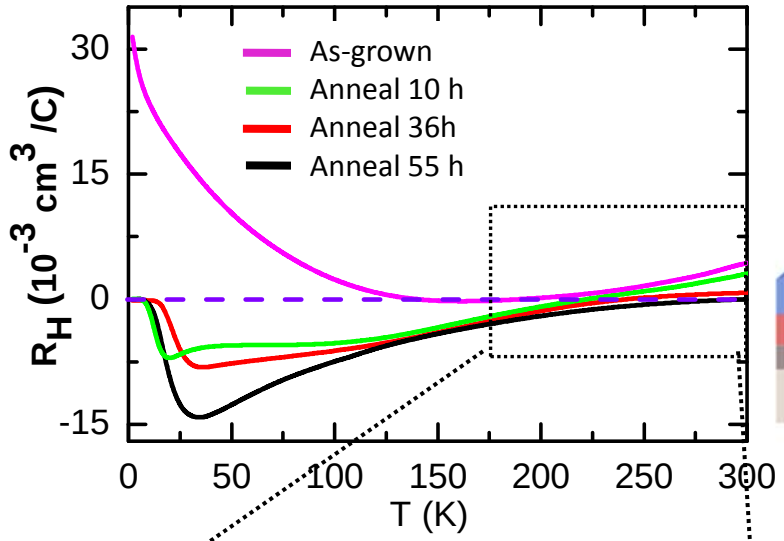


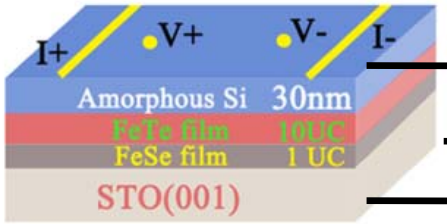


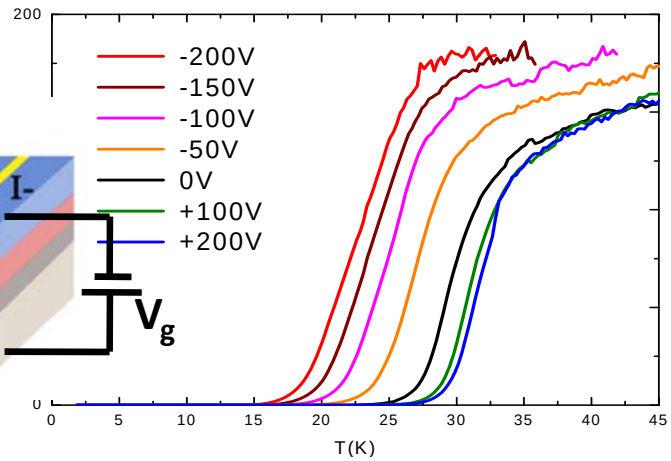
Song et al., Phys. Rev. B ***84****, 020503(2011)*

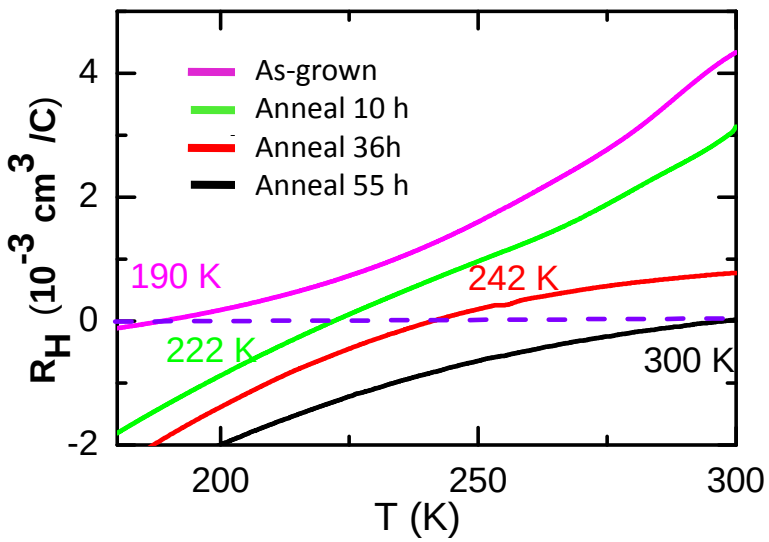
Why high T_c ?

Charge transfer at FeSe/STO interface









The longer the annealing time is, the higher the temperature of the n-p transition is.

Nature Mater. 12, 634-640 (2013)
The superconductivity occurs when the electrons transferred from the oxygen-vacant substrate suppress the otherwise most pronounced SDW in single layer FeSe.

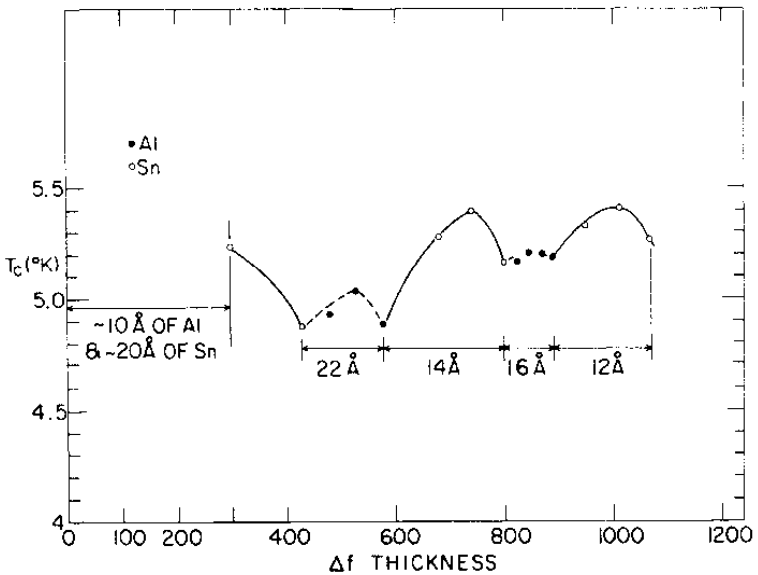
Nature Mater. 12, 605-610 (2013)
The S phase is characterized by an electron-like Fermi surface around the M point.

Phys., Rev. B 87, 220503R (2013)
The charge transfer from the O vacancies to the FeSe layer provides stronger binding of the FeSe layer to the substrate than that without the O vacancies.

Why high T_C ?

Interface enhanced e-p coupling

Al/Sn heterostructure



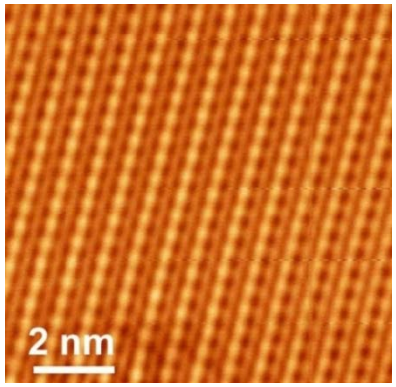
Phys. Rev. Lett. 21, 1320 (1968)

The e-p coupling at interface is enhanced due to the lowering of phonon frequencies.

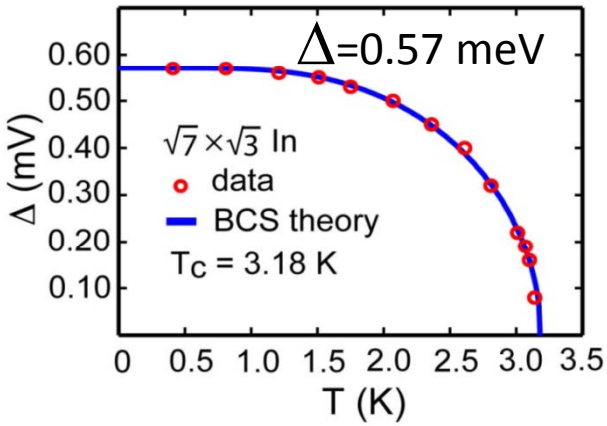
Si(111)- (√7×√3)-In

Our temperature-dependent valence band linewidths indicate an electron-phonon coupling constant λ~ 1, similar to that of bulk indium. We might therefore expect the surface to become superconducting near the critical temperature of bulk In (T_c =3.4 K).

Phys. Rev. Lett. ***91****, 246404 (2003).*



Nat. Phys. 6, 104 (2010)



Bulk In : T_c = 3.4 K

Single atomic-layer In on graphene, T_c < 0.3 K

Macroscopic Superconducting Current through a Silicon Surface Reconstruction with Indium Adatoms: Si(111)- (√7×√3)-In

Phys. Rev. Lett. 107, 207001(2011)

Phys. Rev. B 86, 134508 (2012)

The effects of screening due to the $SrTiO_3$ ferroelectric phonons ….can significantly enhance the energy scale of Cooper pairing and even change the pairing symmetry.

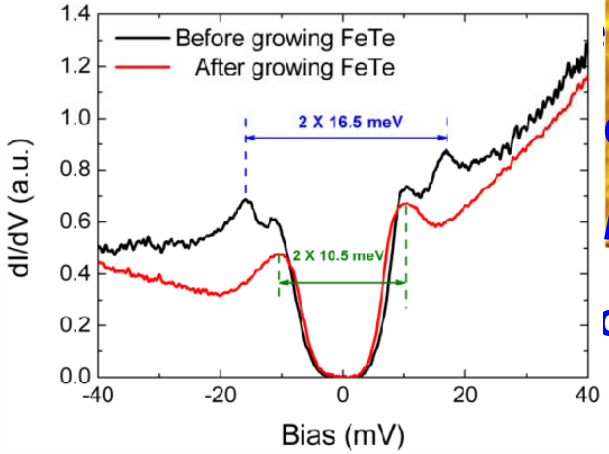
Summary and perspectives

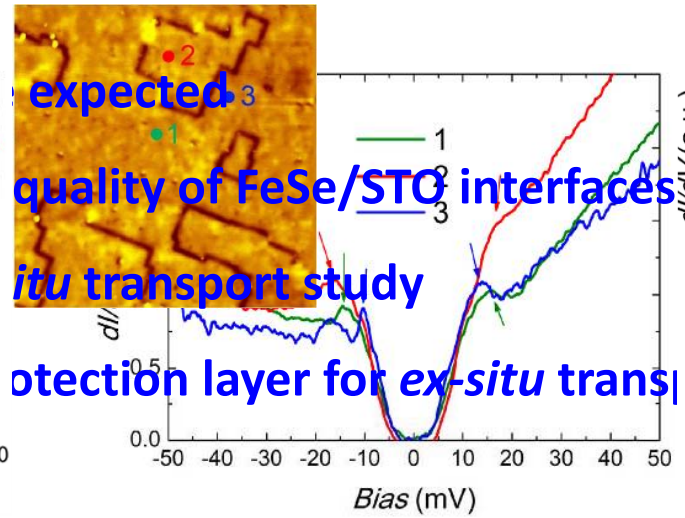
1-UC FeSe films on STO:

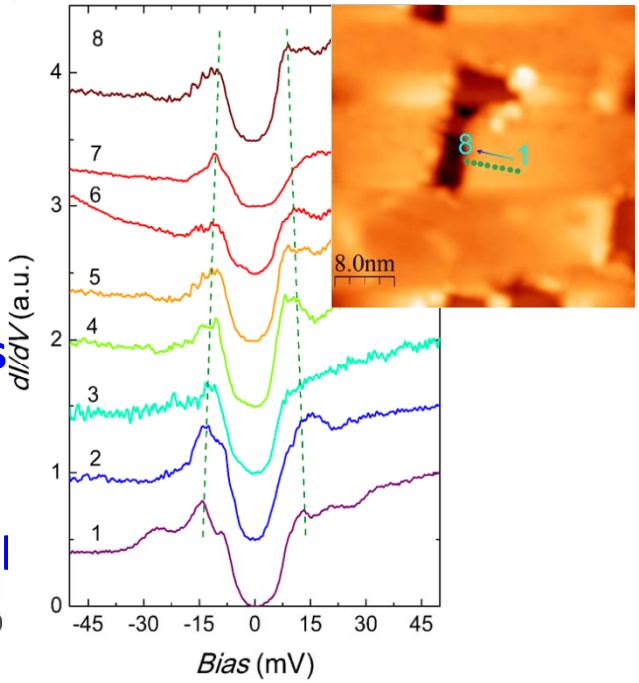
T_C > 40 K, $H_{C2}(0)$ > 52 T, and J_C > 10^6 A/cm^2

$T_{C,\ transport} < T_{C,ARPES}$ ($T_{C,\ STS}$) ?

- The proximity effect from the FeTe protection layer may lead to a reduction in T_C.
- The closed domain walls and defects can locally suppress superconductivity with Josephson junctions and electrons scattering.
- KTB transition.







expected

quality of FeSe/STO interfaces

itu transport study

otection layer for *ex-situ* trans

Thank you for your attention!