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Generic buffer layers for Fe-based superconductors: Epitaxial $FeTe_{1-x}Se_x$ thin films

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Leibniz Association DFG SEVENTH FRAMEWORK PROGRAMME IRON-SEA

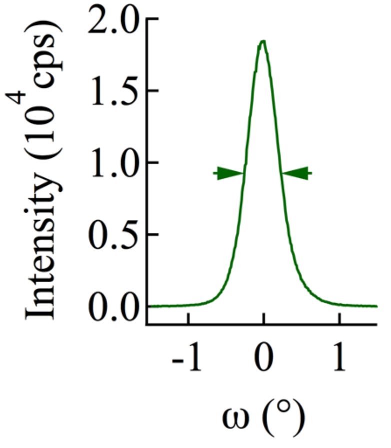
Leibniz Institute for Solid State and Materials Research Dresden

Outline

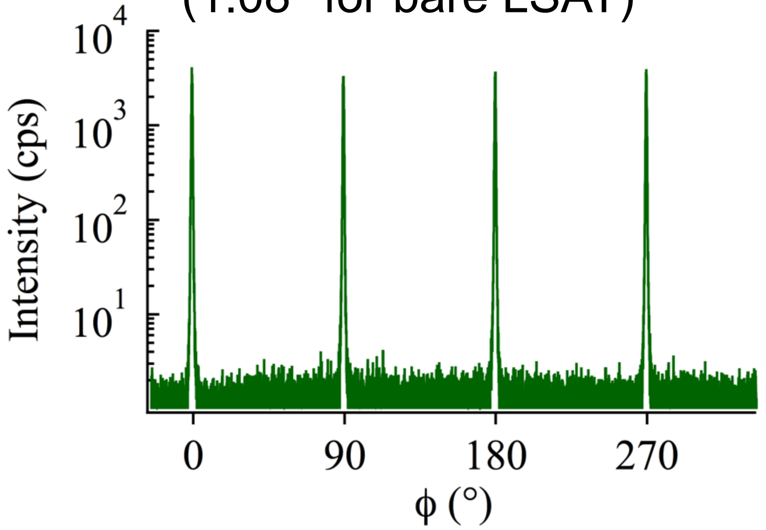
1. General features of Ba-122 / Fe bilayers
2. $FeTe_{1-x}Se_x$ / Fe bilayers on MgO
   i) Structural characterization
   ii) Transport properties
3. Intrinsic pinning in SmFeAs(O,F)
4. Summary

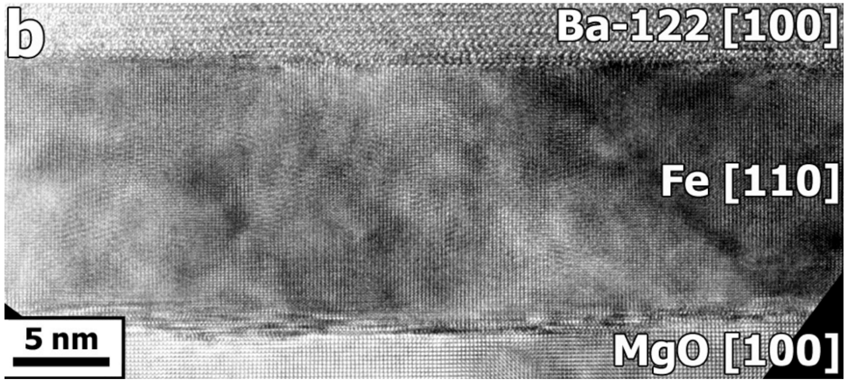
Excellent crystalline quality and clean interface of Ba-122/Fe bilayer

$\Delta\omega$=0.49° (26 % less)
(0.66° for bare LSAT)



$\Delta\phi$=0.58° (46 % less)
(1.08° for bare LSAT)

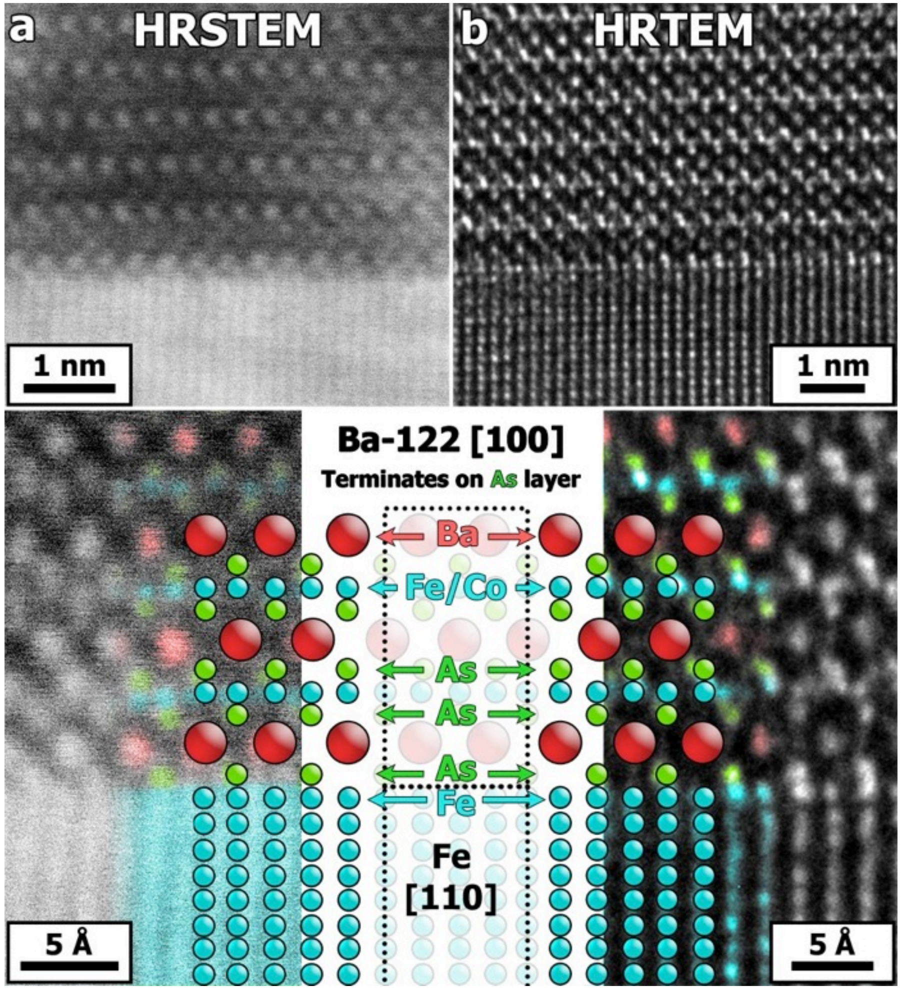




Clean interface

K.Iida *et al.*, APL **97**, 172507 (2010)

Direct observation of bonding between Fe and Ba-122



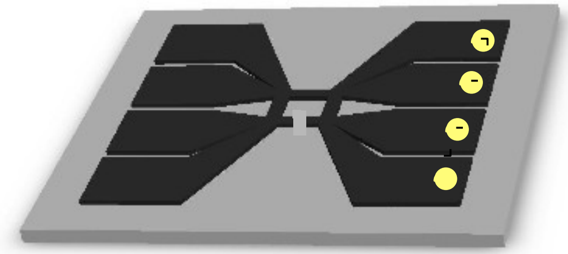
T. Thersleff *et al.*, APL **97**, 022506 (2010)

Highly coherent interface between Fe and Ba-122

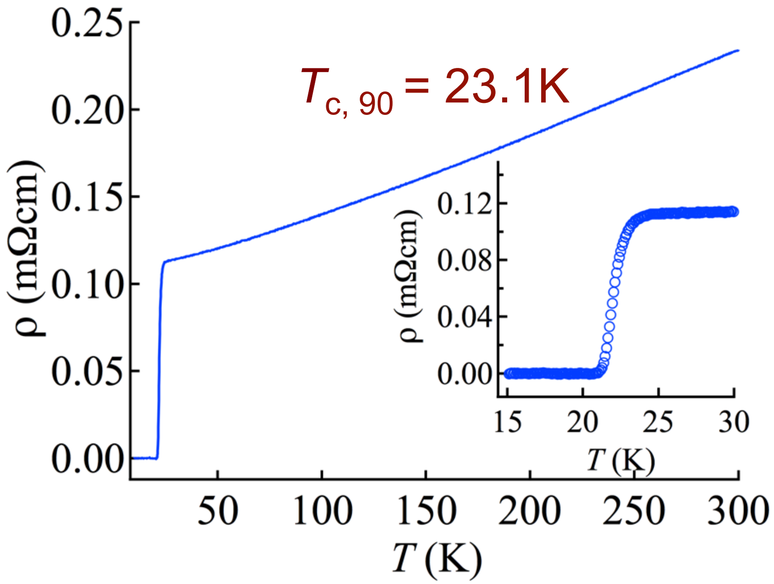
Bonding takes place at the **square-planar Fe sublayer**

No evidence for a reaction layer or **loss of crystallographic ordering**

Transport properties of Ba-122/Fe bilayers



Structured sample: 500 μm width
Standard 4 probe method

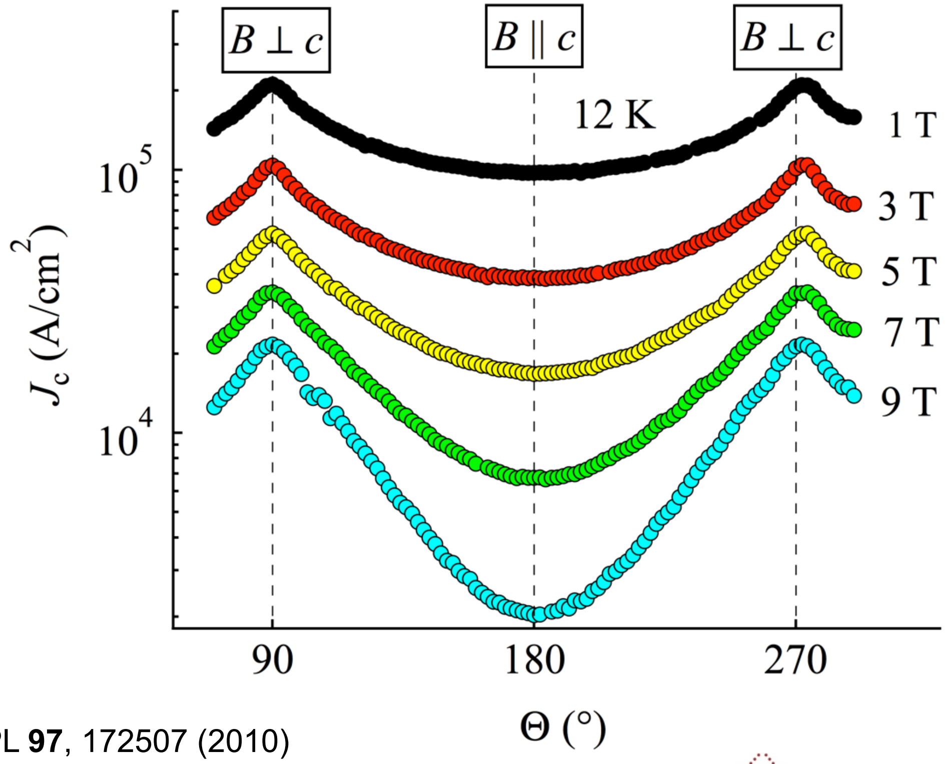


No J_c peaks at $B \parallel c$

-> **Absence of correlated defects**

(Also confirmed by TEM)

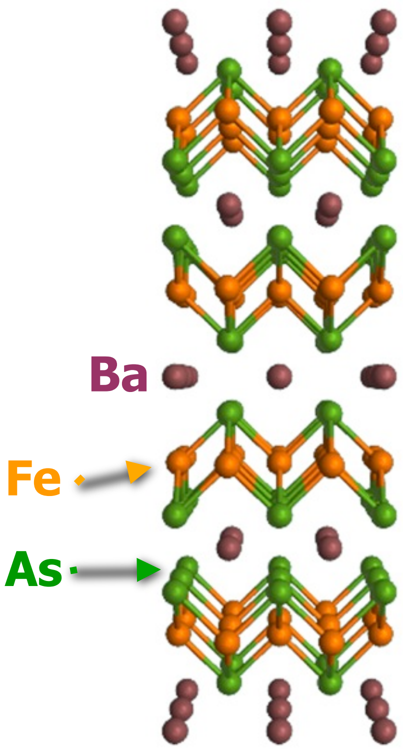
J_c maximum at $B \perp c$



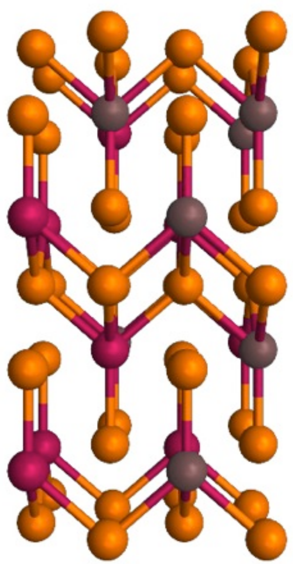
K.Iida *et al.*, APL **97**, 172507 (2010)

Generic buffer layers for Fe-based superconductors

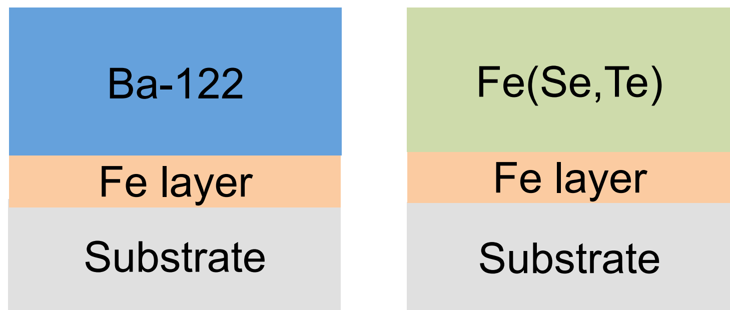
$Ba(Fe_{1-x}Co_x)_2As_2$
"122" family



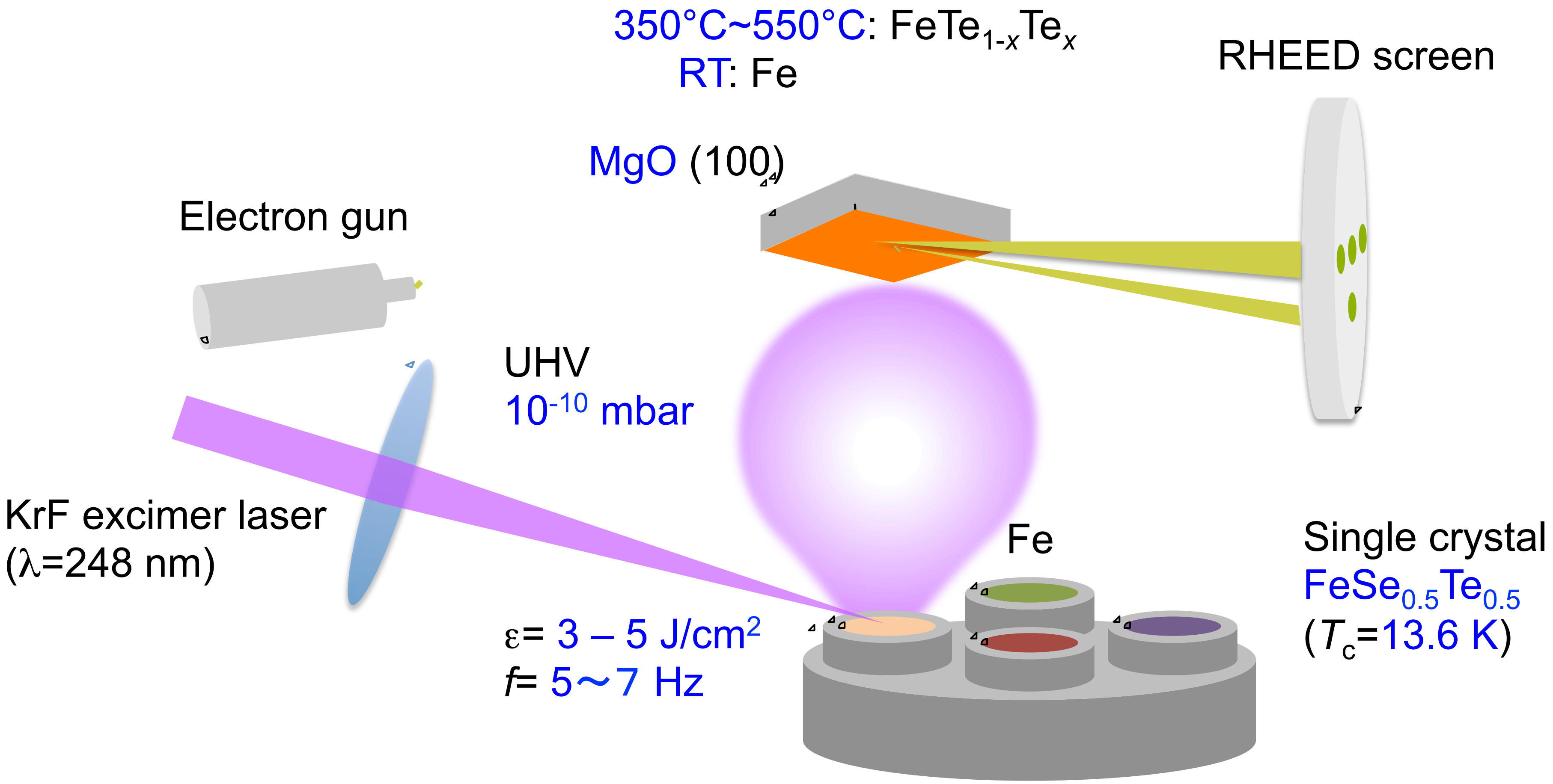
$Fe(Te_{0.5}Se_{0.5})$
"11" family



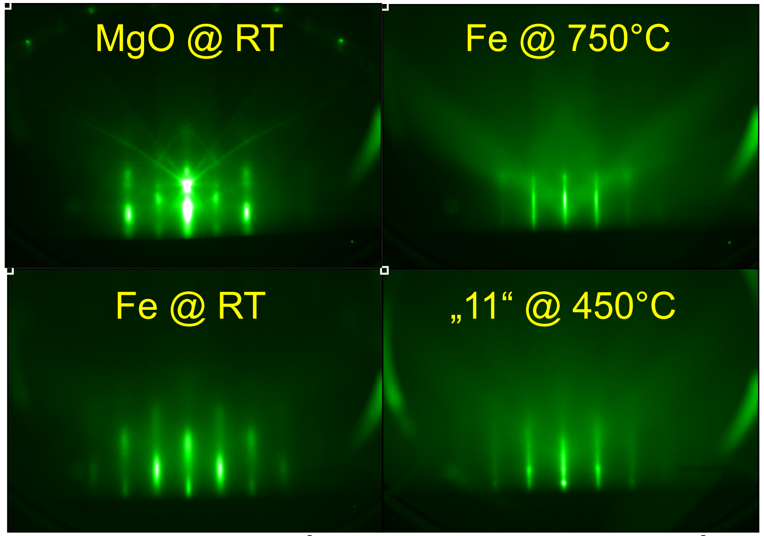
- ✓ **Tetrahedrally coordinated FePn** (Pn: pnicogen or chalcogen) layer
- ✓ **This architecture** should work for "11"



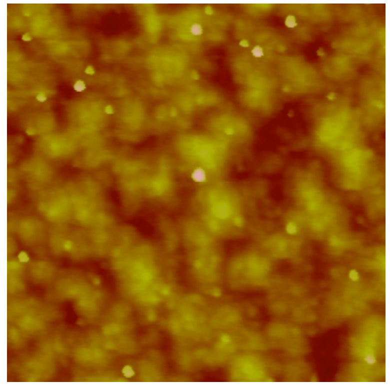
$FeTe_{1-x}Se_x$ / Fe Films have been prepared by PLD under UHV condition

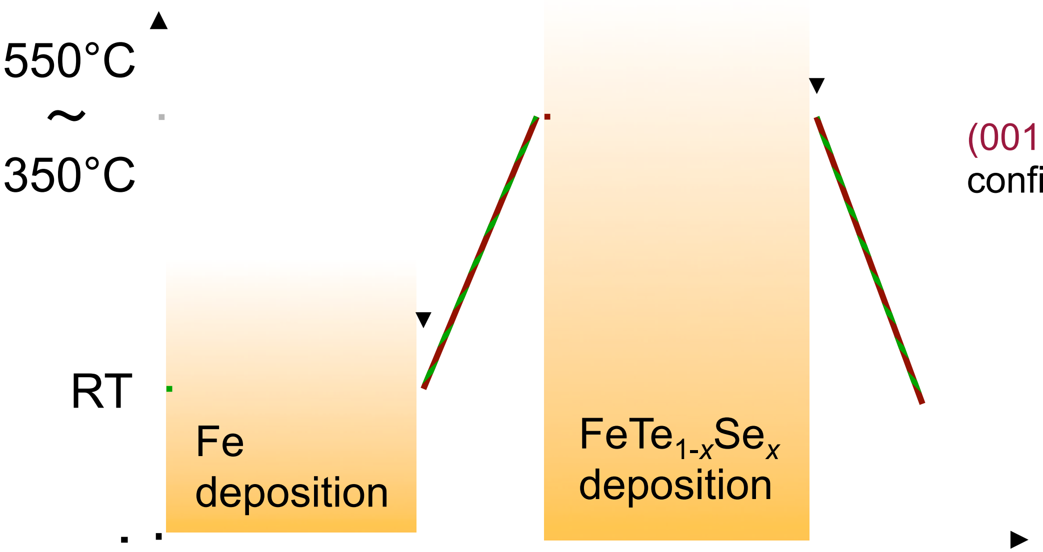


$FeTe_{1-x}Se_x$ on Fe-buffered MgO

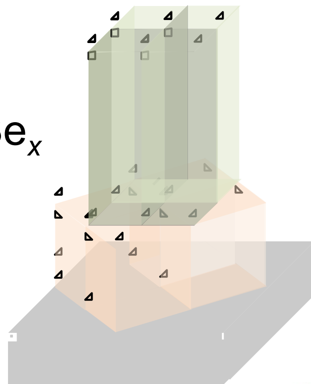


- ✓ Epitaxial Fe even @ RT
- ✓ Fe surface is smoothing on heating
- ✓ Epitaxial “11” with flat surface (RMS=1 nm)

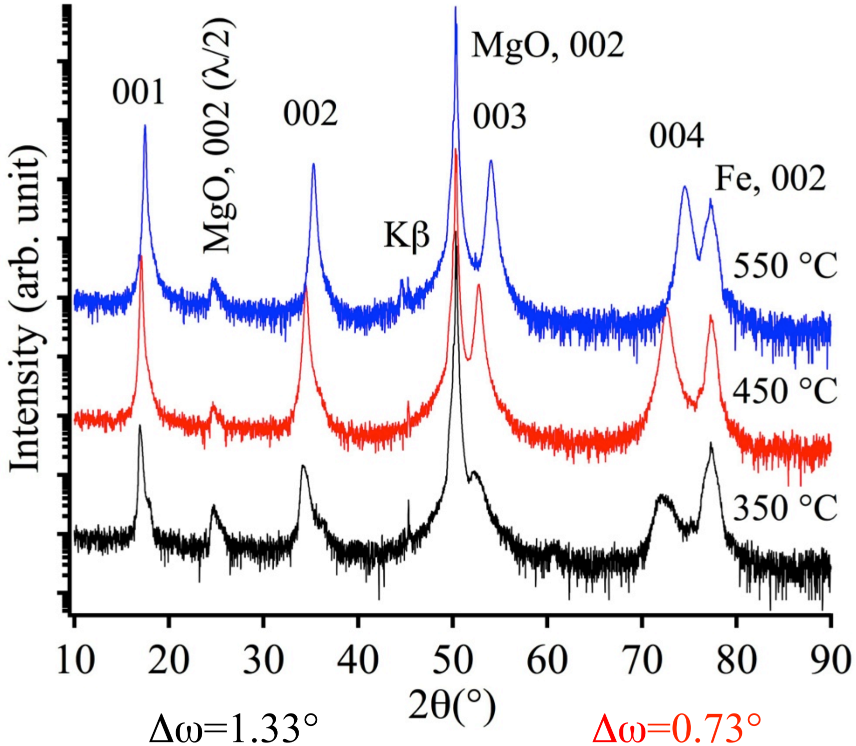




(001)[100]$FeTe_{1-x}Se_x$ || (001)[110]Fe || (001)[100]MgO confirmed by XRD

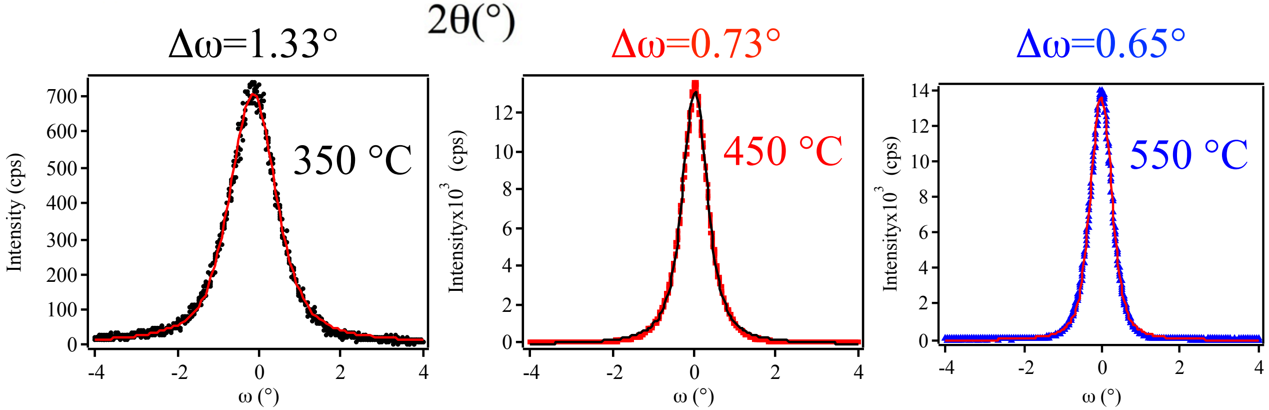


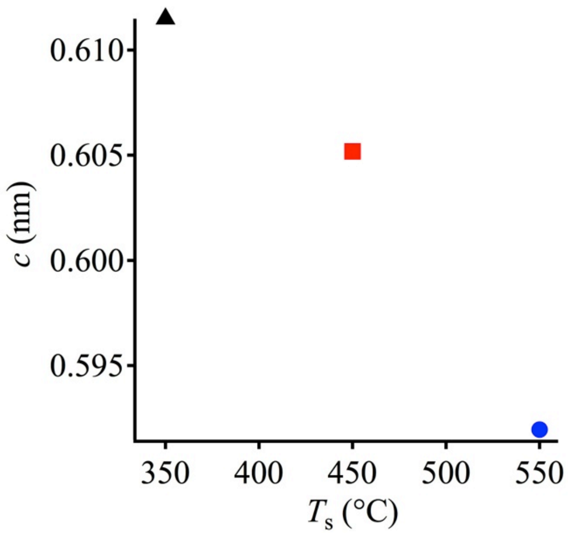
Structural characterization of $FeTe_{1-x}Se_x$/Fe bilayers



- ✓ Phase pure films
- ✓ Crystalline quality is improved with T_s
- ✓ Lattice parameters change with T_s

T_s (°C)	Δω (°)	Δφ (°)
350°C	1.33	1.9
450°C	0.73	0.97
550°C	0.65	0.72

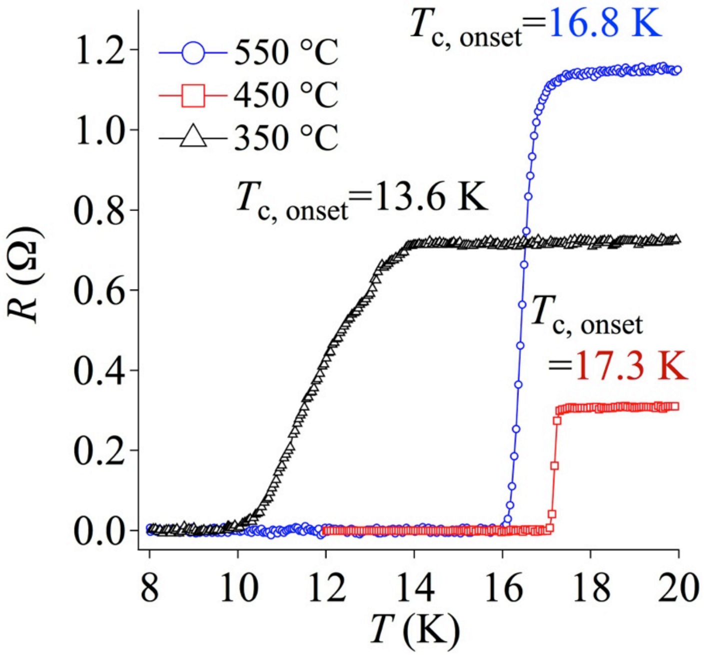


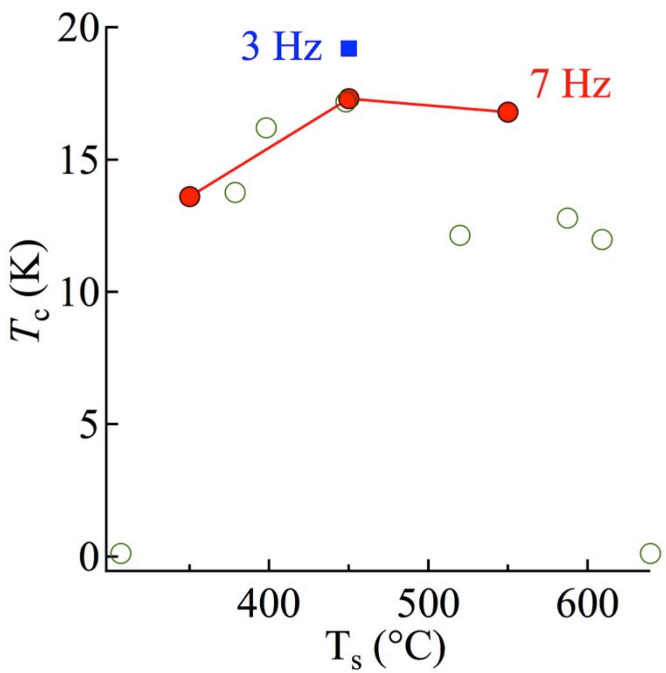


Optimum deposition temp. (T_s) is around 450°C

- ✓ T_c strongly depends on both T_s and f
- ✓ Optimum T_s is 450°C
- ✓ High T_c over 19 K is possible

f=7 Hz, T_s=350°C~550°C



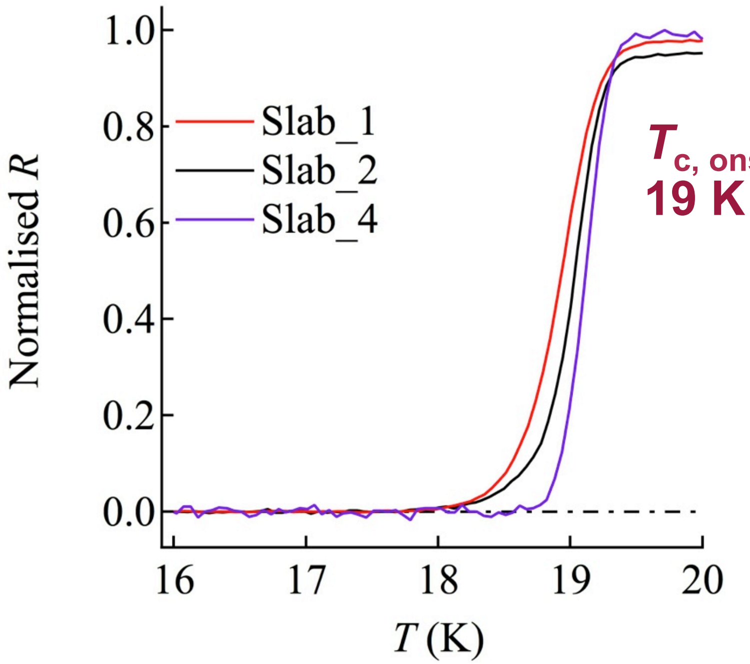


E. Bellingeri *et al.*, Sust **22**, 105007 (2009)

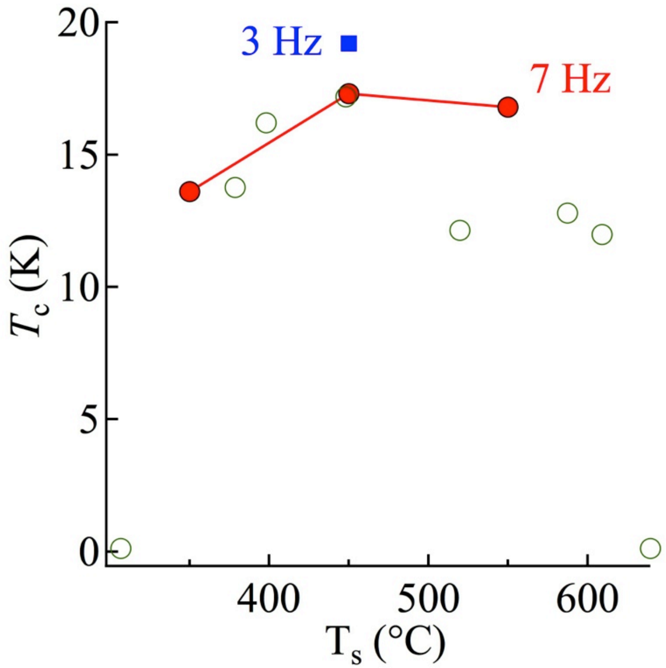
Optimum deposition temp. (T_s) is around 450°C

- ✓ T_c strongly depends on both T_s and f
- ✓ Optimum T_s is 450°C
- ✓ High T_c over 19 K is possible

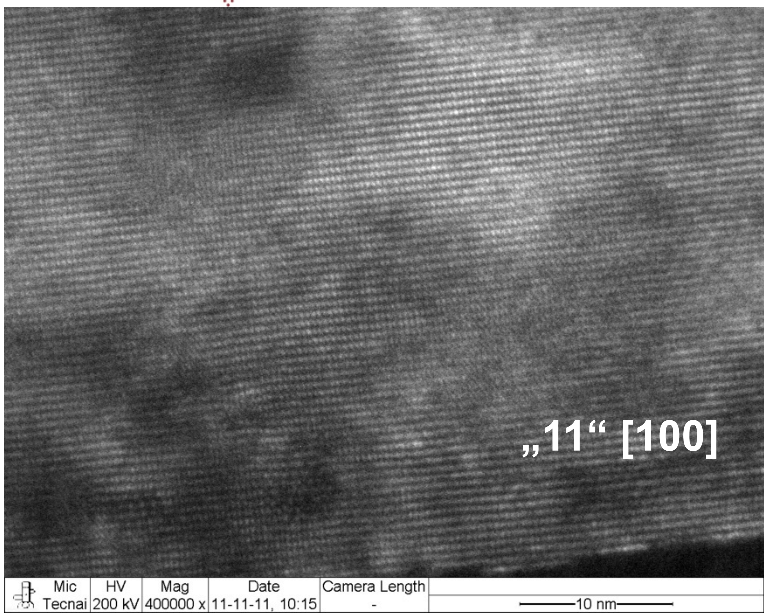
f=3 Hz, T_s=450°C



$T_{c,\ onset}$ over 19 K

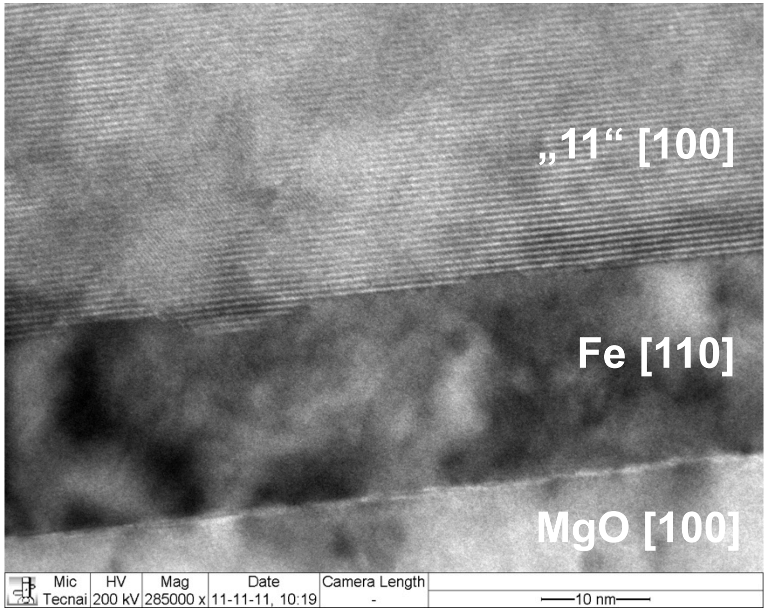


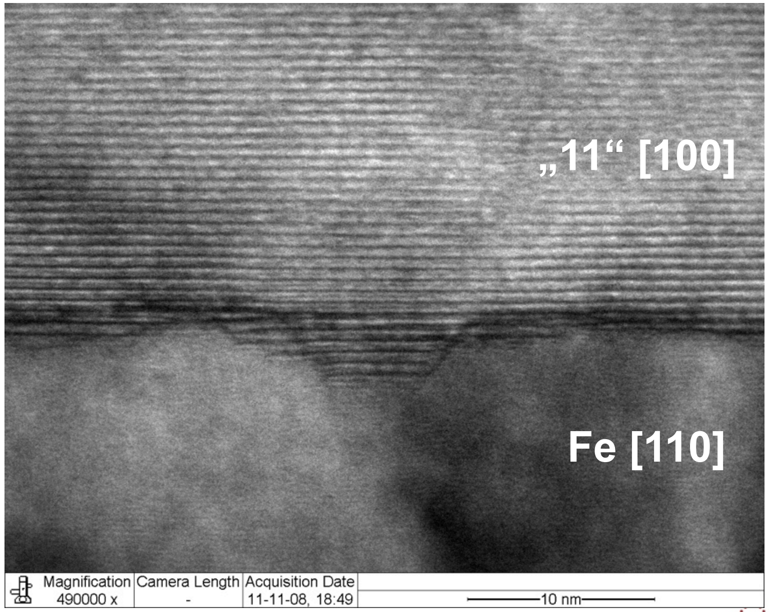
E. Bellingeri *et al.*, Sust **22**, 105007 (2009)

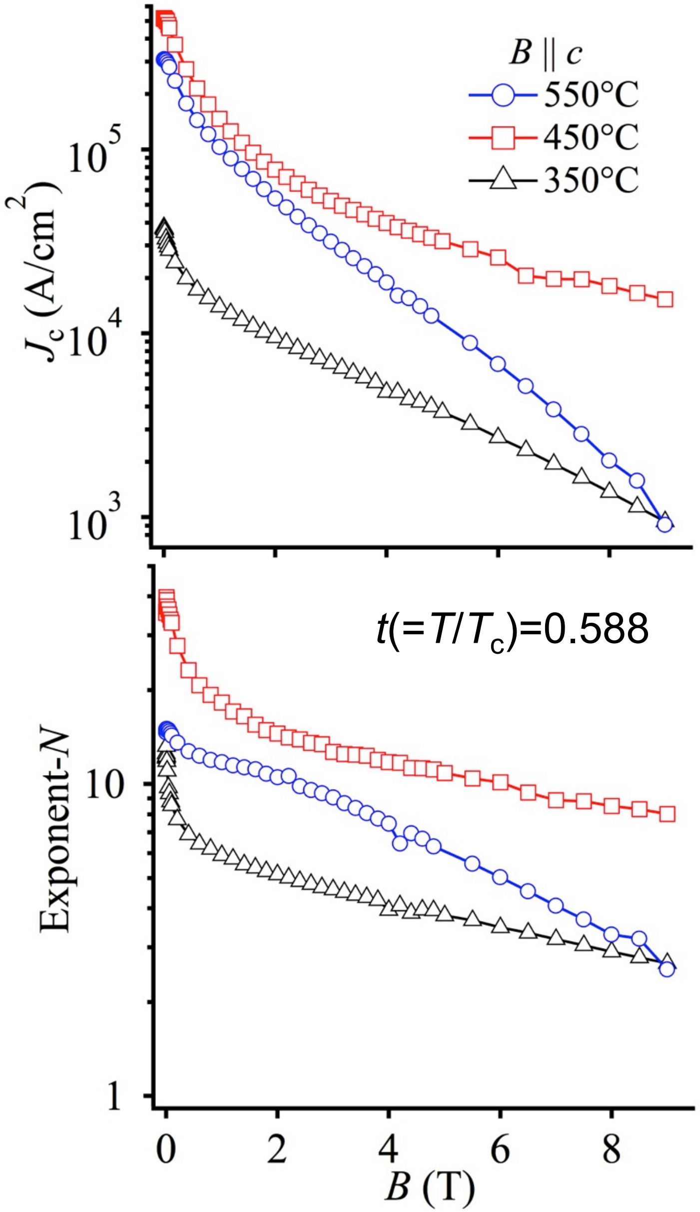


Relatively clean micorstructure of $FeTe_{1-x}Se_x$/Fe bilayers

- ✓ Almost no *c*-axis defects
- ✓ Clean interface
- ✓ Pyramidal growth nature of Fe is observed
- ✓ Stacking faults are formed at the interface







J_c-B curves are almost identical to N-B curves for B || c

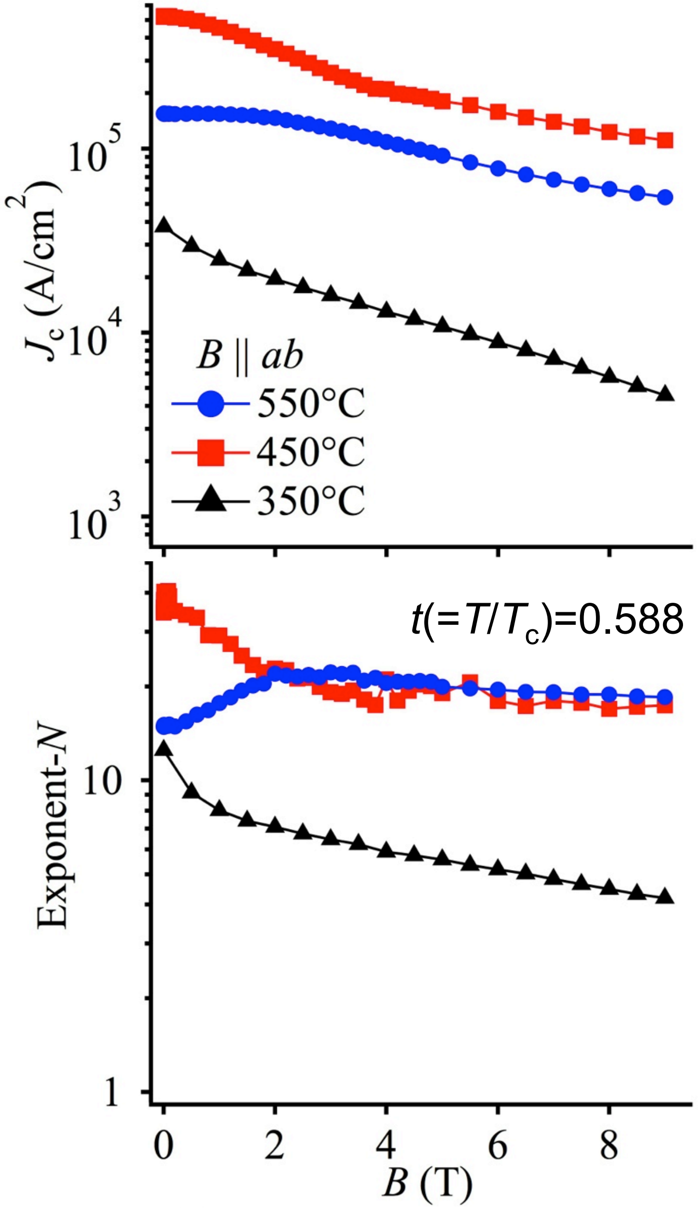
$V \propto I^N$

$N \sim U_p/k_B T$

$J_c \propto U_p$

U_p: pinning energy

- ✓ J_c is decreased monotonously with *B*
- ✓ *N*-*B* curves almost behave similar to J_c-*B*



J_c-B curves are almost identical to N-B curves except 550°C

$V \propto I^N$
$N \sim U_p/k_B T$
$J_c \propto U_p$

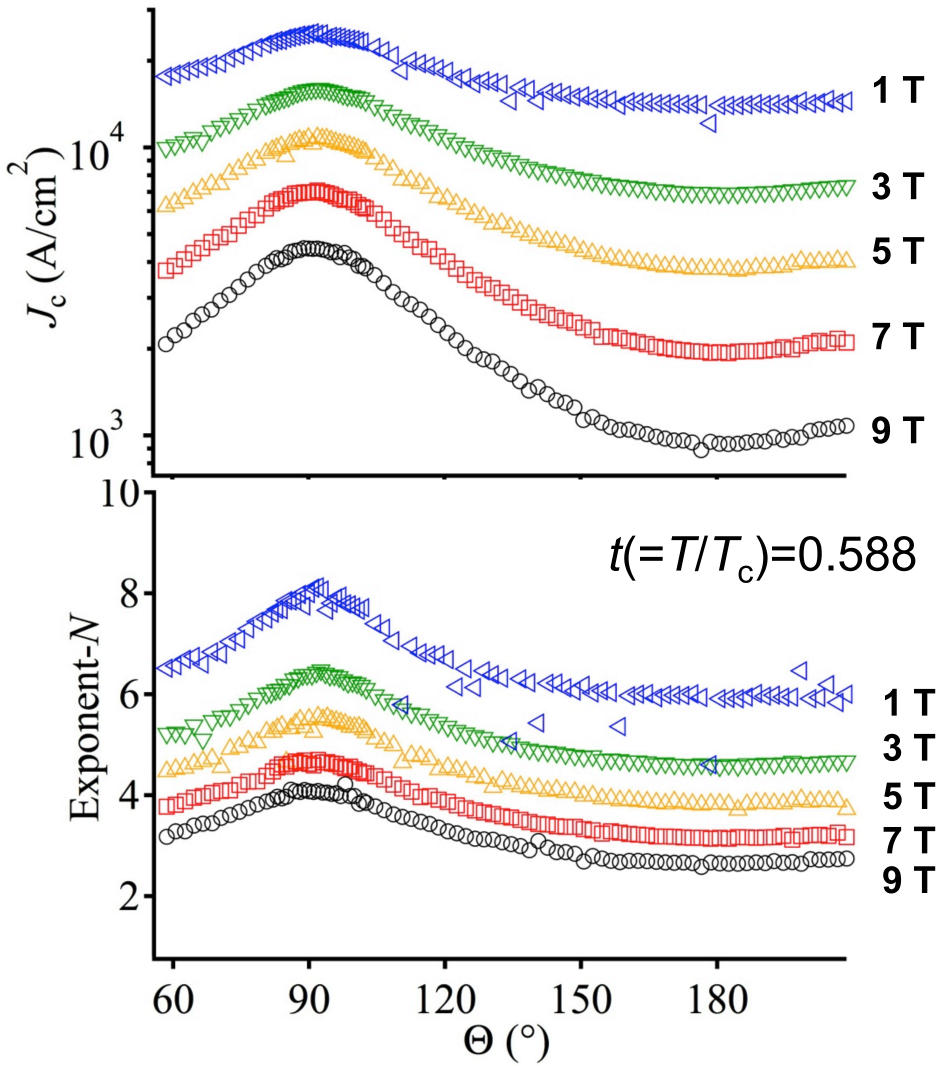
U_p: pinning energy

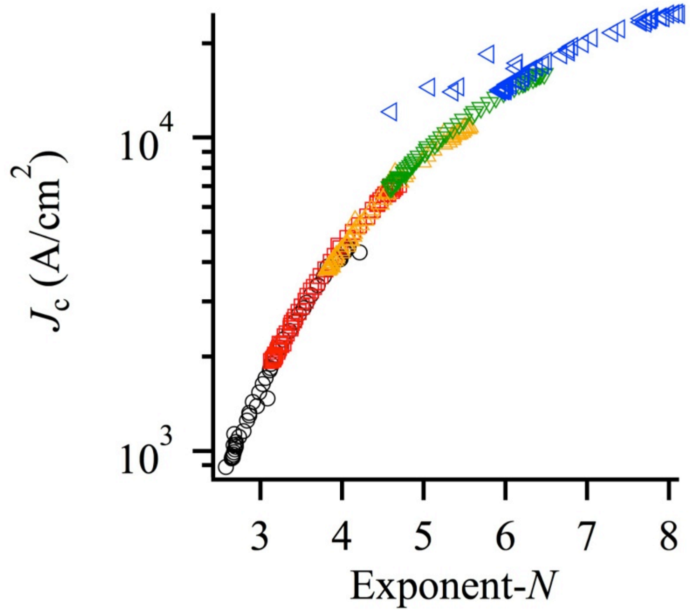
- ✓ $J_c(B)$ is almost identical to $N(B)$ (T_s=350°C)
- ✓ J_c is constant up to 2 T (T_s=550°C) (*N* is increased with *B*)

-> presence of planar defects ?

- ✓ Over 2 T, *N* is almost constant regardless of *B* (T_s=450°C and 550°C)

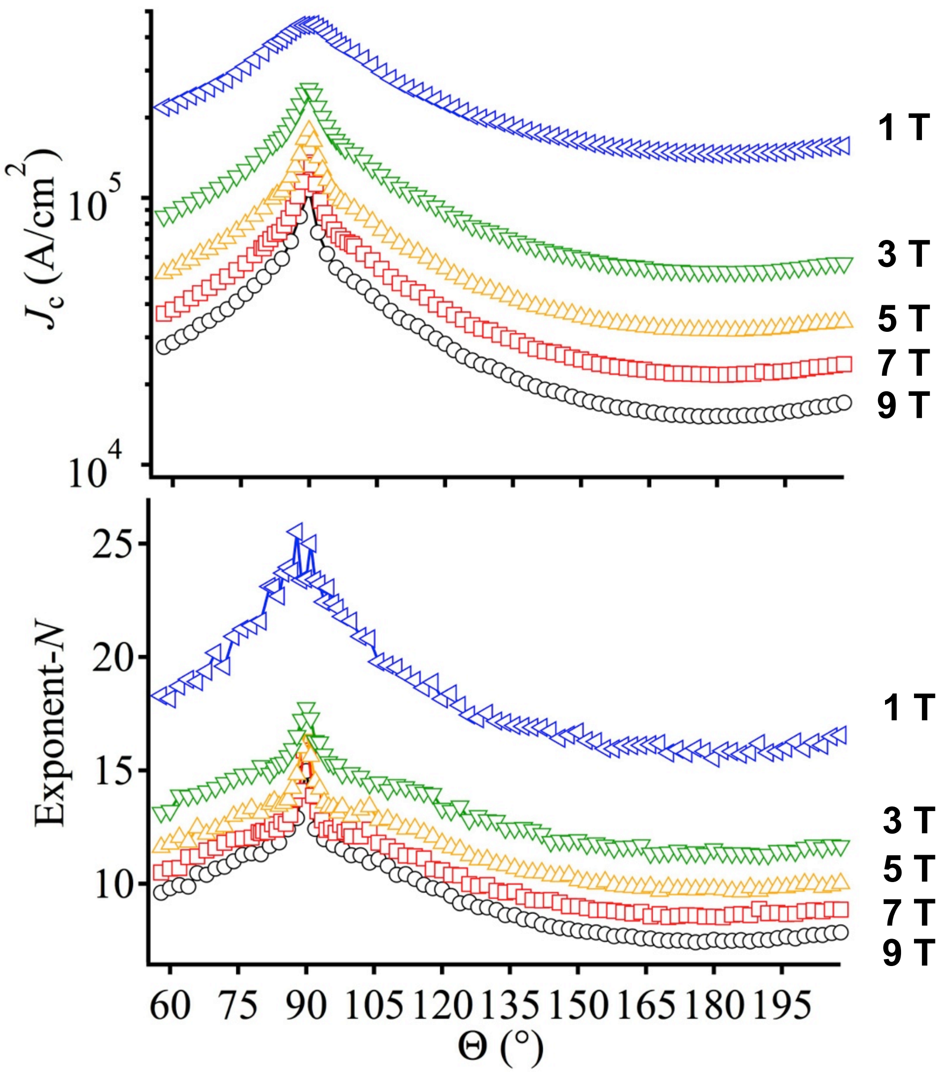
$J_c(\Theta)$ is also almost identical to $N(\Theta)$ (T_s=350°C)

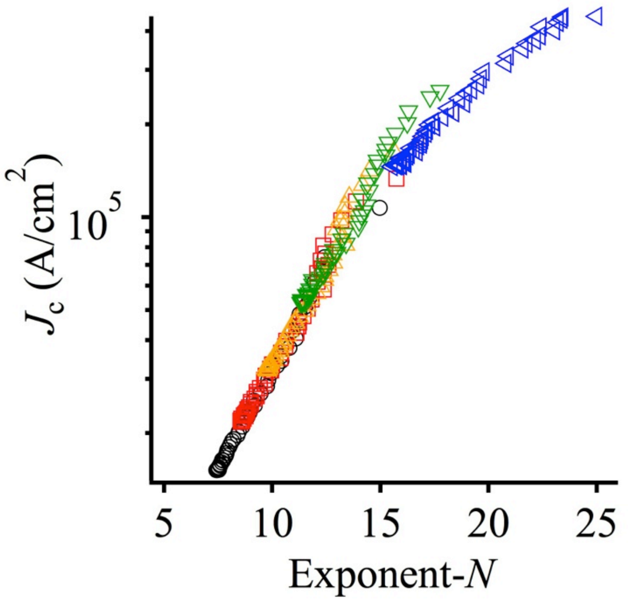




- ✓ Broad *ab* peaks (due to large Δω)
- ✓ No J_c peaks at B || c
- ✓ $N(\Theta)$ behaves similarly to $J_c(\Theta)$
- ✓ J_c is scaled with N

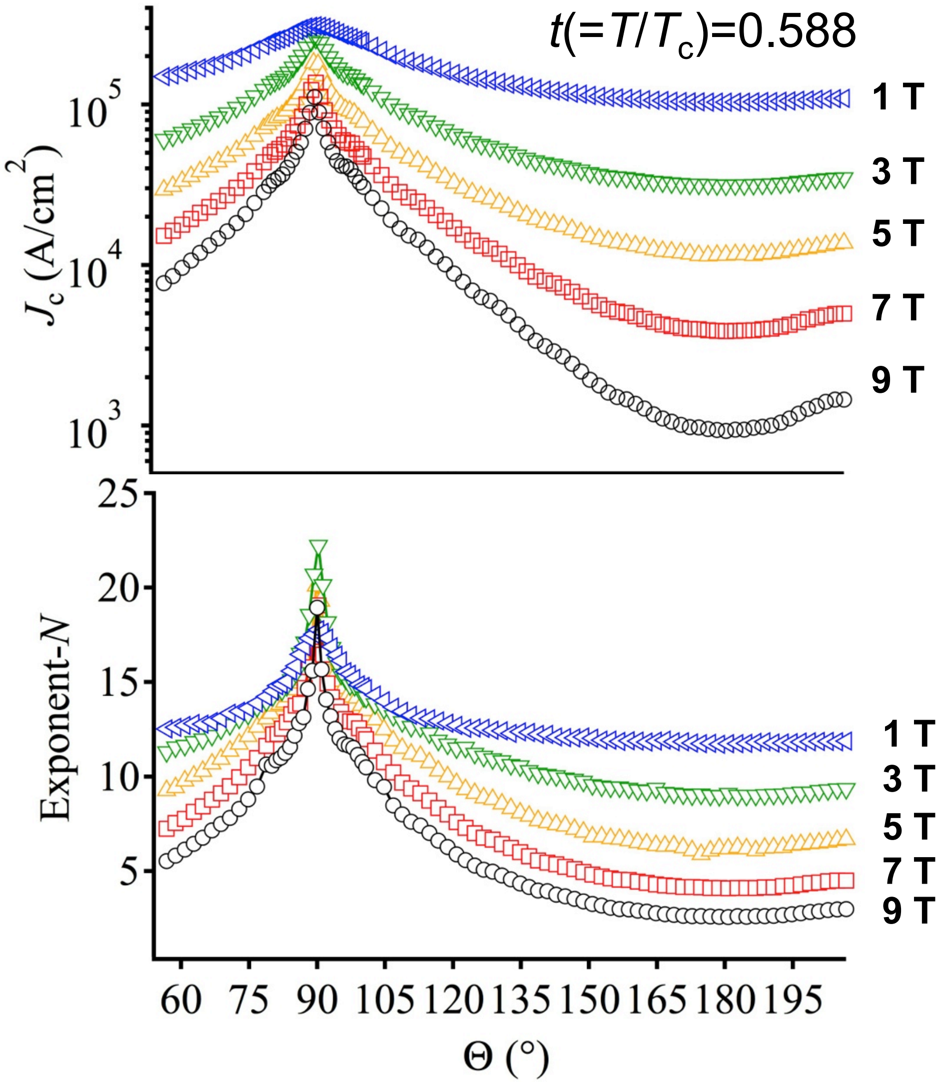
$J_c(\Theta)$ is also almost identical to $N(\Theta)$ (T_s=450°C)

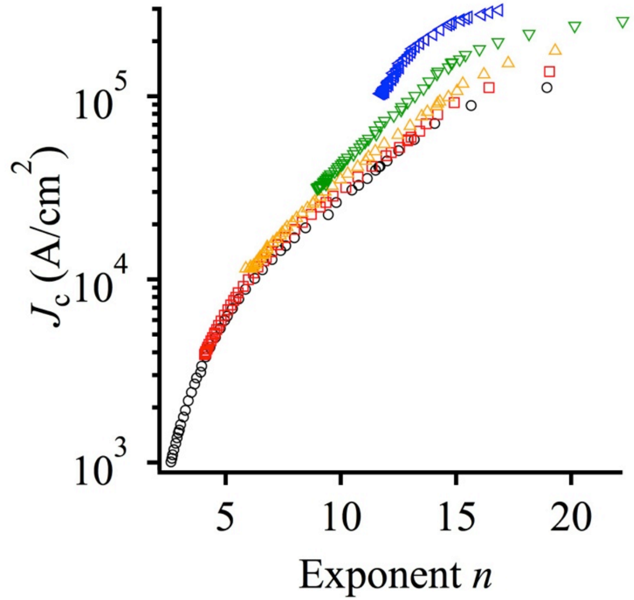




- ✓ Relatively sharp *ab* peaks
- ✓ No J_c peaks at $B \parallel c$
- ✓ $N(\Theta)$ behaves similarly to $J_c(\Theta)$
- ✓ J_c is scaled with N (3T~9T)

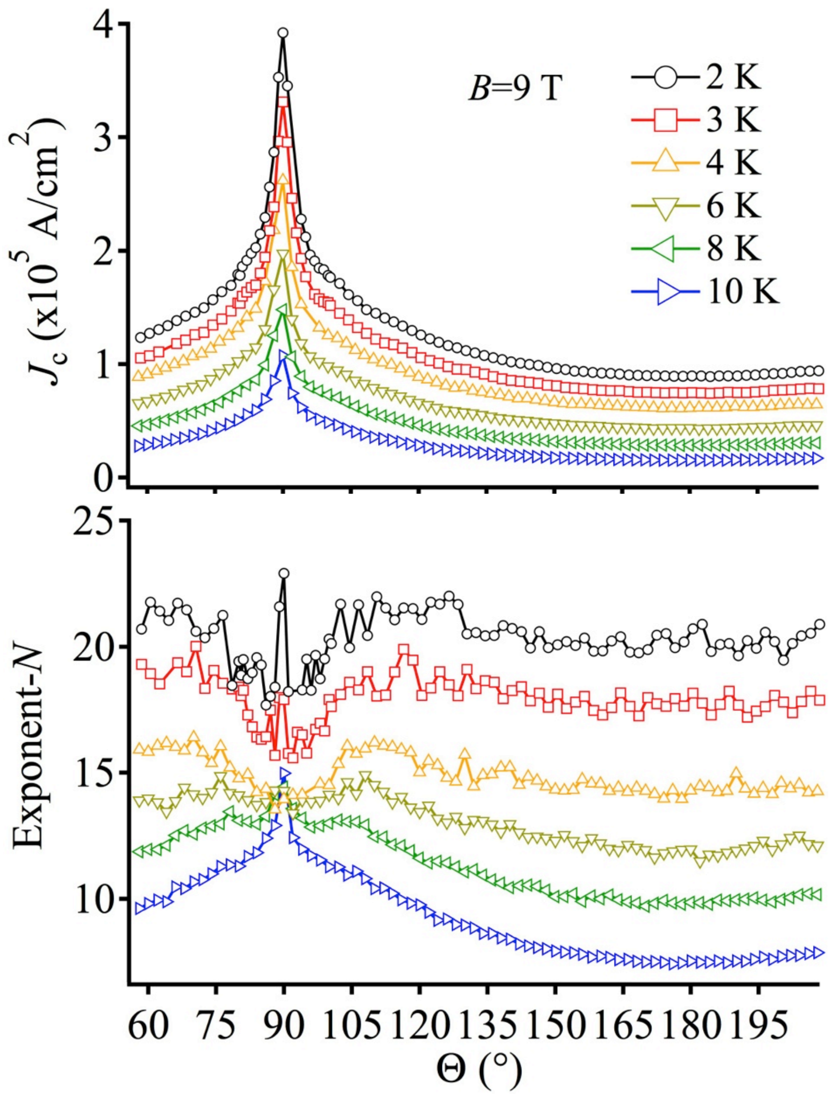
$J_c(\Theta)$ is also almost identical to $N(\Theta)$ (T_s=550°C)





- ✓ Sharp *ab* peaks
- ✓ No J_c peaks at $B \parallel c$
- ✓ $N(\Theta)$ behaves similarly to $J_c(\Theta)$
- ✓ J_c is scaled with N only high fields (5T~9T)

Presence of intrinsic pinning-1 (T_s=450°C)



- ✓ Inverse correlation between J_c and *N* *@ 4 and 6 K*

  (Similar observations in YBCO) due to the double kink excitation of vortices

  (Civale *et at*. IEEE**15**, 2808 (2005))

- ✓ Increasing in *N* upon further cooling

  (Usual depinning owing to the reduction of double-kink excitation)

  (Awaji *et al*, APEX**4**, 013101 (2011))

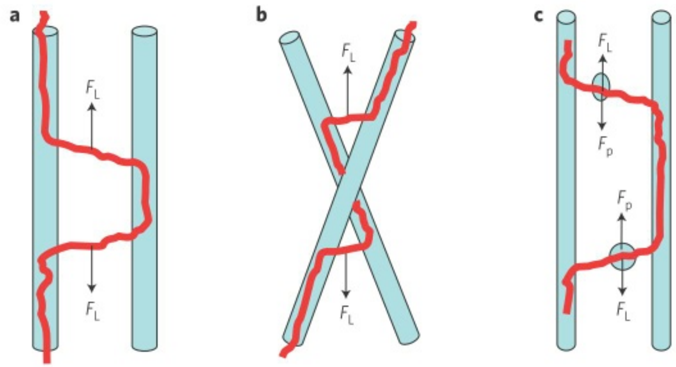
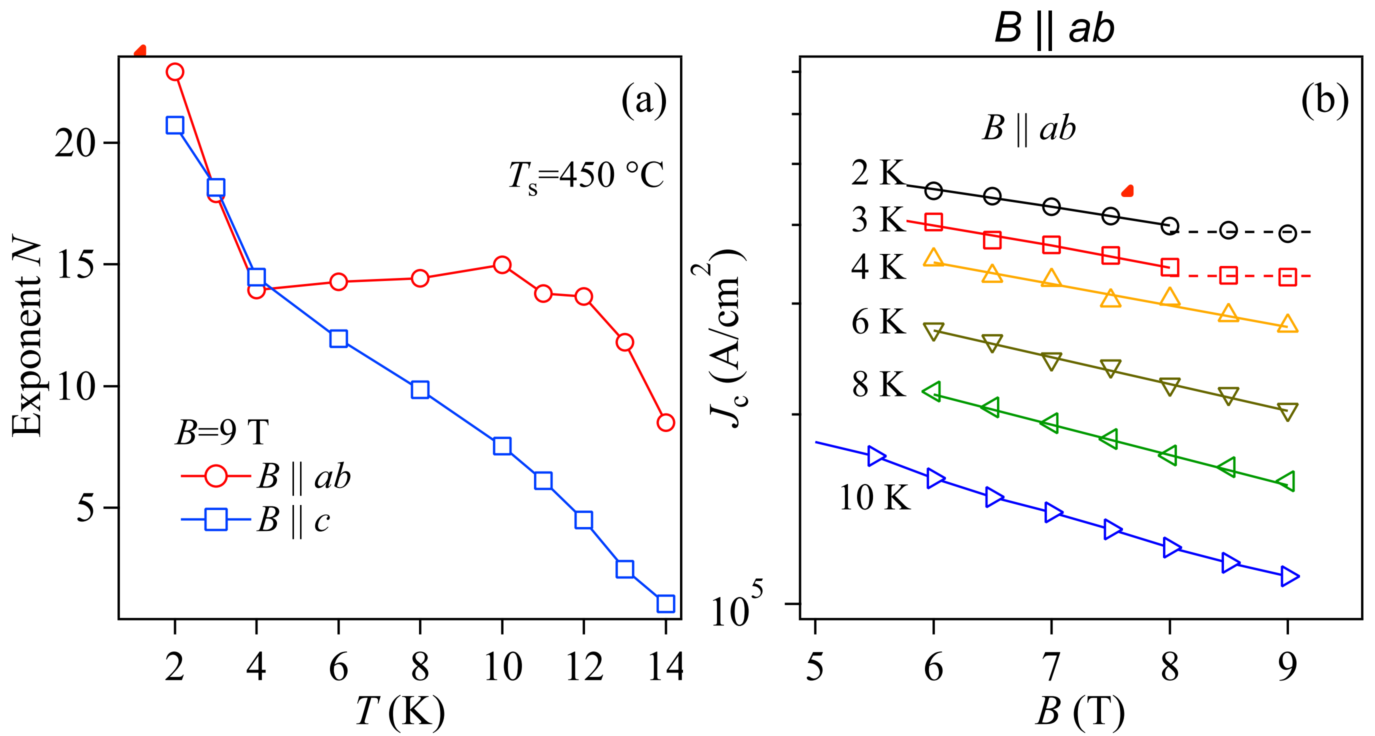
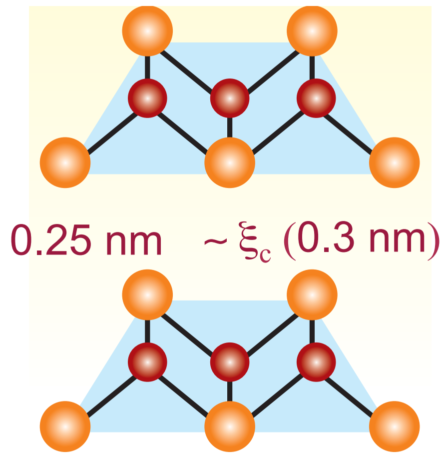


Diagram of vortex double kinks (Maiorov *et al*, NMAT**8**, 398 (2009))

Presence of intrinsic pinning-2 (T_s=450°C)

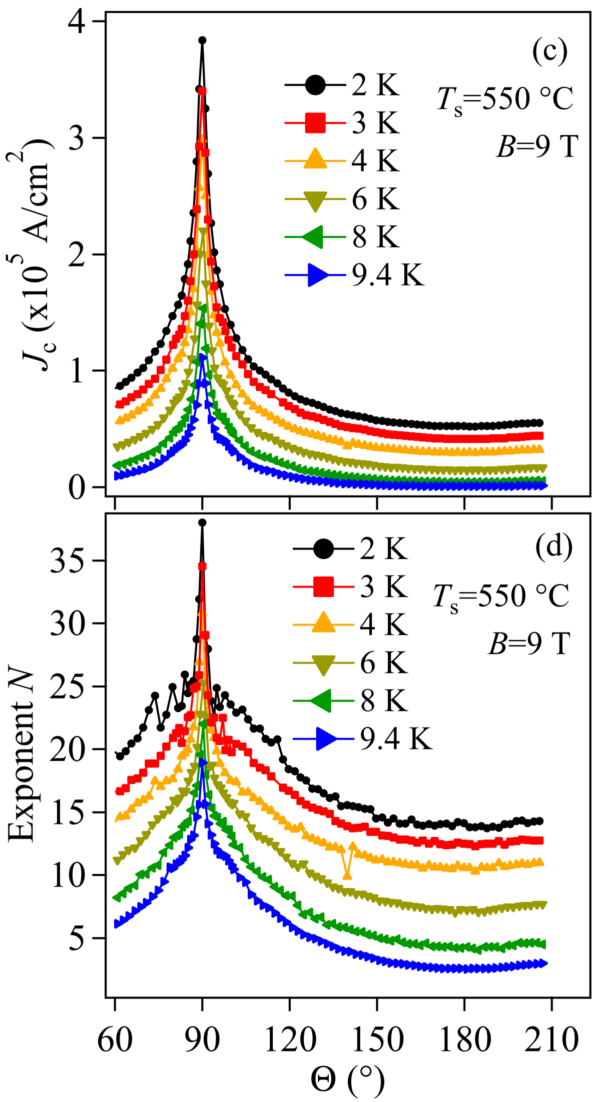




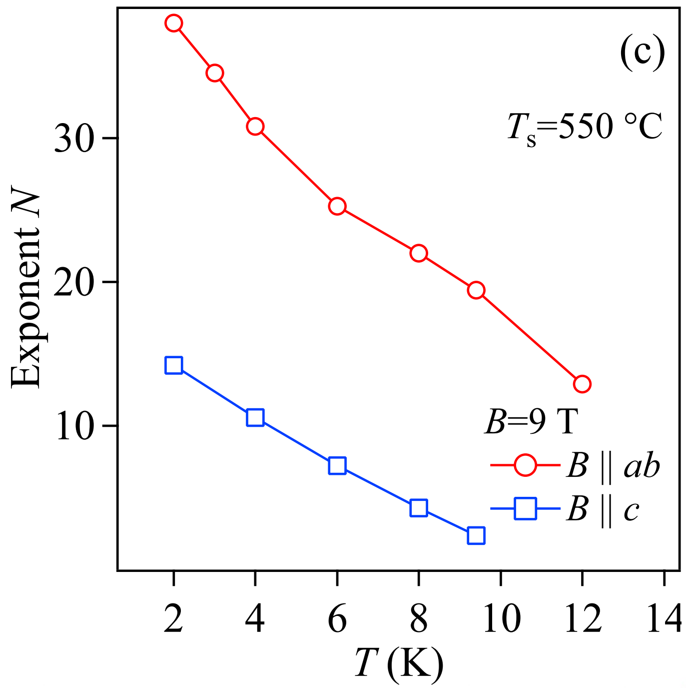
- ✓ Exponent *N* is monotonously increased upon cooling for *B* || *c*
- ✓ For *B* || *ab*, *N* is constant regardless of T (4 K < T < 10 K)
- ✓ Increasing in *N* upon further cooling. J_c is constant at the corresponding temp.

(Similar observation in YBCO (Awaji *et al*, APEX **4**, 013101 (2011))

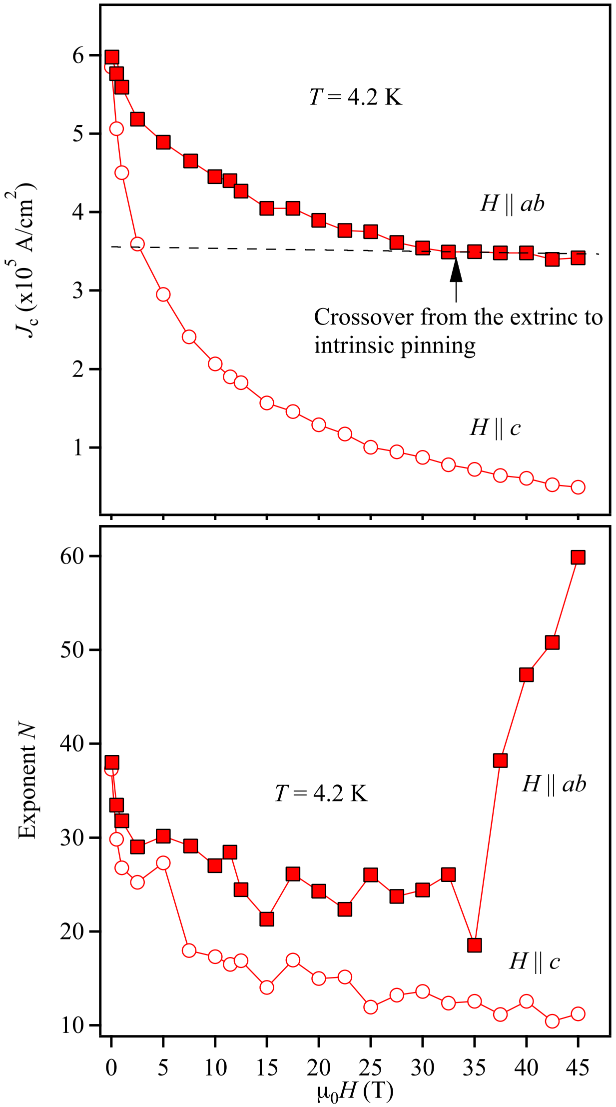
No inverse correlation between J_c and N (T_s=550°C)



- ✓ No inverse correlation between J_c and *N* *@ all temp.*
- ✓ *N* is increased upon cooling for both direction



J_c-B measurements up to 45 T (SmFeAs(O,F))



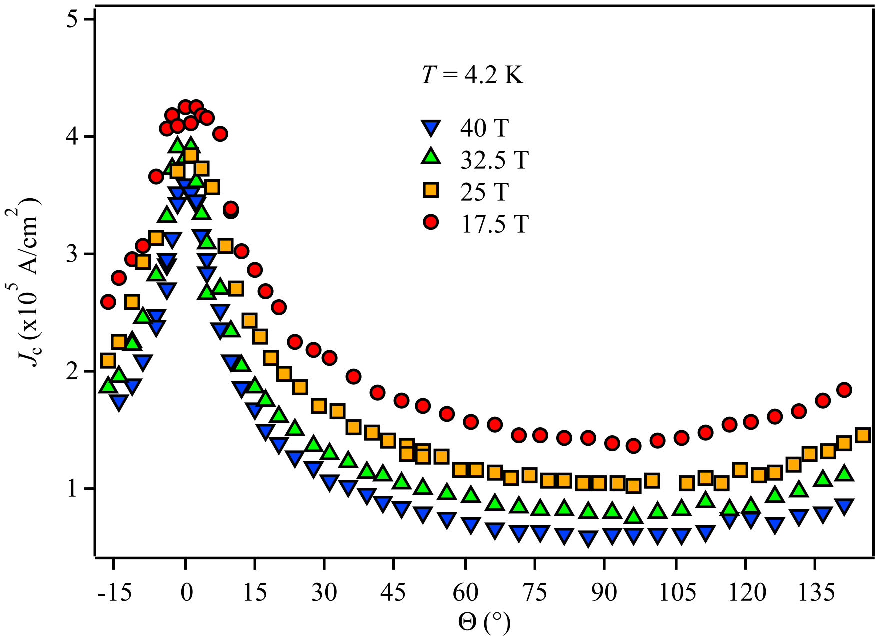
Epitaxial SmFeAs(O,F), T_c=56 K

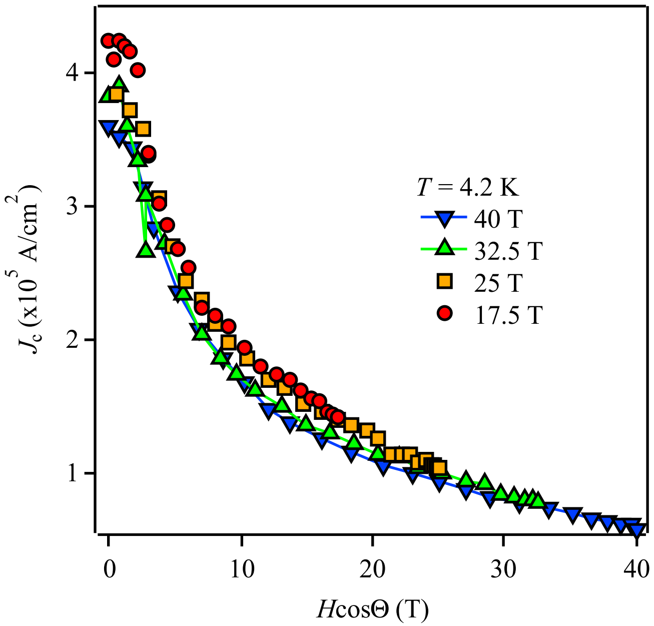
Measurements in dc fields up to 45 T

- For *H* || *ab*, J_c is almost field independent above 30 T
  (Above 30 T, *N* is suddenly increased with *H*)
  -> Intrinsic pinning
- Crossover field from extrinsic to intrinsic is 32 T
- For *H* || *c*, J_c is observed to monotonously decrease with *H*
  (*N*-*H* curve shows almost the same behavior as J_c-*H*)

Angular dependent of J_c measurements

- No *c*-axis peaks in J_c-Θ -> absence of *c*-axis correlated defects
- Large *ab*-peaks
- J_c –Θ are scaled with *H*cosΘ above 30 T (Intrinsic pinning)





Summary

- ✓ Epitaxial $FeTe_{1-x}Se_x$ is grown on Fe-buffered MgO without compromising structural and sc properties
- ✓ Inverse correlation between J_c and N is recognised
  -> Intrinsic pinning is dominating
- ✓ Dip of N-values at $B||ab$ is hardly observed, when extrinsic pinning > intrinsic pinning
- ✓ Observation of intrinsic pinning in SmFeAs(O,F)