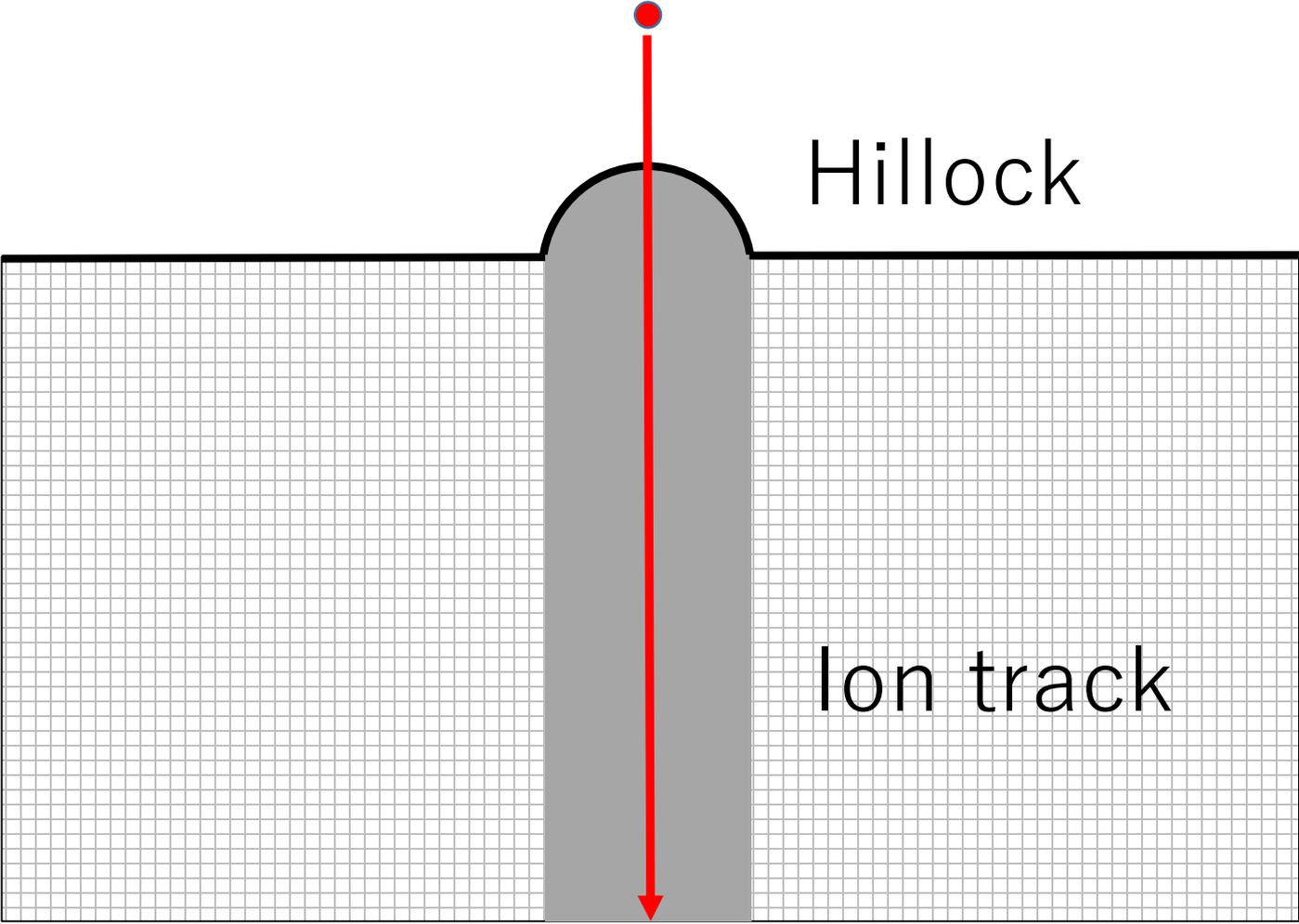


高速重イオン照射によるセラミックスの  
単一ナノヒロック形成プロセス

原子力機構 (JAEA)  
量研(QST)

石川法人, 喜多村茜  
田口富嗣

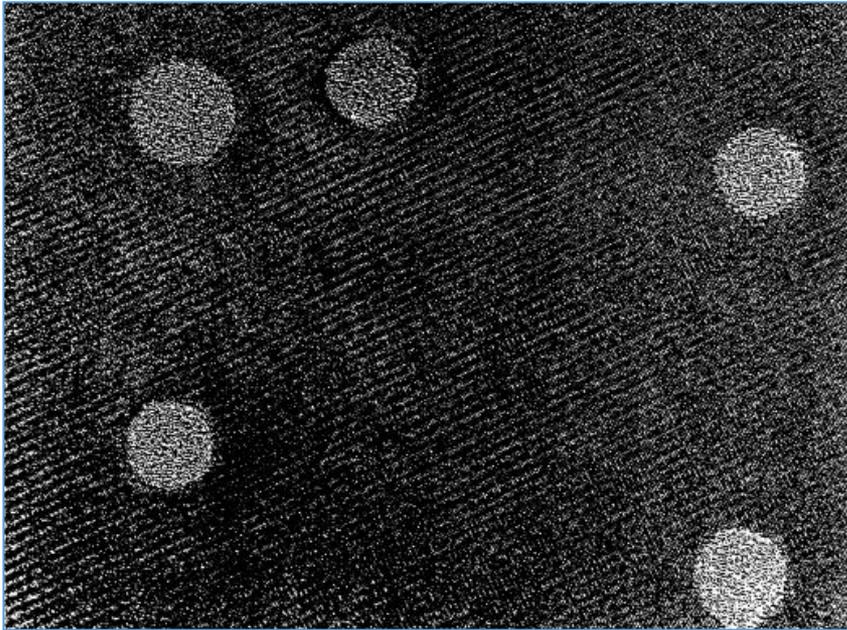


Hillock

Ion track

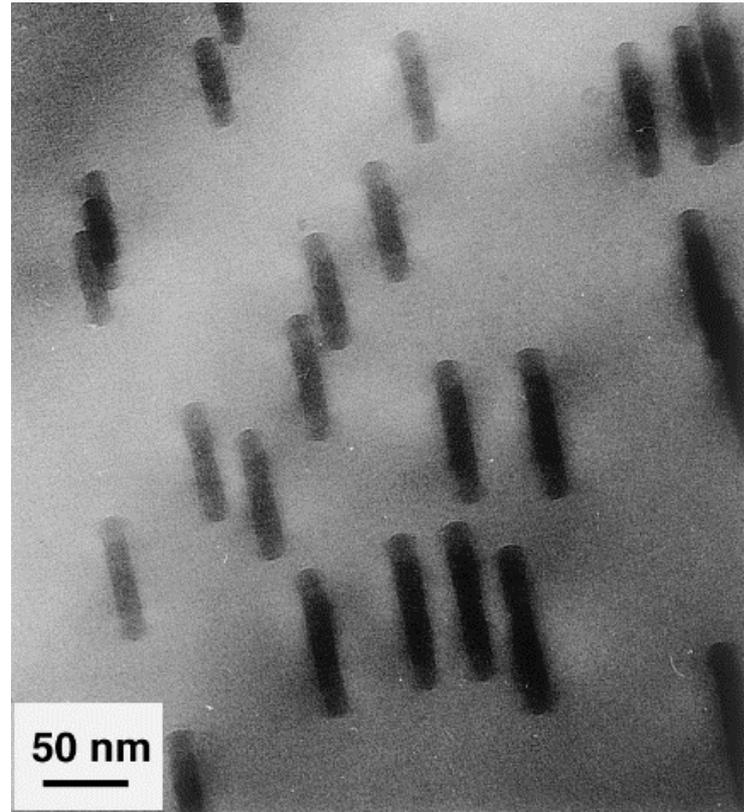
# イオントラック

4 GeV Ta  $\rightarrow$   $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_y$



*N. Kuroda et al., PRB 63 (2001) 224502.*

880 MeV U  $\rightarrow$   $\text{Y}_3\text{Fe}_5\text{O}_{12}$



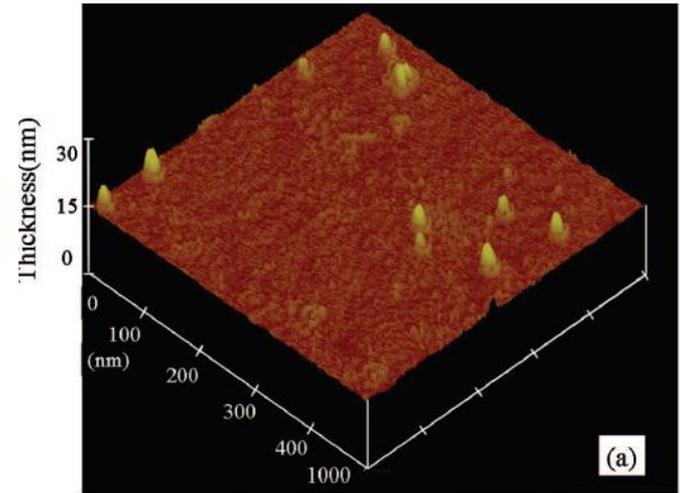
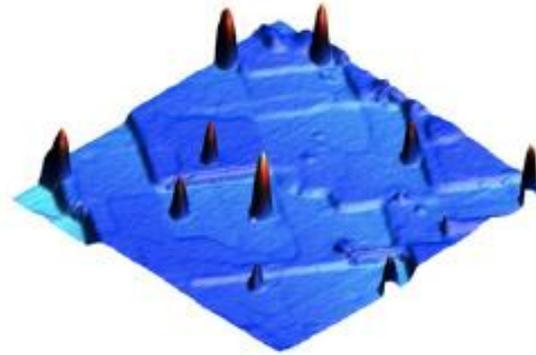
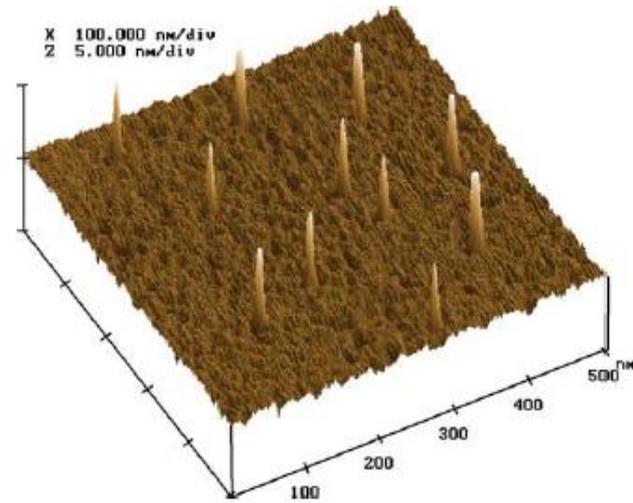
*J. Jensen et al., NIM B 135 (1998) 295.*

# ヒロック

870 MeV Xe  $\rightarrow$  CaF<sub>2</sub>

93 MeV Xe  $\rightarrow$  LiF

150 MeV Au  $\rightarrow$  TiO<sub>2</sub>

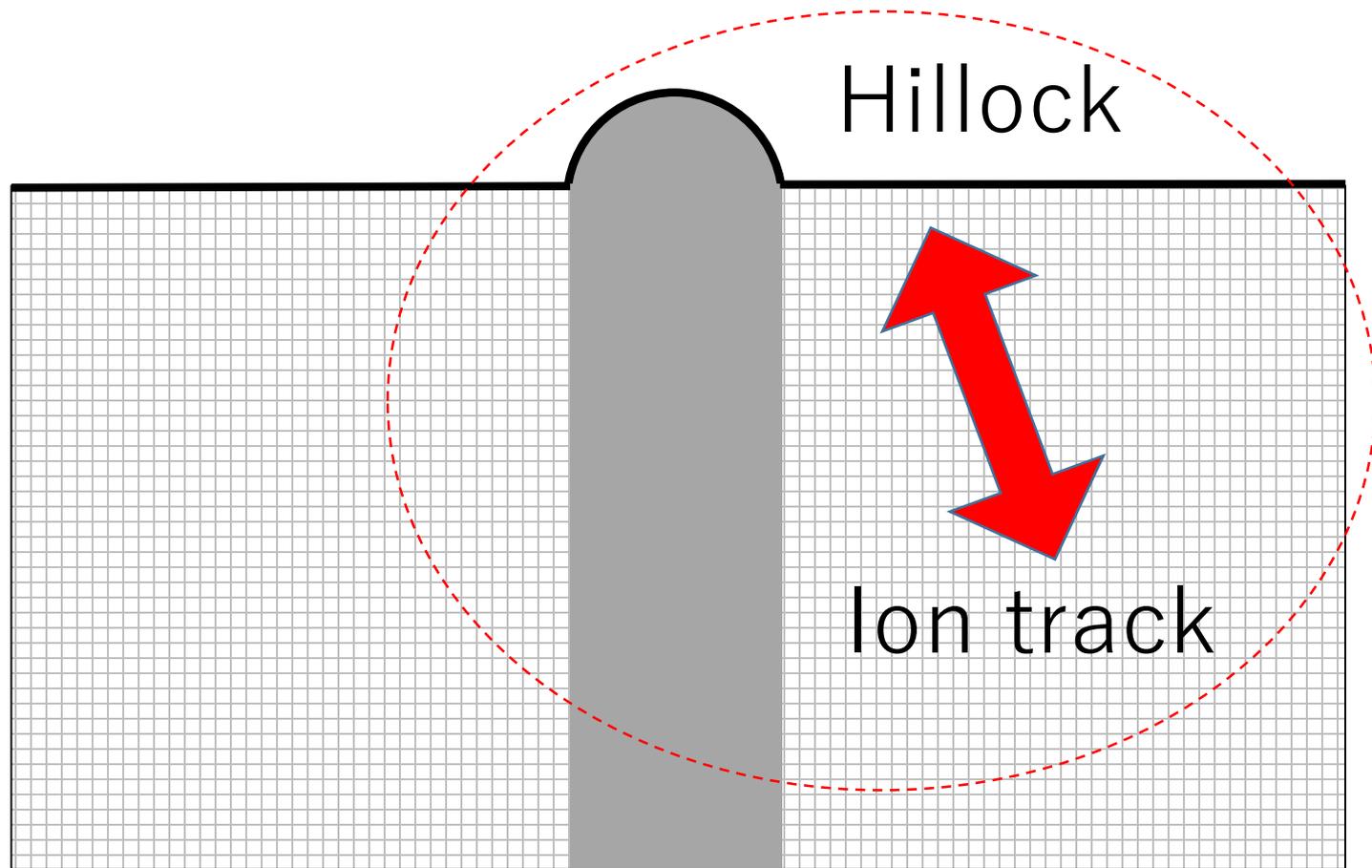


*N. Khalfaoui et al.,  
NIMB 240 (2005) 219.*

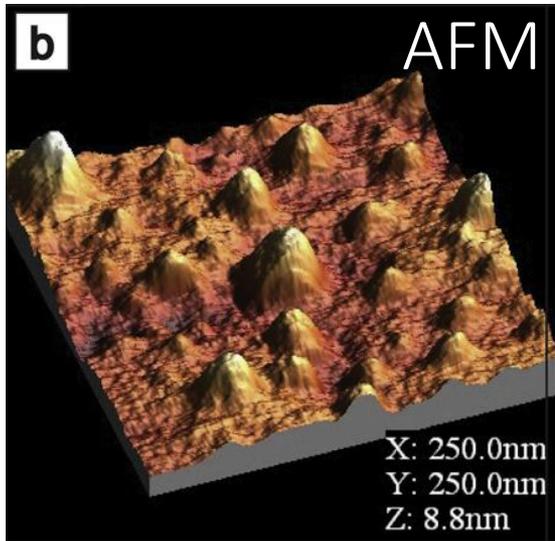
*E. Akcoltekin (2007) unpublished.  
Cited from F. Aumayr et al.,  
J. Phys.: Condens. Matter 23  
(2011) 393001.*

*K. Awazu et al.,  
J. Appl. Phys. 100  
(2006) 044308.*

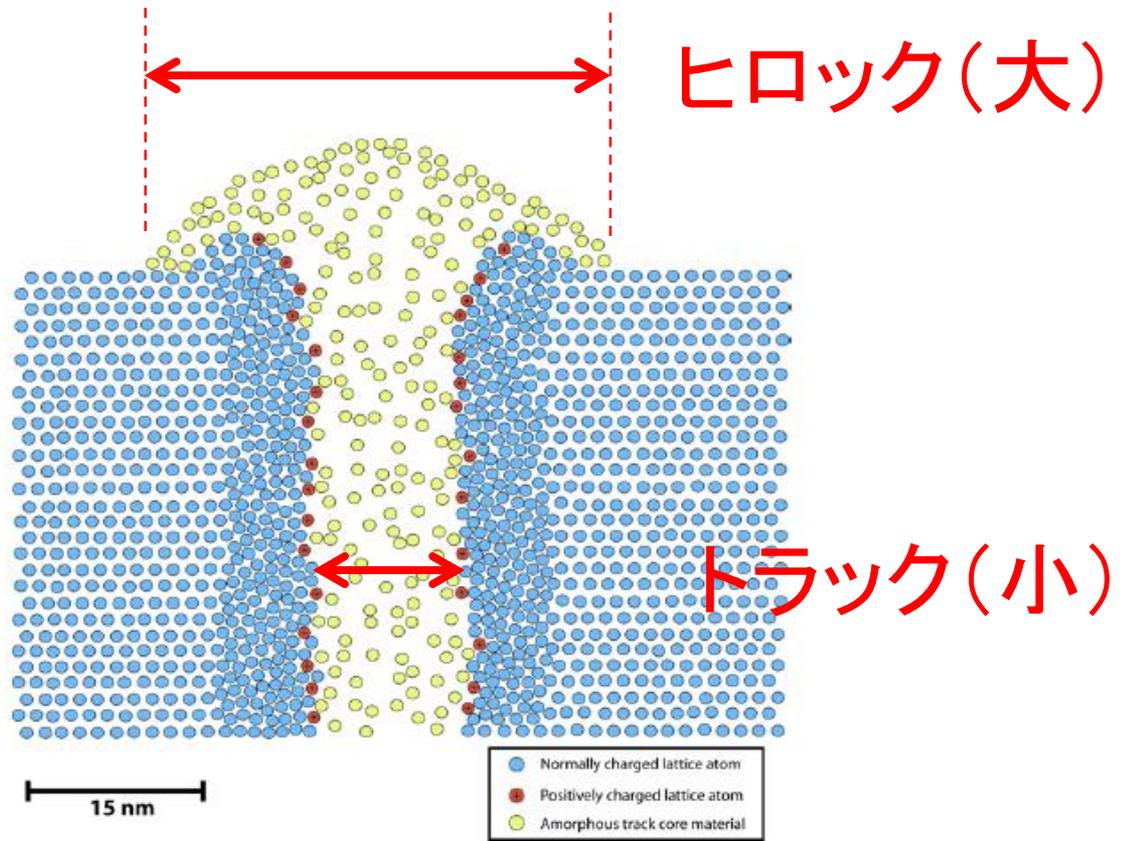
# 照射損傷メカニズム説明



# ヒロック vs. イオントラック (2013)

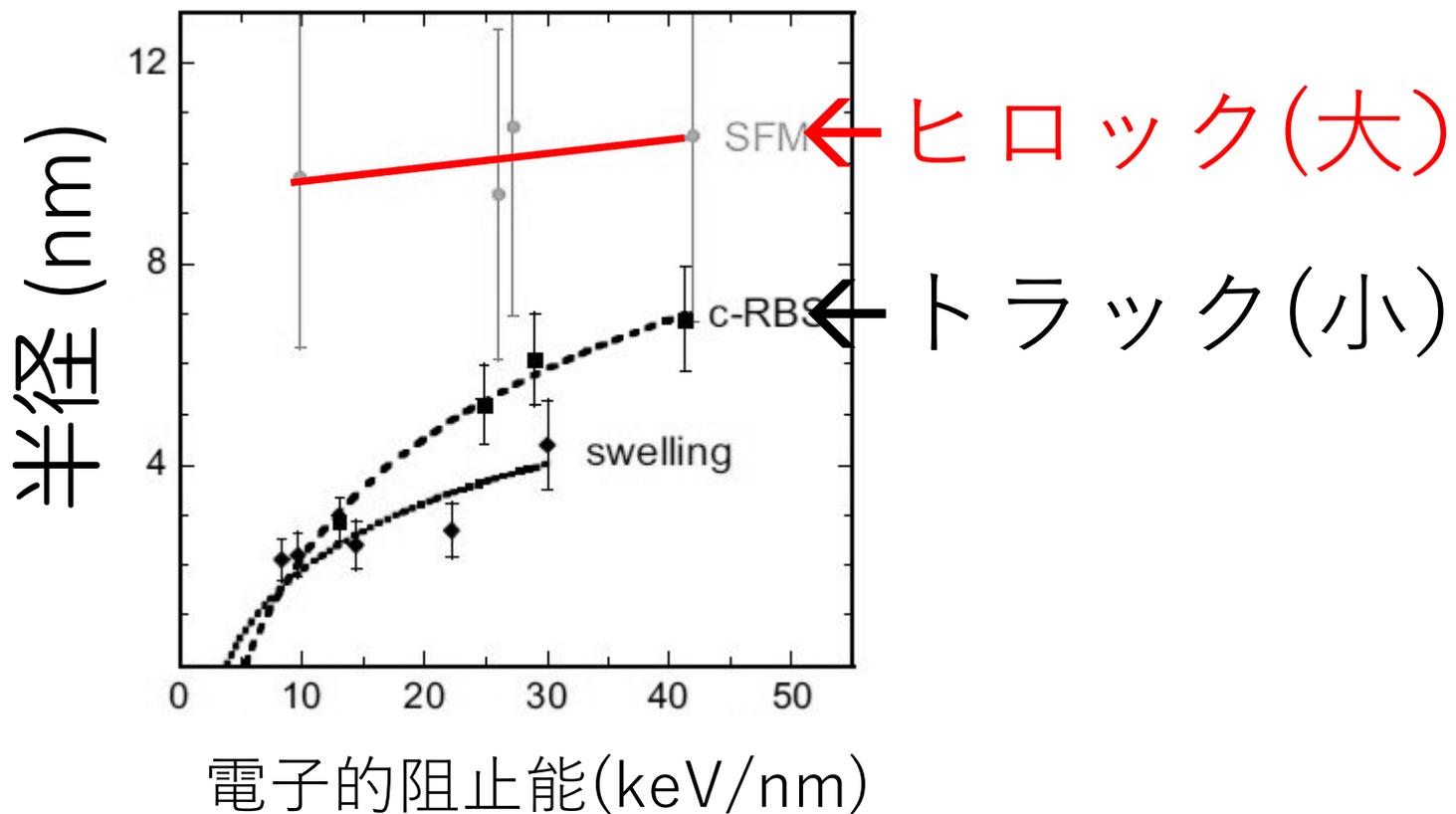


71 MeV I $\rightarrow$ ZrSiO<sub>4</sub>



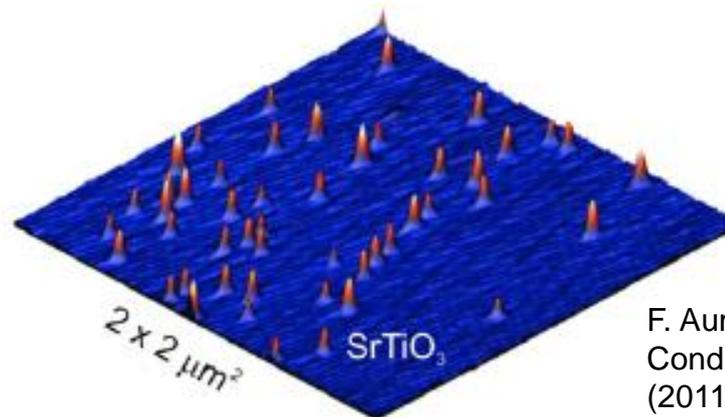
*F. Kohlmann et al., Radiation Measurements 51-52 (2013) 83.*

# $Y_3Fe_5O_{12}$ (2016)



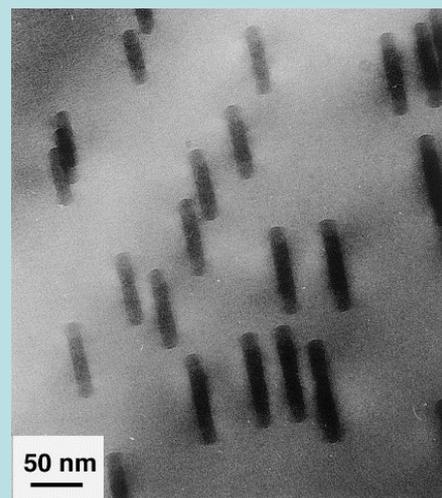
# 観察手段が異なる( → 大問題)

AFM



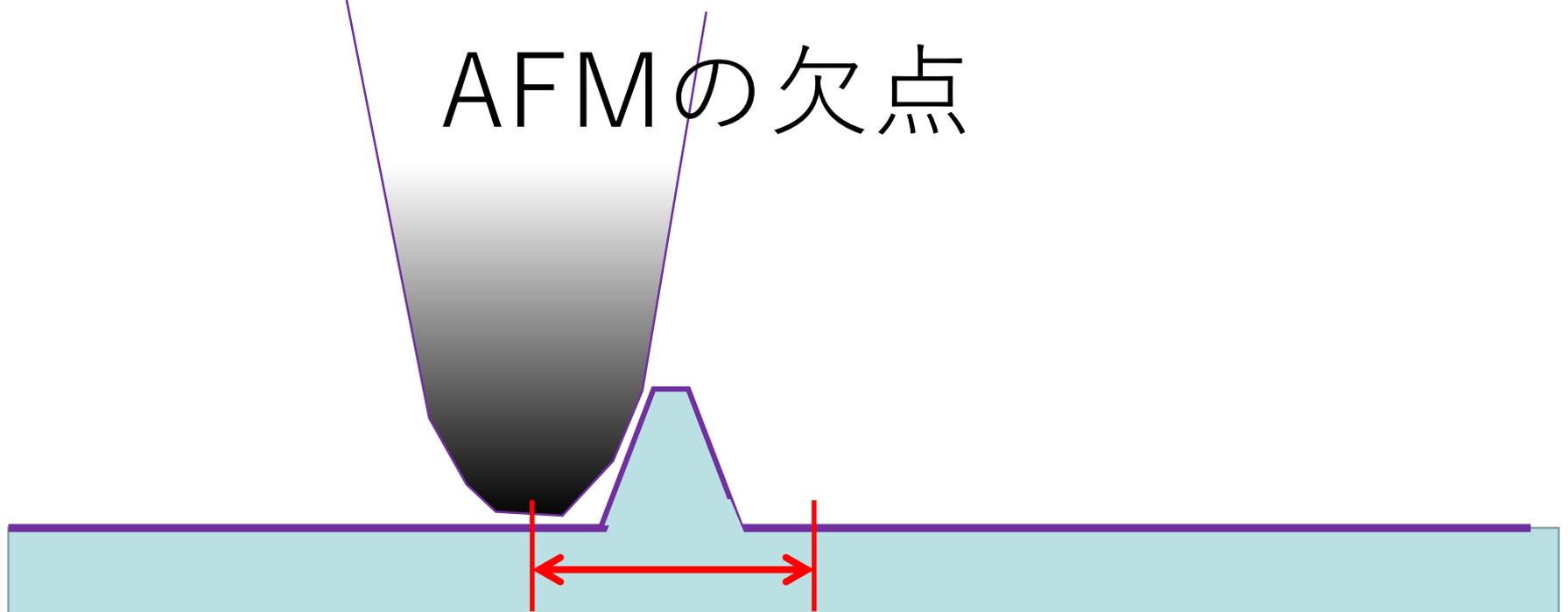
F. Aumayr et al., J. Phys.:  
Condens. Matter 23  
(2011) 393001.

TEM  
c-RBS



J. Jensen et al., NIMB 135 (1998) 295.

# AFMの欠点

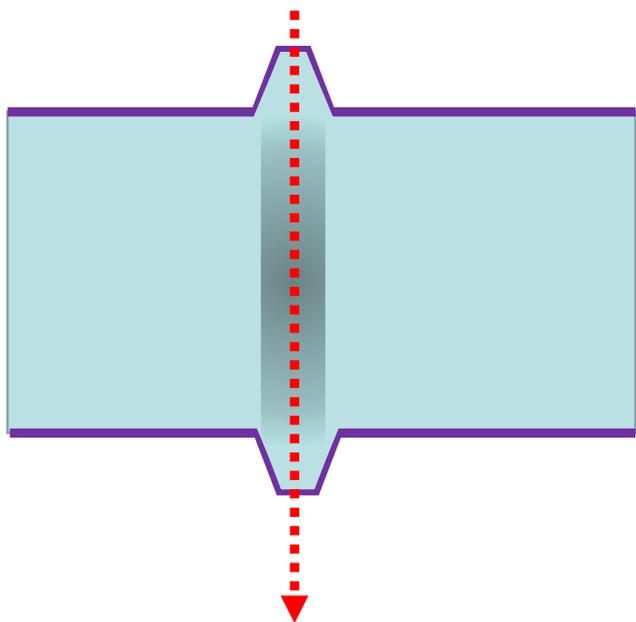


- (1) 直径を過剰評価してしまう.
- (2) 結晶構造を分析できない.

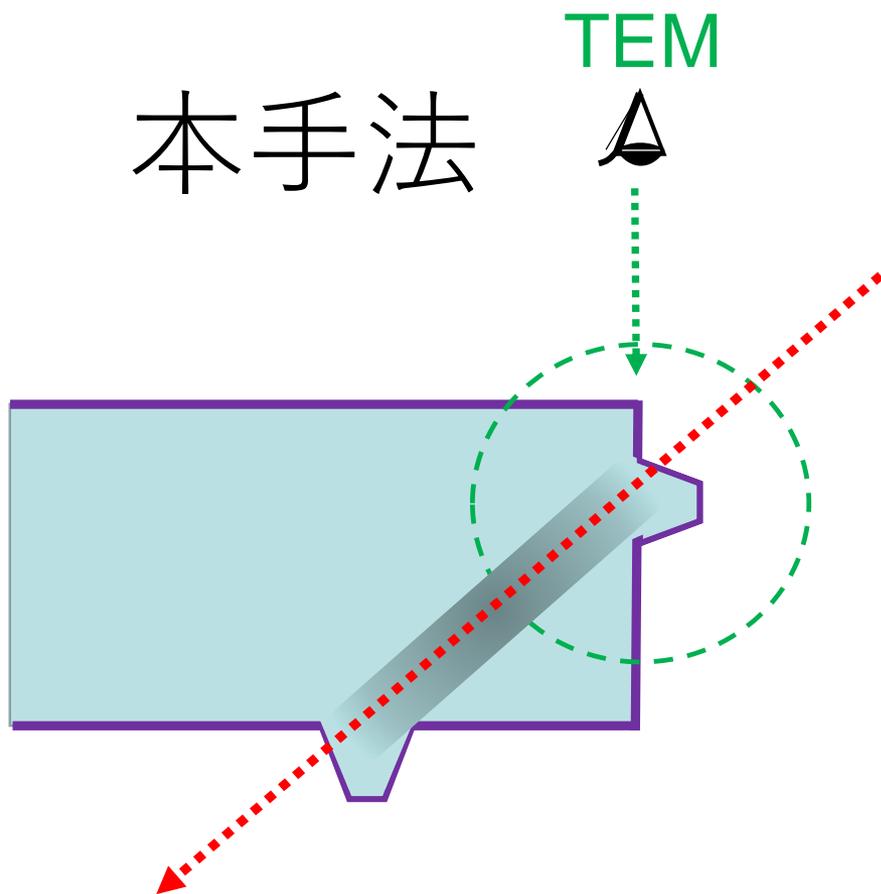


問題を解決できる方法 = TEM

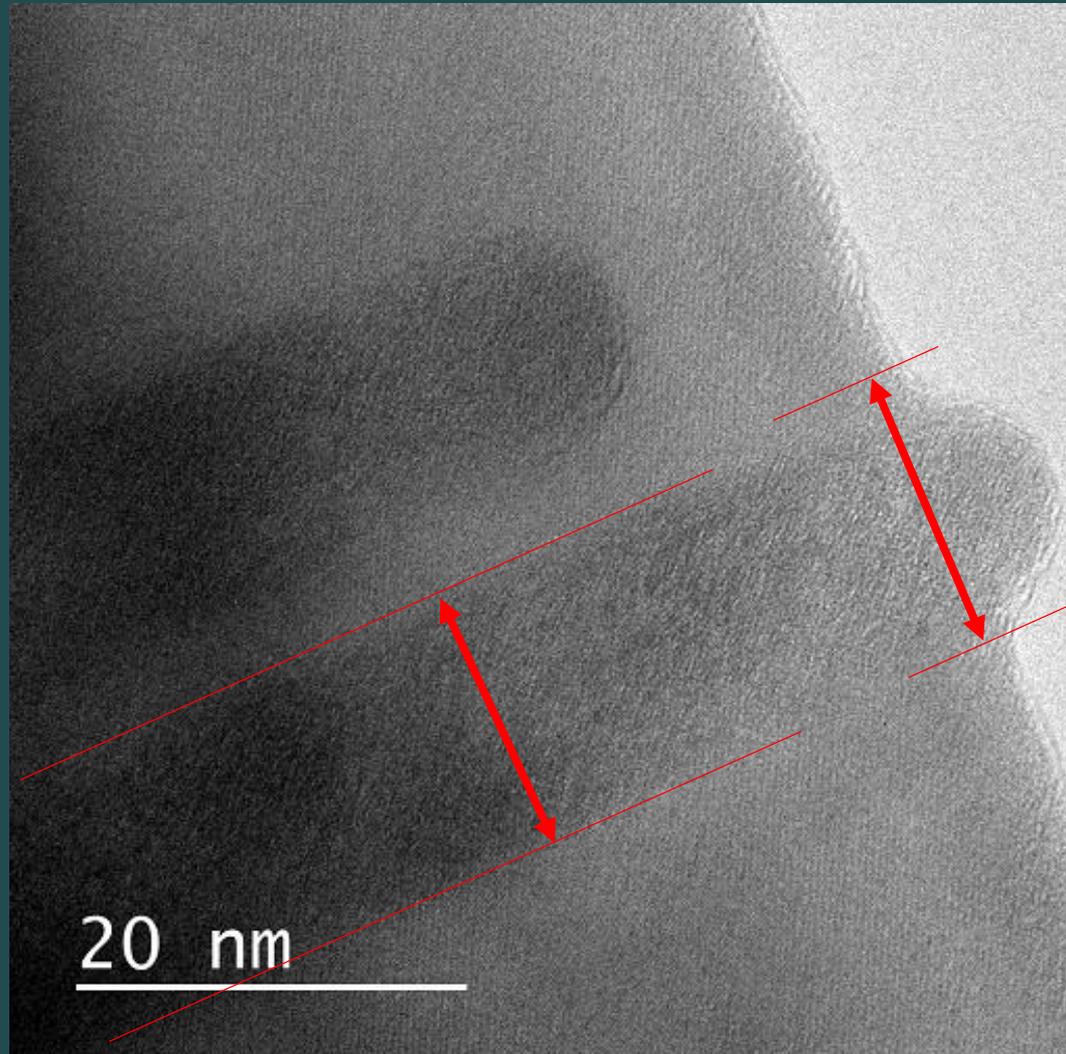
従来法



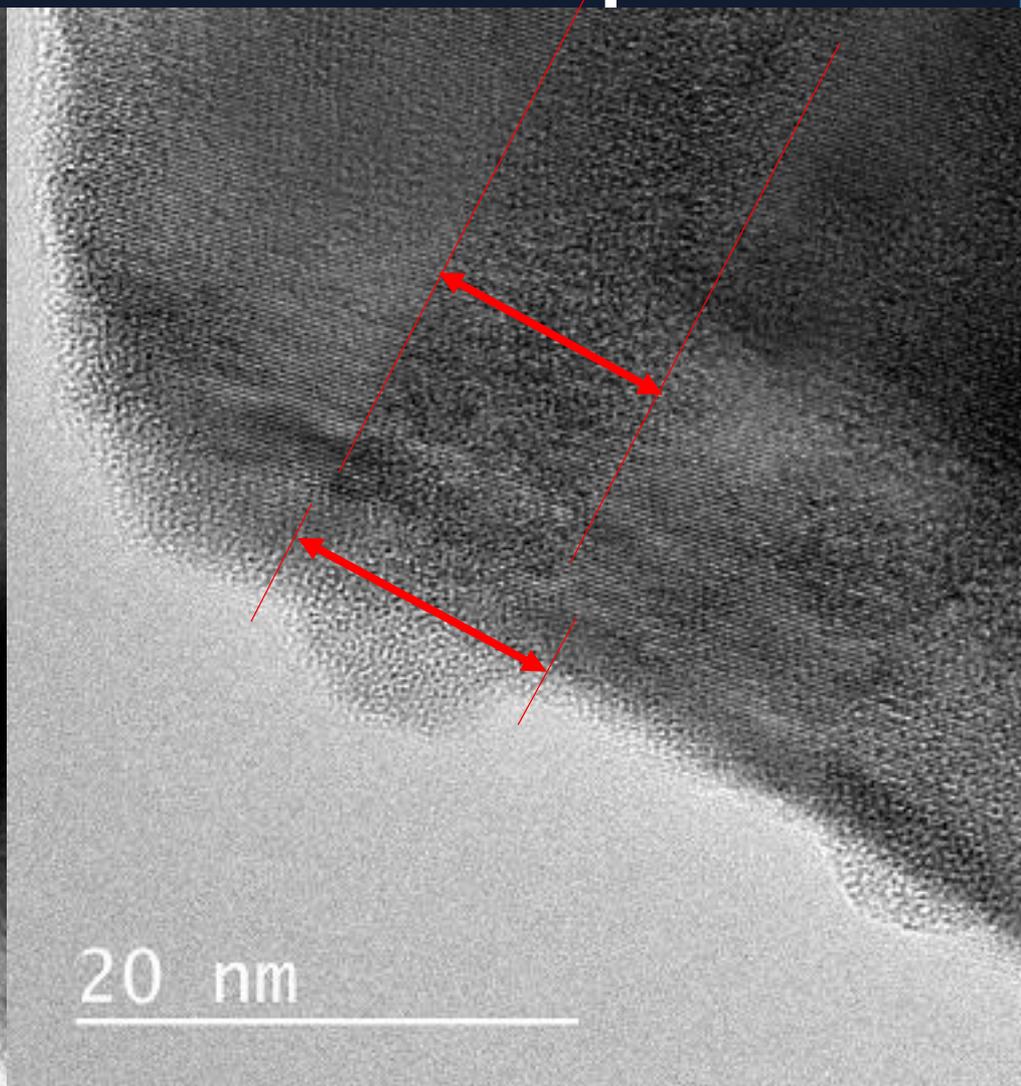
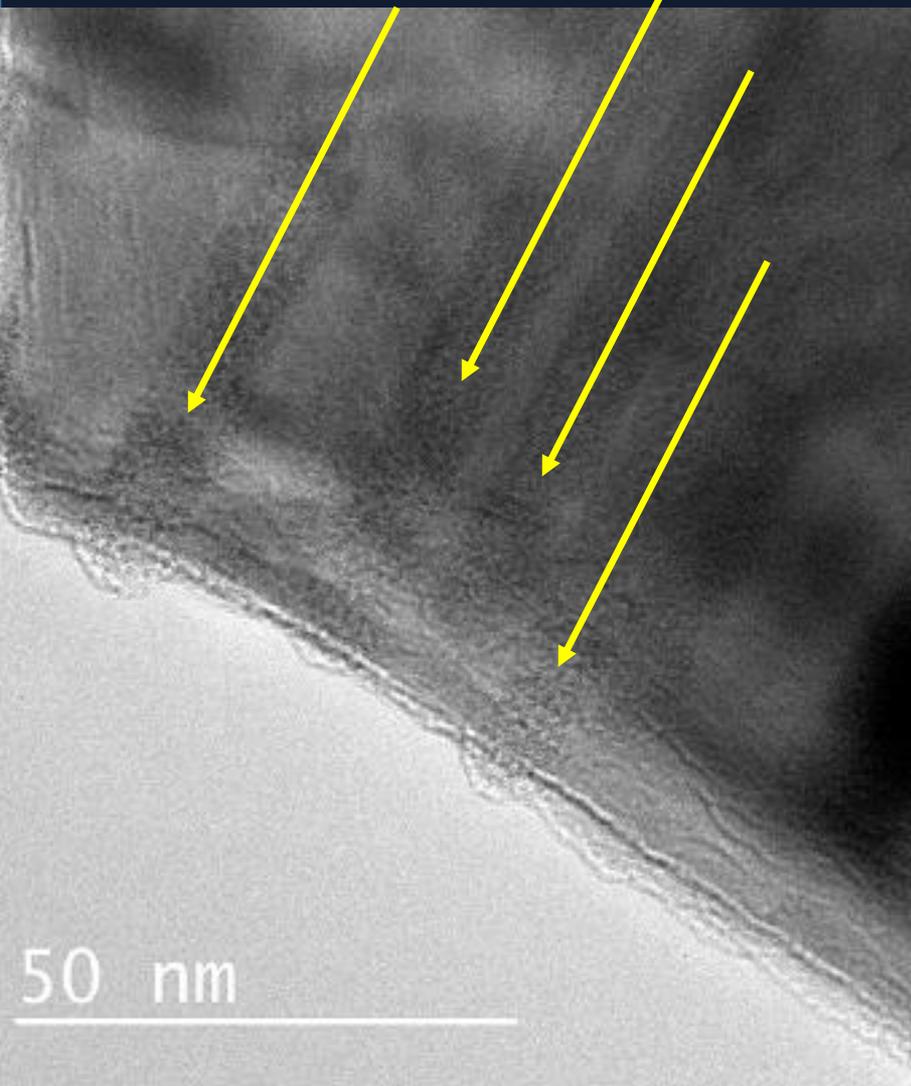
本手法



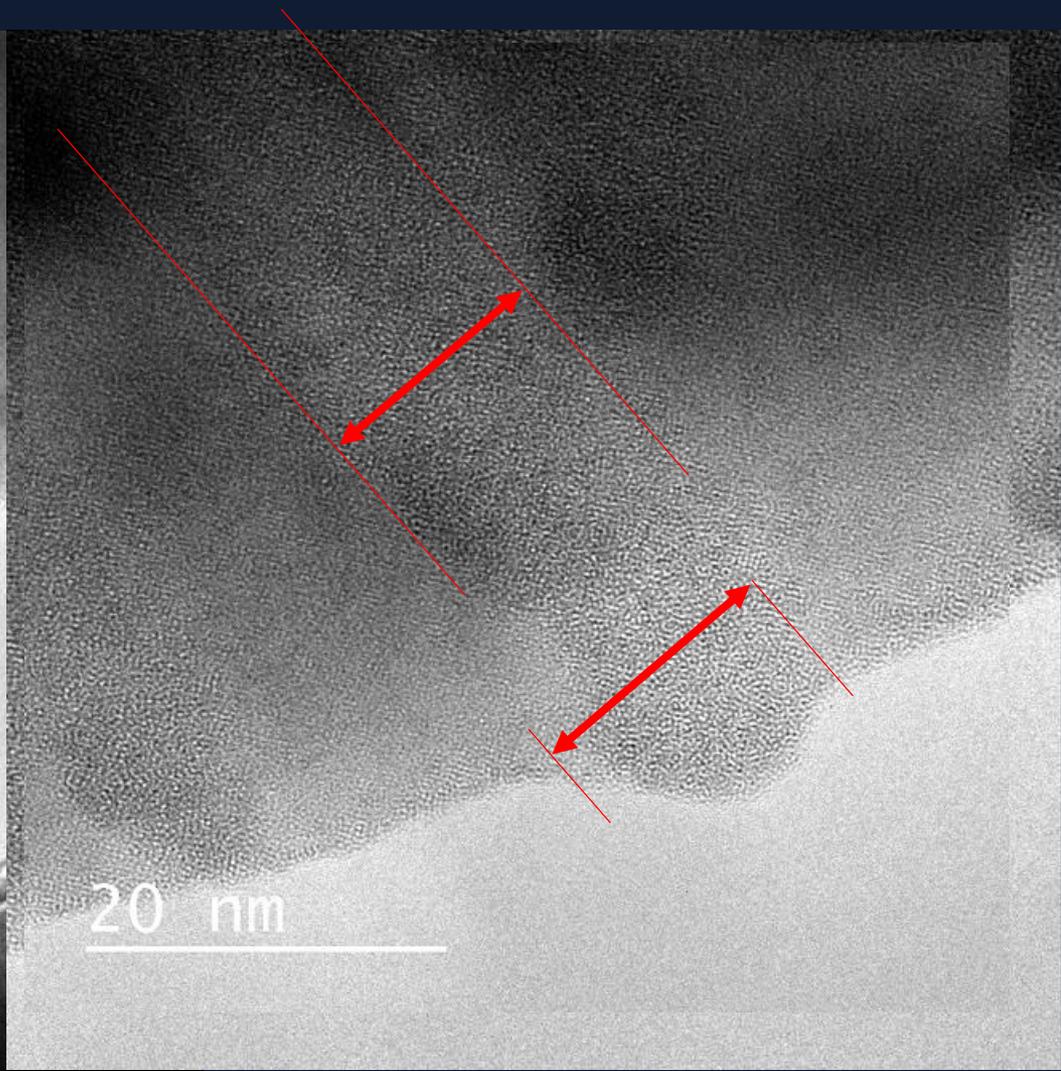
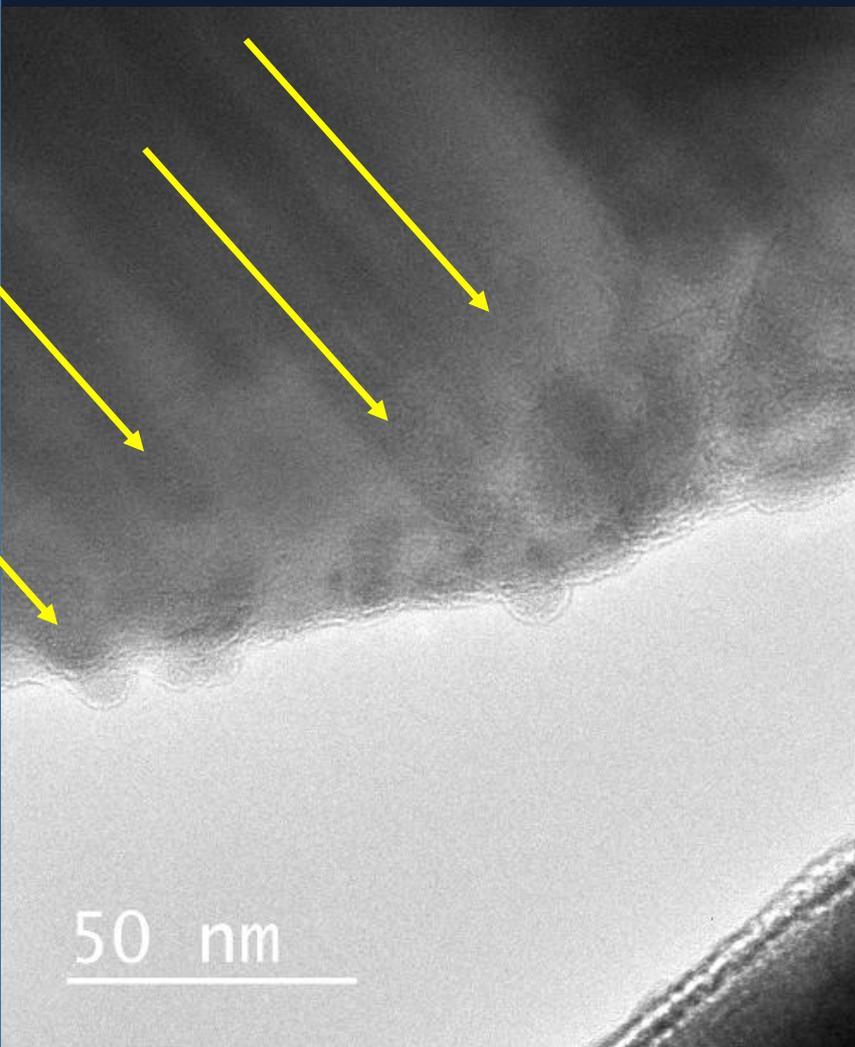
**200 MeV Au  $\rightarrow$  Y<sub>3</sub>Fe<sub>5</sub>O<sub>12</sub>**



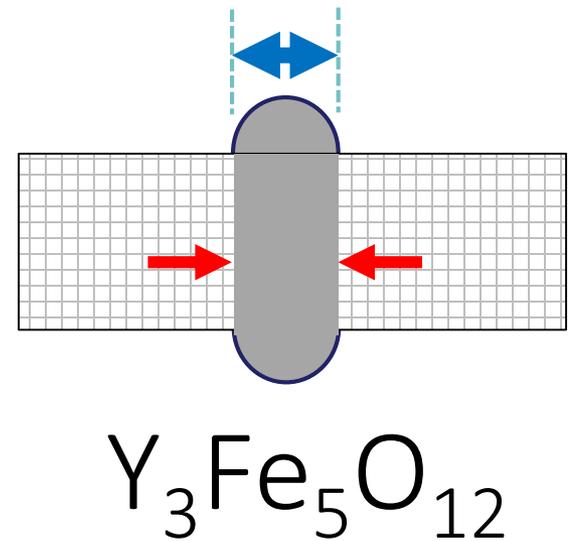
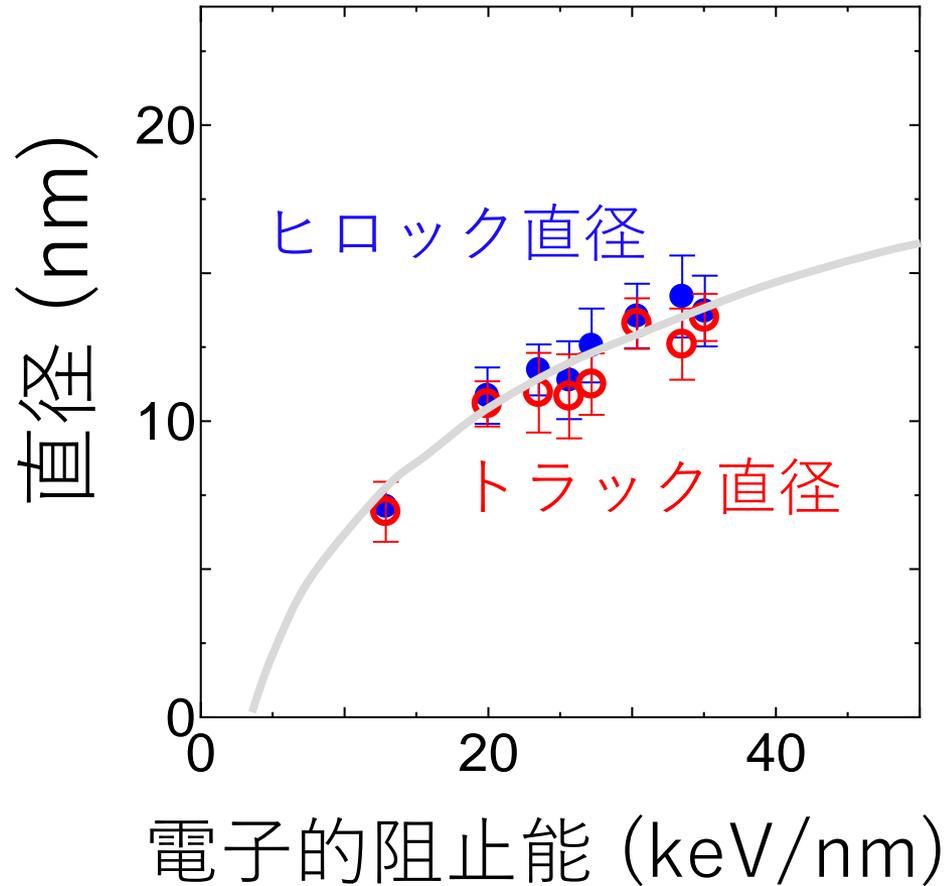
# 120 MeV Au $\rightarrow$ ZrSiO<sub>4</sub>



# 200 MeV Au $\rightarrow$ LiNbO<sub>3</sub>



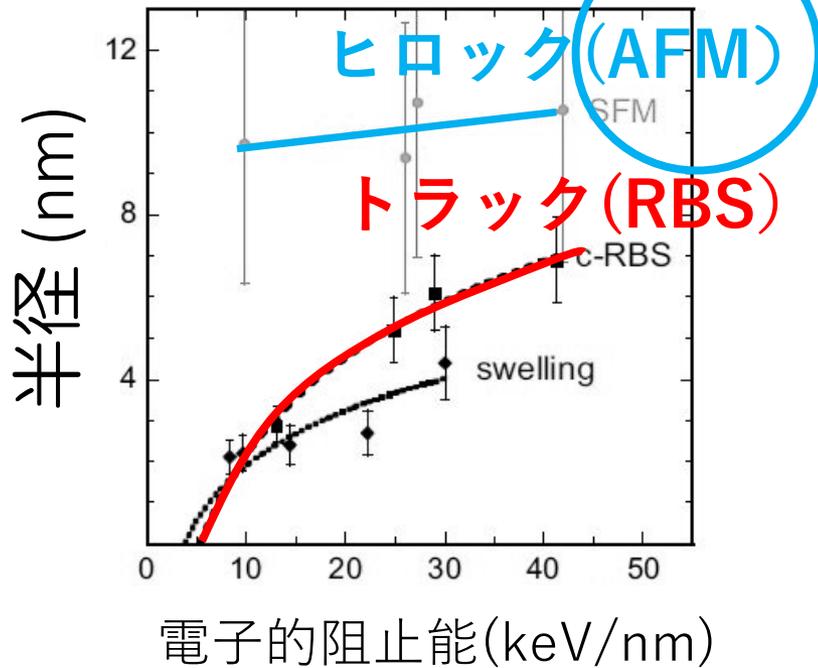
# ヒロック直径 $\approx$ トラック直径



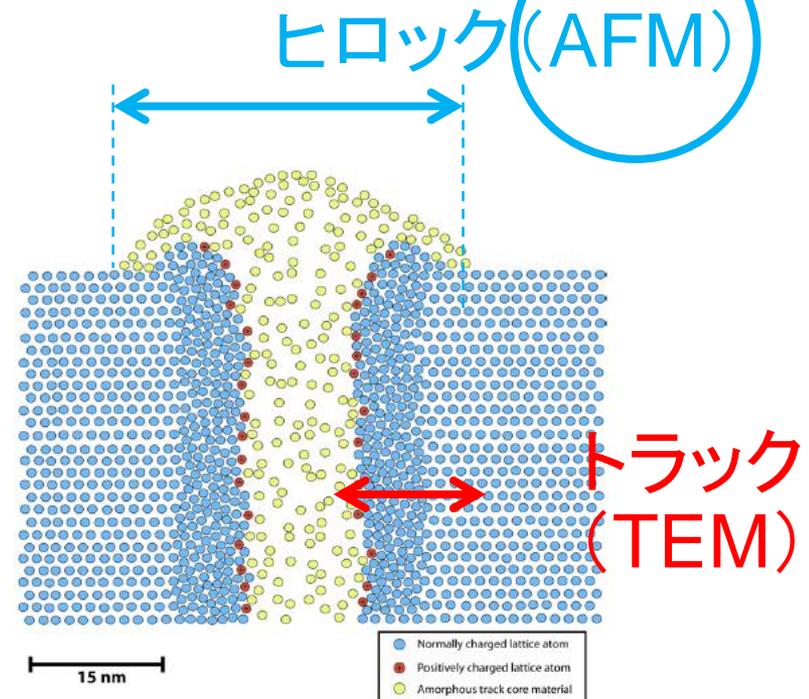
$Y_3Fe_5O_{12}$ (2016)

$ZrSiO_3$ (2013)

大問題



大問題



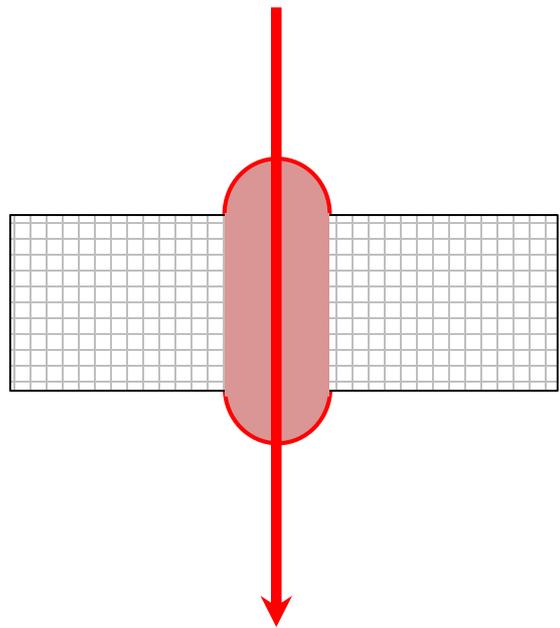
A. Meftah et al., NIMB 366 (2016) 155.

F. Kohlmann et al., Radiat. Meas. 51-52 (2013) 83.

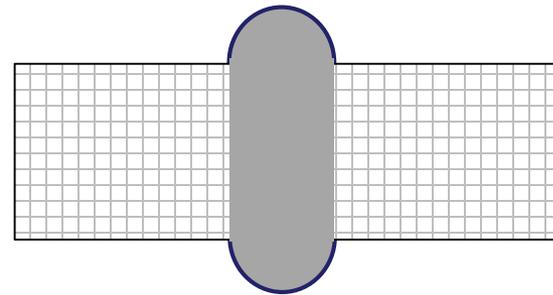
# ヒロック形成プロセス

① 局所溶融

② 急速冷却

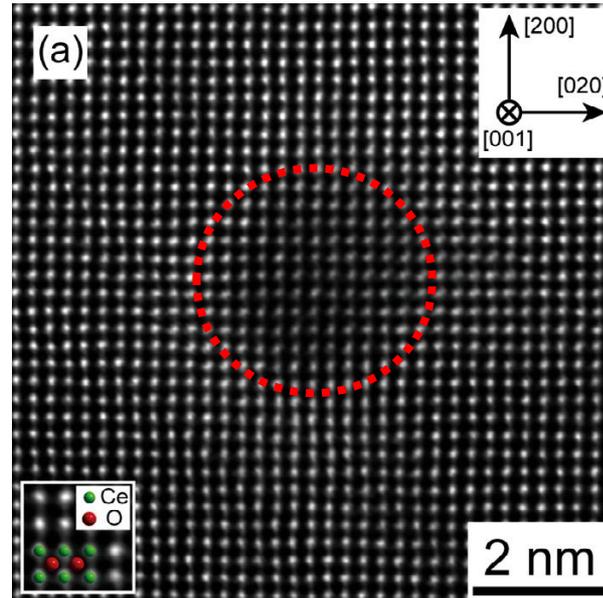


(アモルファス化する.)



( $\text{Y}_3\text{Fe}_5\text{O}_{12}$ ,  $\text{ZrSiO}_4$ ,  $\text{LiNbO}_3$ )

# アモルファス化しない材料

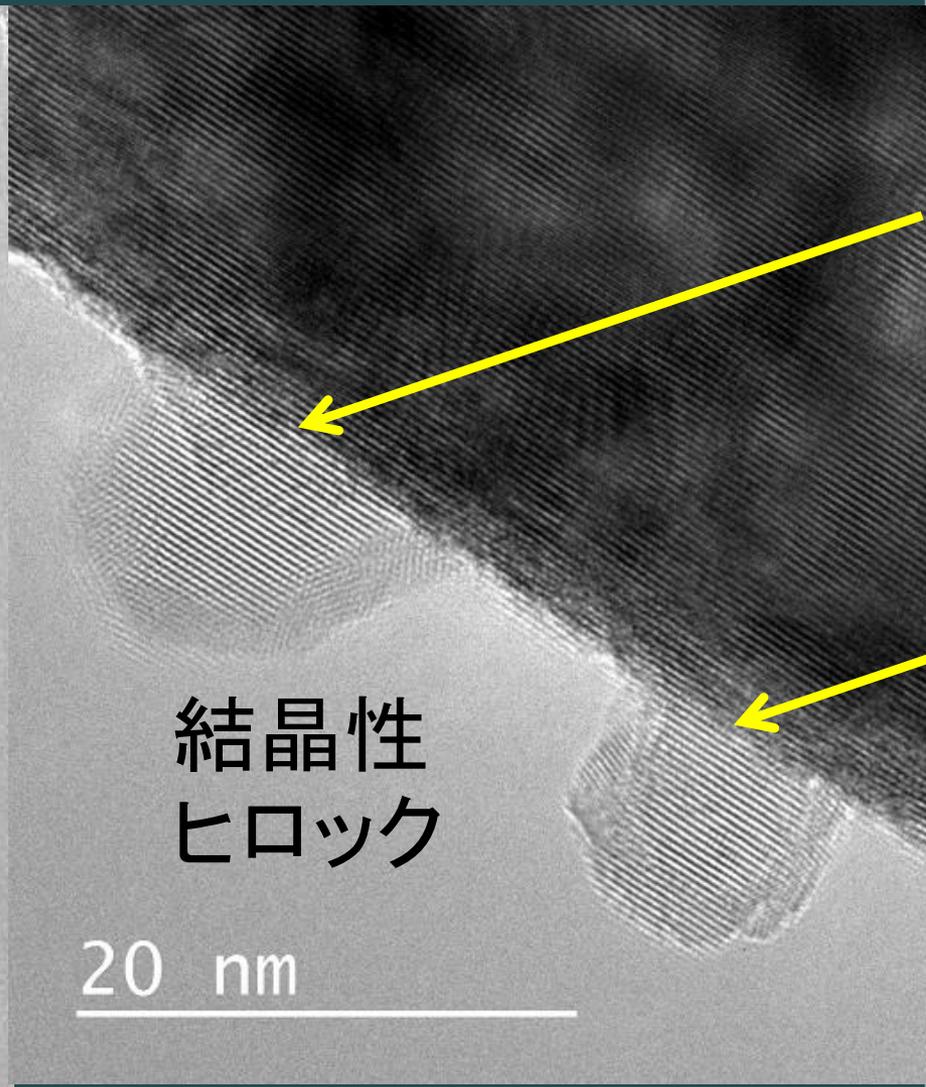
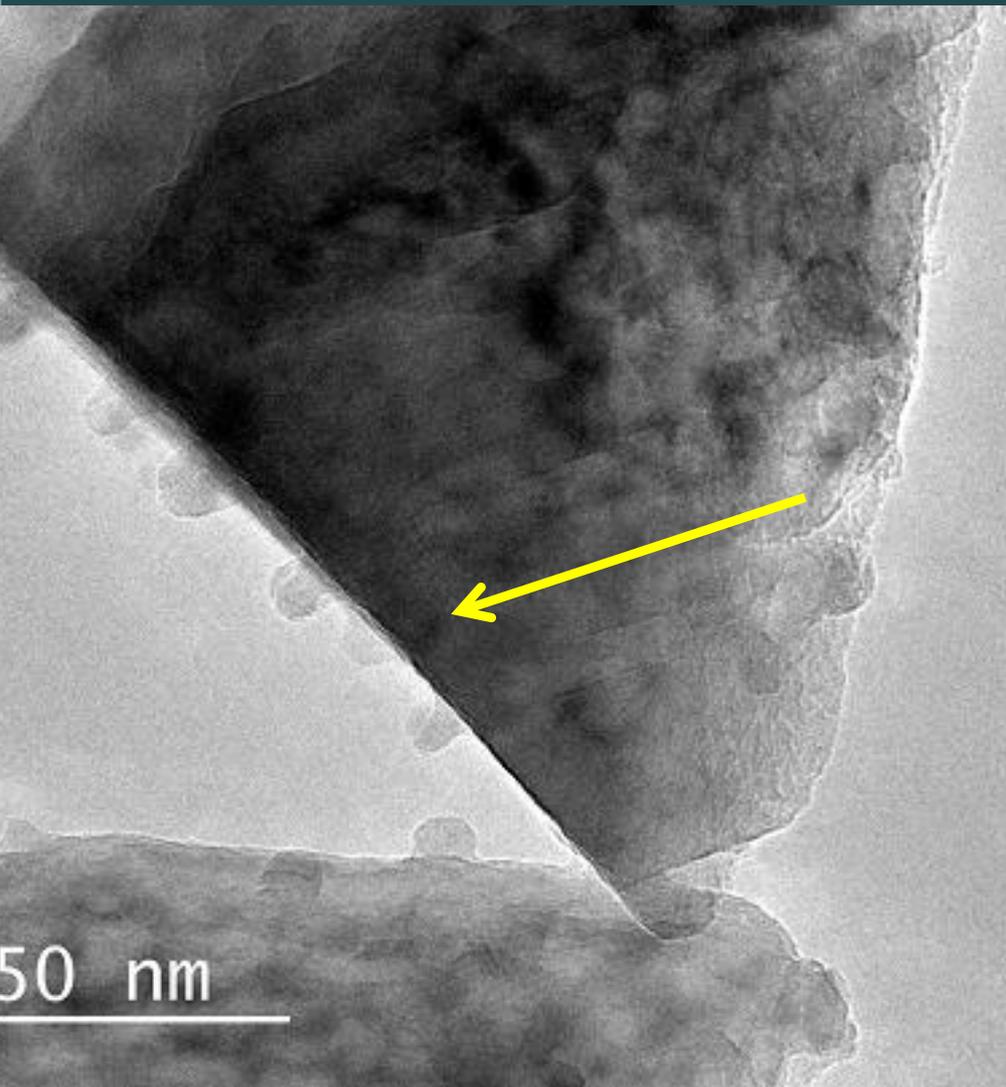


200 MeV Xe  $\rightarrow$  CeO<sub>2</sub>

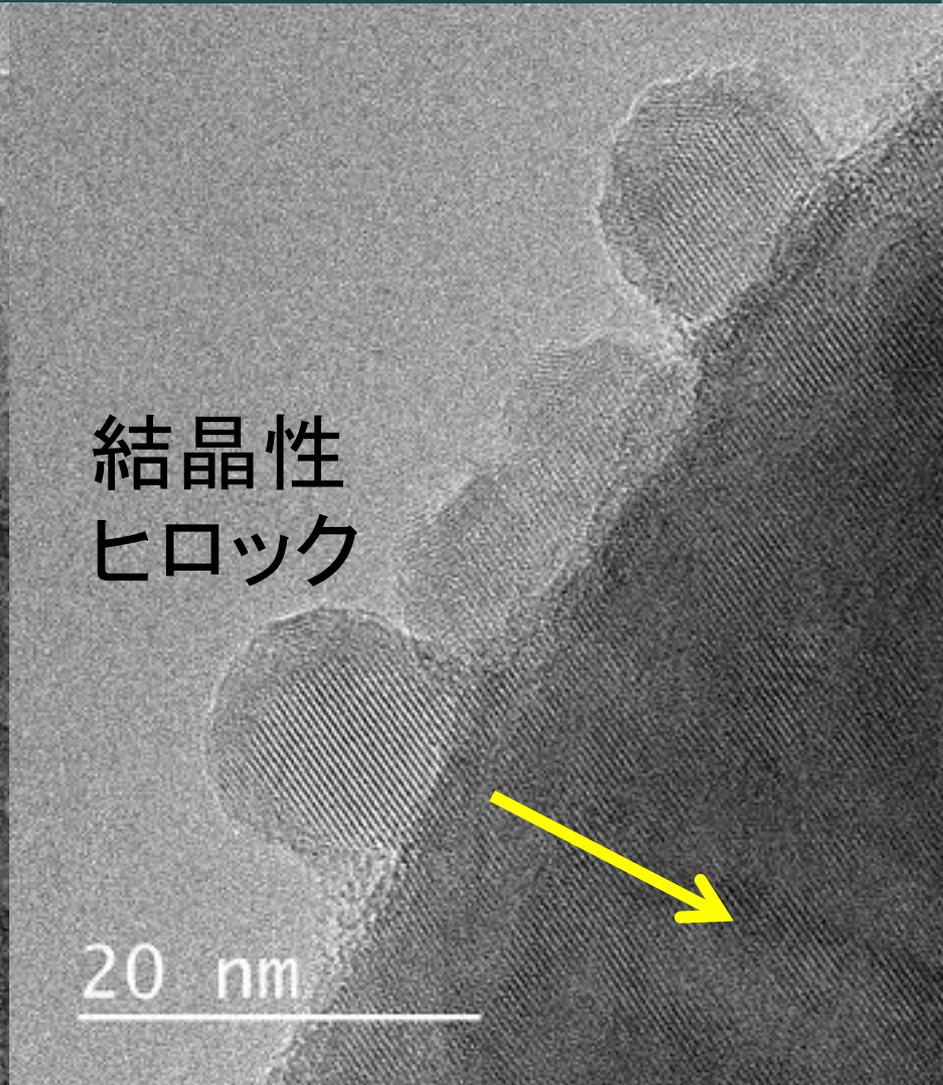
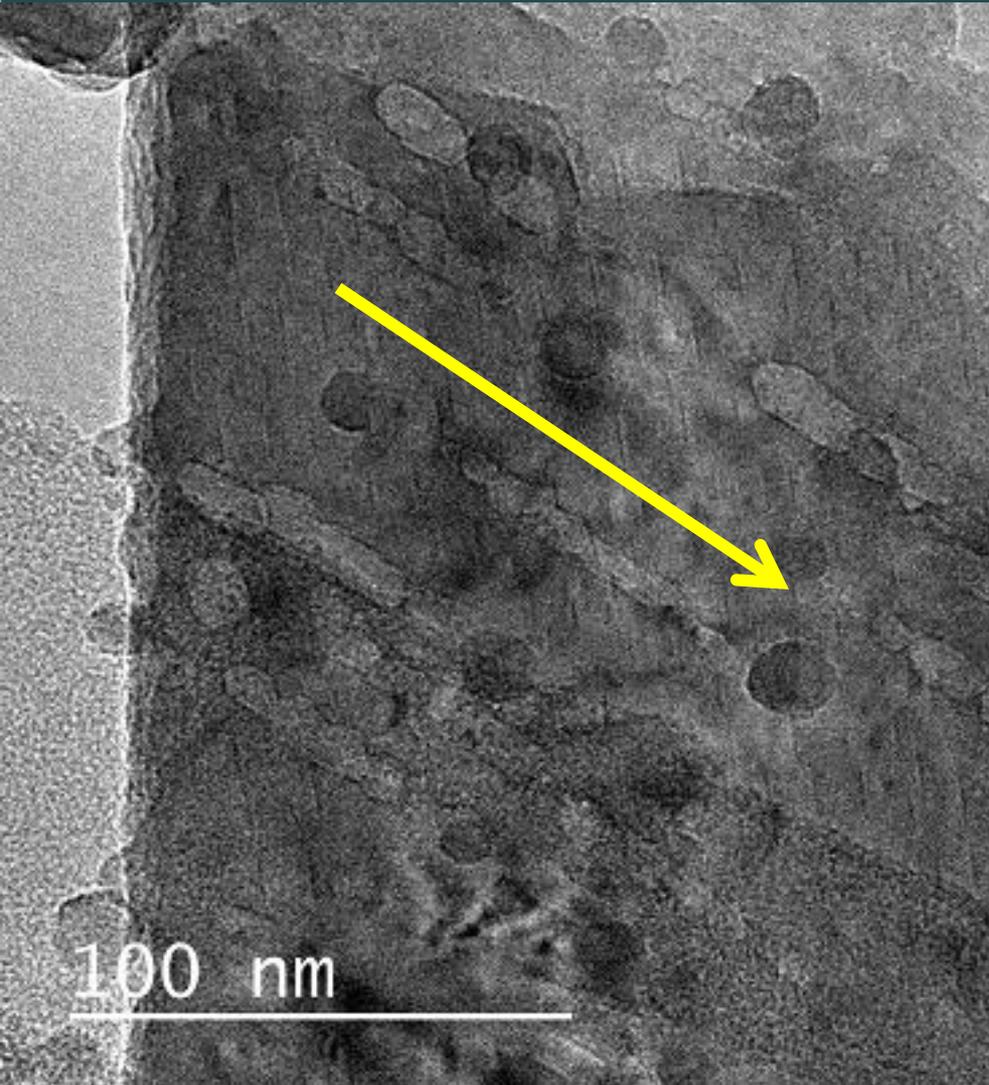
*S. Takaki et al., NIMB 326 (2014) 140.*

e.g. CaF<sub>2</sub>, SnO<sub>2</sub>, CeO<sub>2</sub>, UO<sub>2</sub>, ...

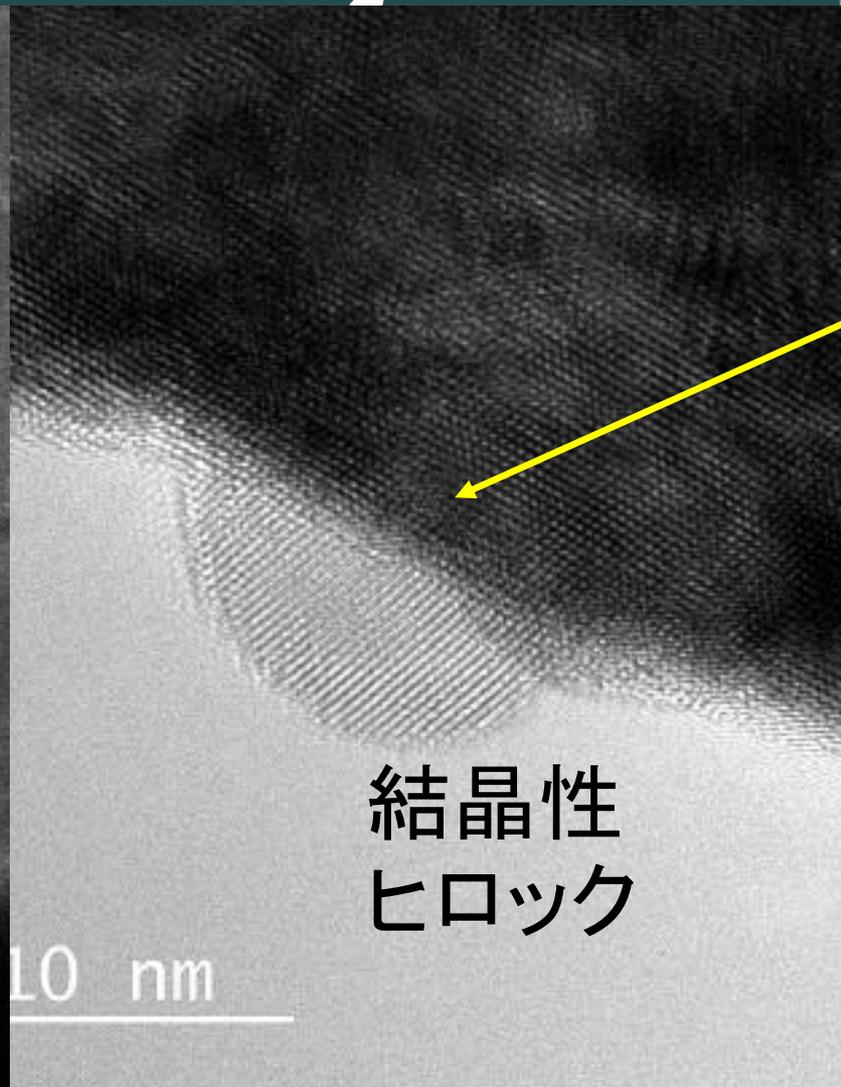
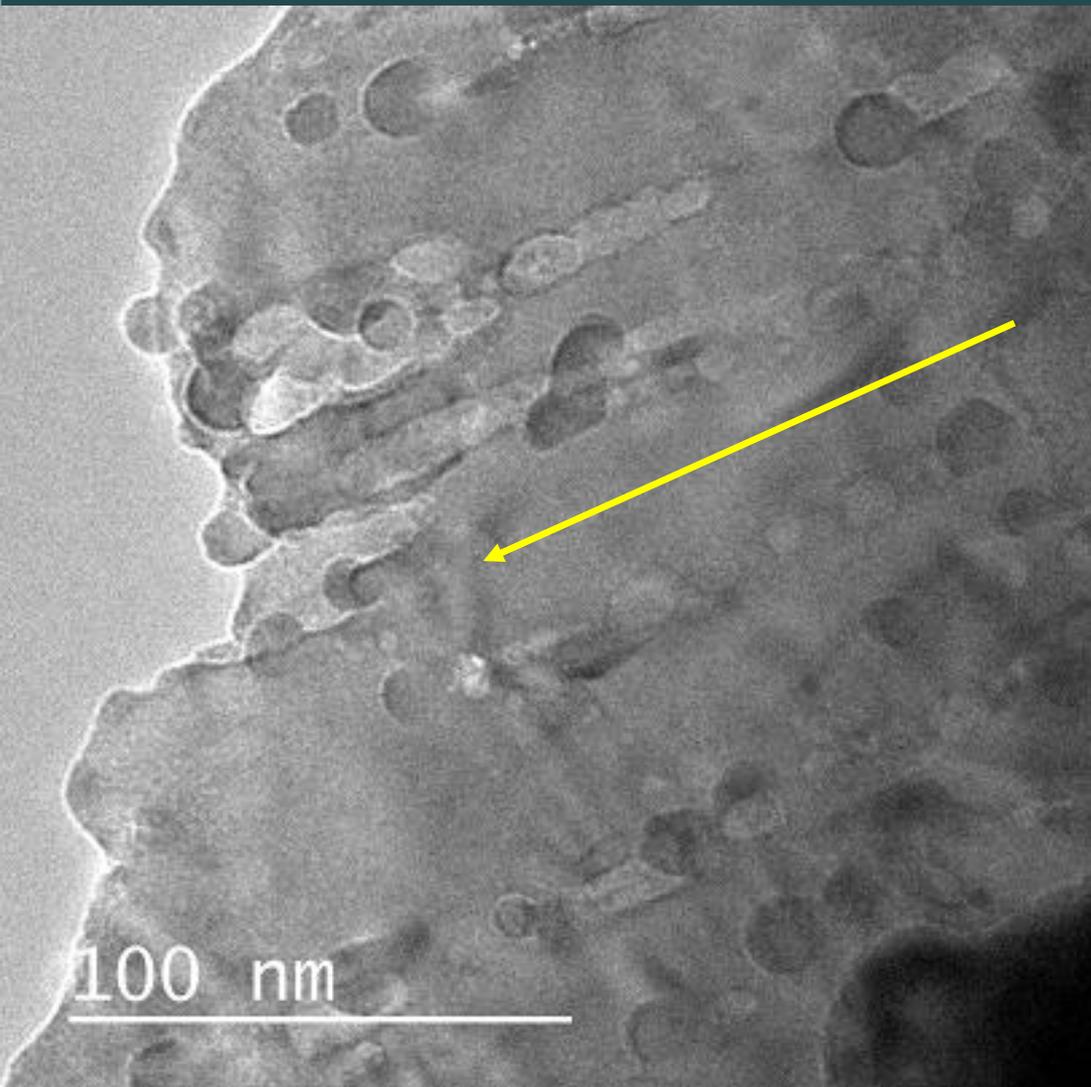
# 200 MeV Au $\rightarrow$ CaF<sub>2</sub>



# 200 MeV Au $\rightarrow$ SrF<sub>2</sub>

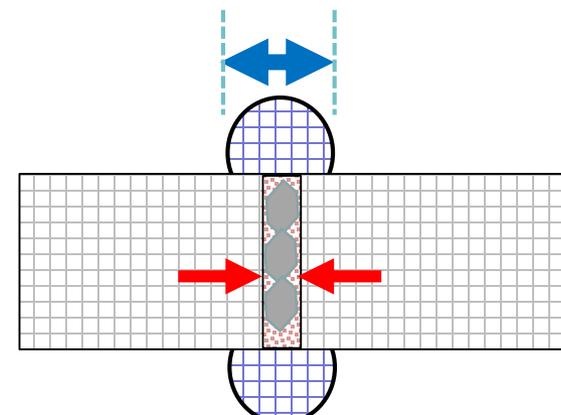
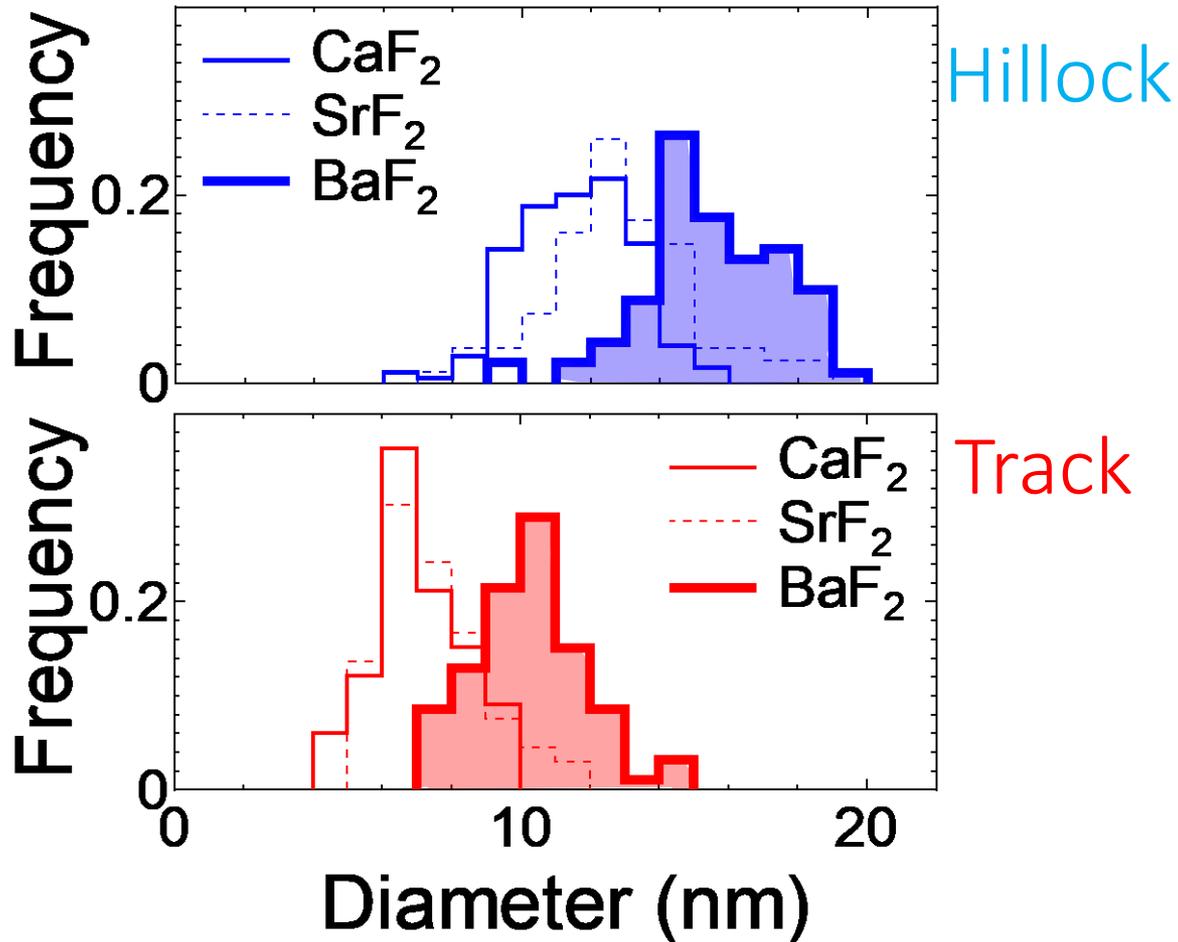


# 200 MeV Au $\rightarrow$ BaF<sub>2</sub>



ヒロック直径 > トラック直径

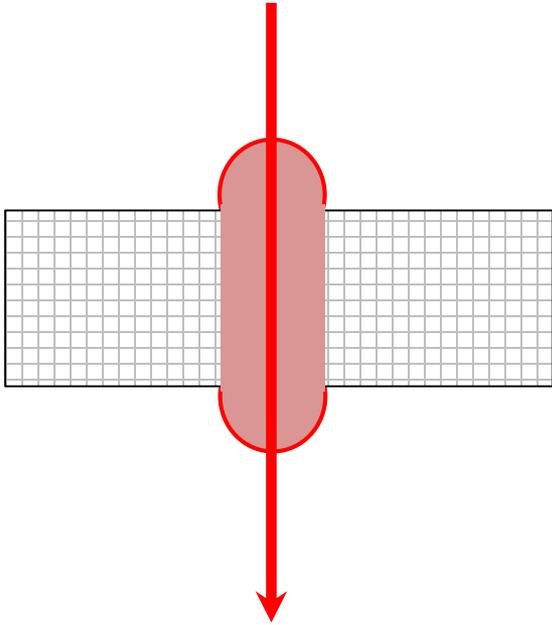
200 MeV Au



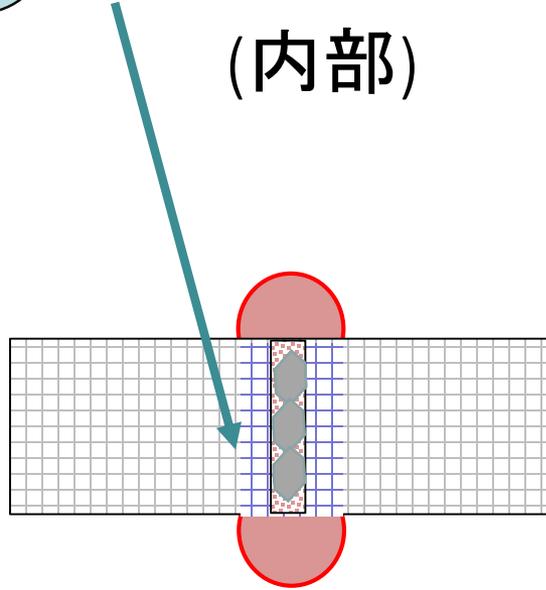
(CaF<sub>2</sub>, SrF<sub>2</sub>, BaF<sub>2</sub>)

# ヒロック形成プロセス(ver.2)

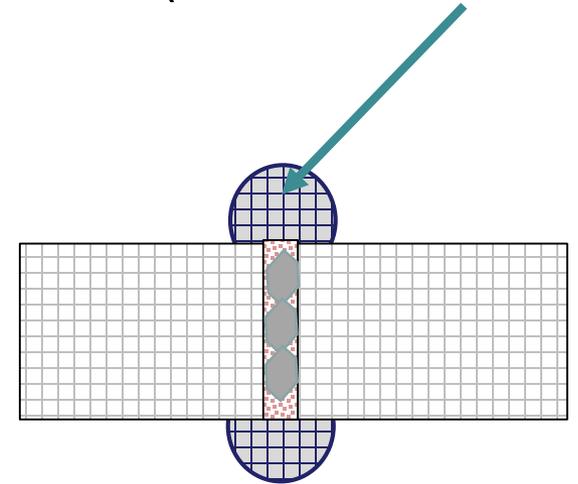
① 局所溶融



② 再結晶化  
(内部)

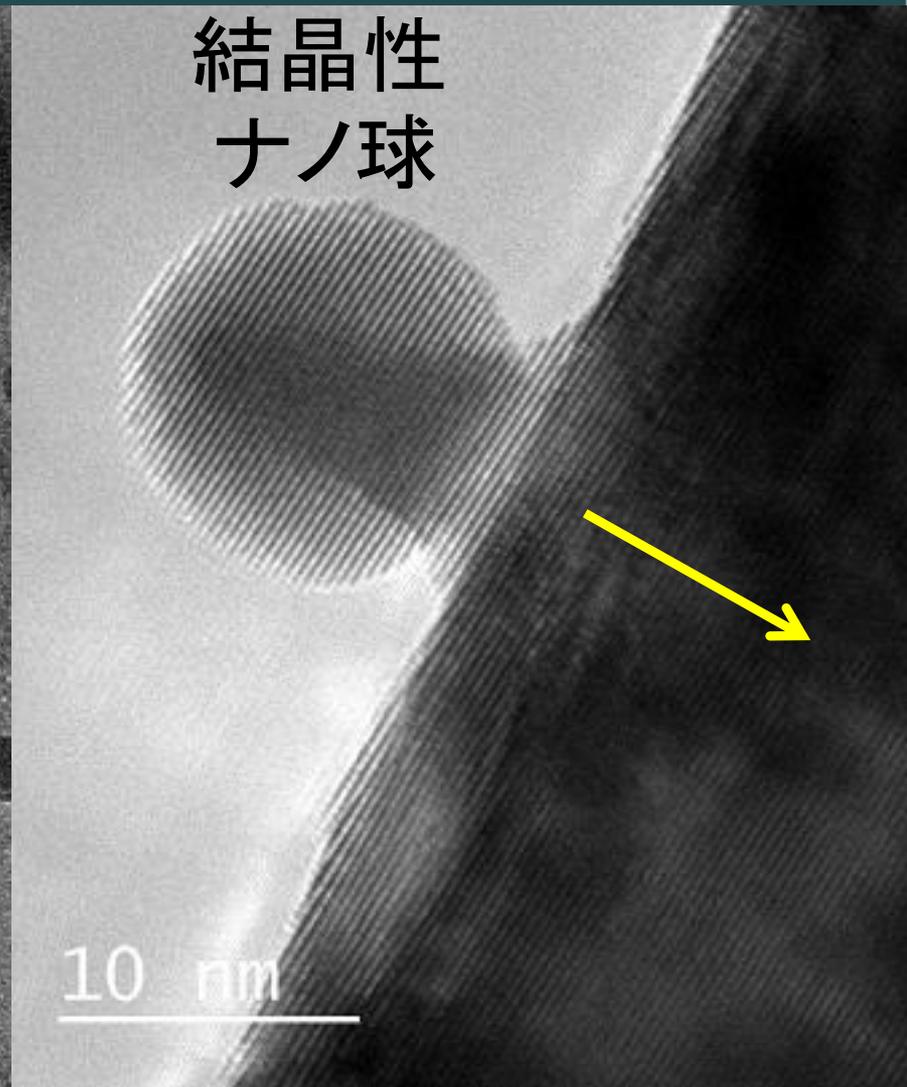
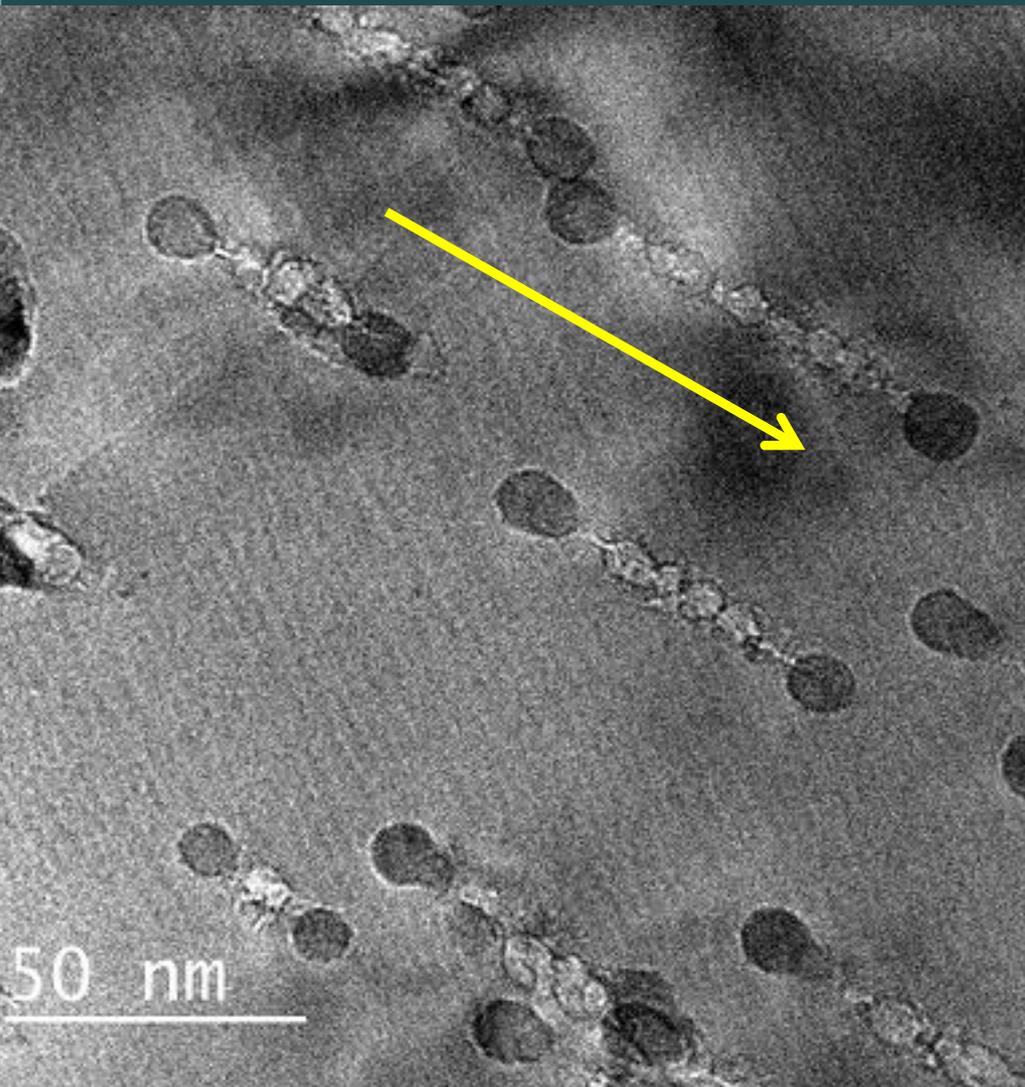


③ 再結晶化  
(結晶性ヒロック)

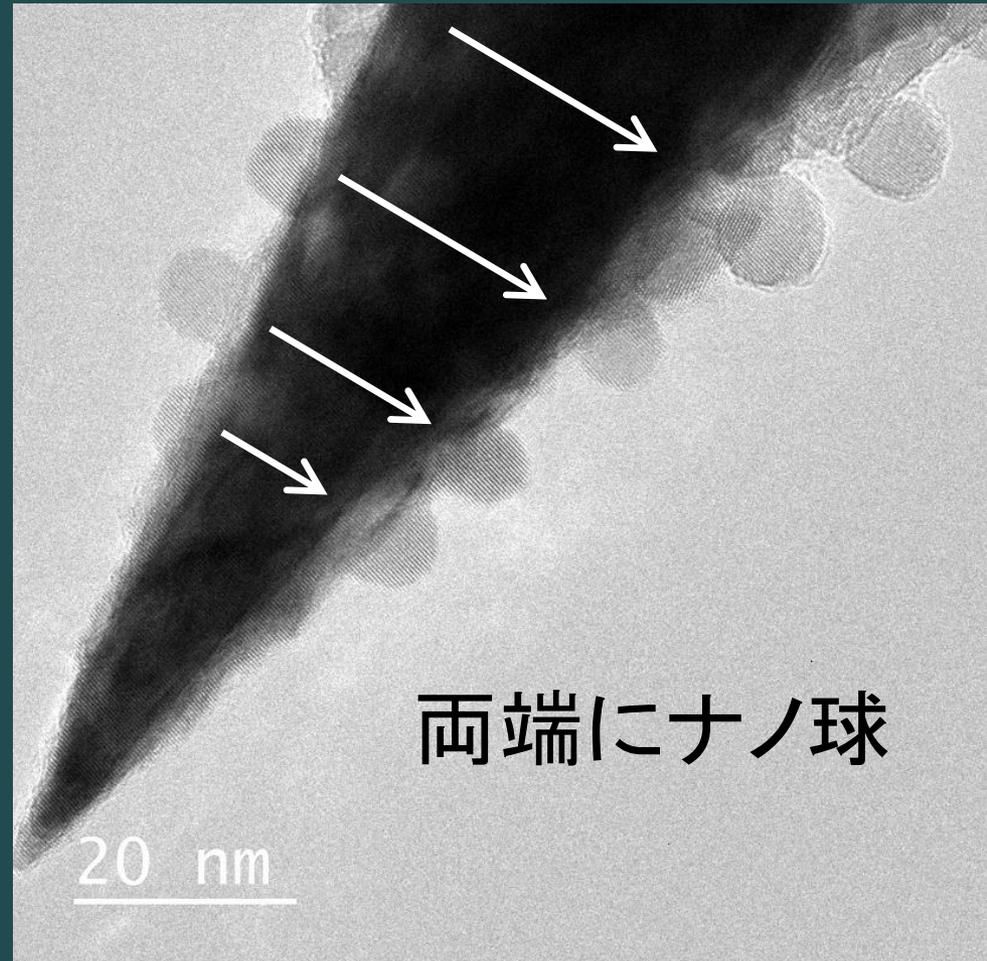
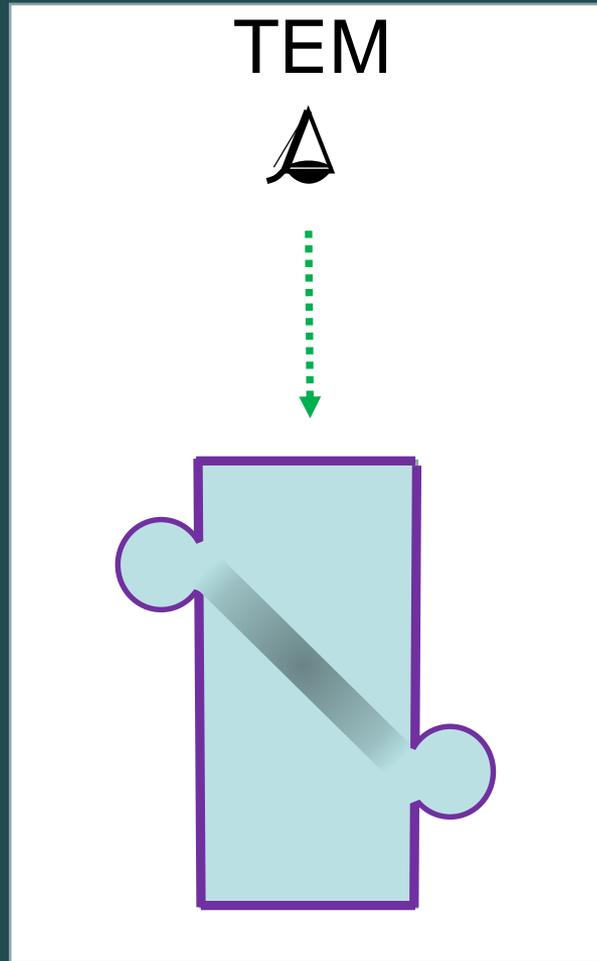


Fluorides ( $\text{CaF}_2$ ,  $\text{SrF}_2$ ,  $\text{BaF}_2$ )

# 200 MeV Au $\rightarrow$ CeO<sub>2</sub>

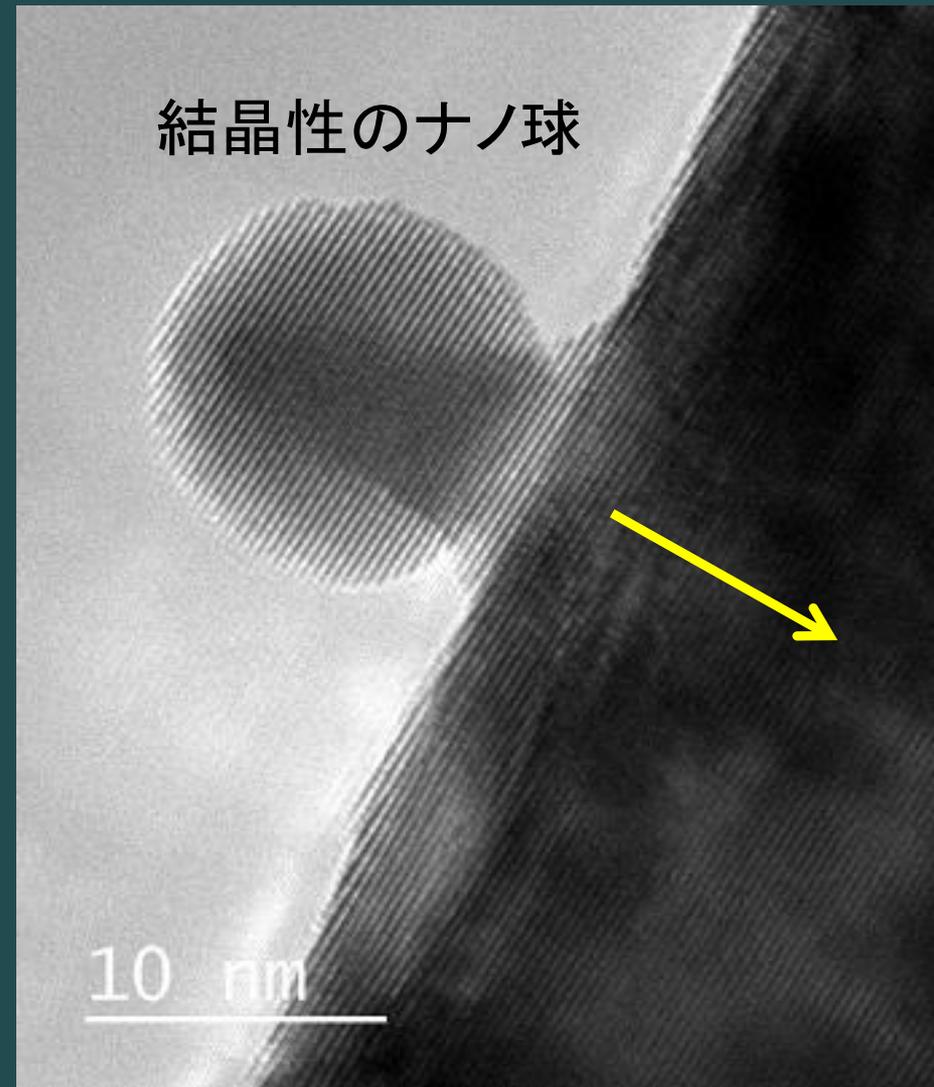


# 200 MeV Au $\rightarrow$ CeO<sub>2</sub>



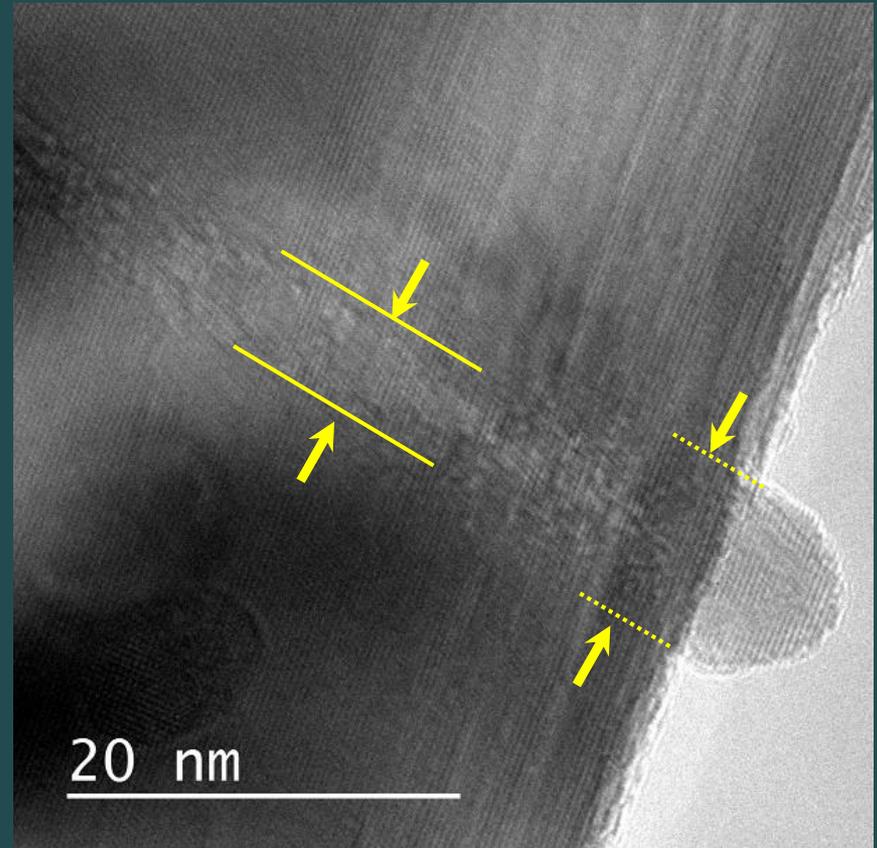
# 200 MeV Au $\rightarrow$ CeO<sub>2</sub>

- ✓ 「高温液体」
- ✓ 球体化した後に  
再結晶化

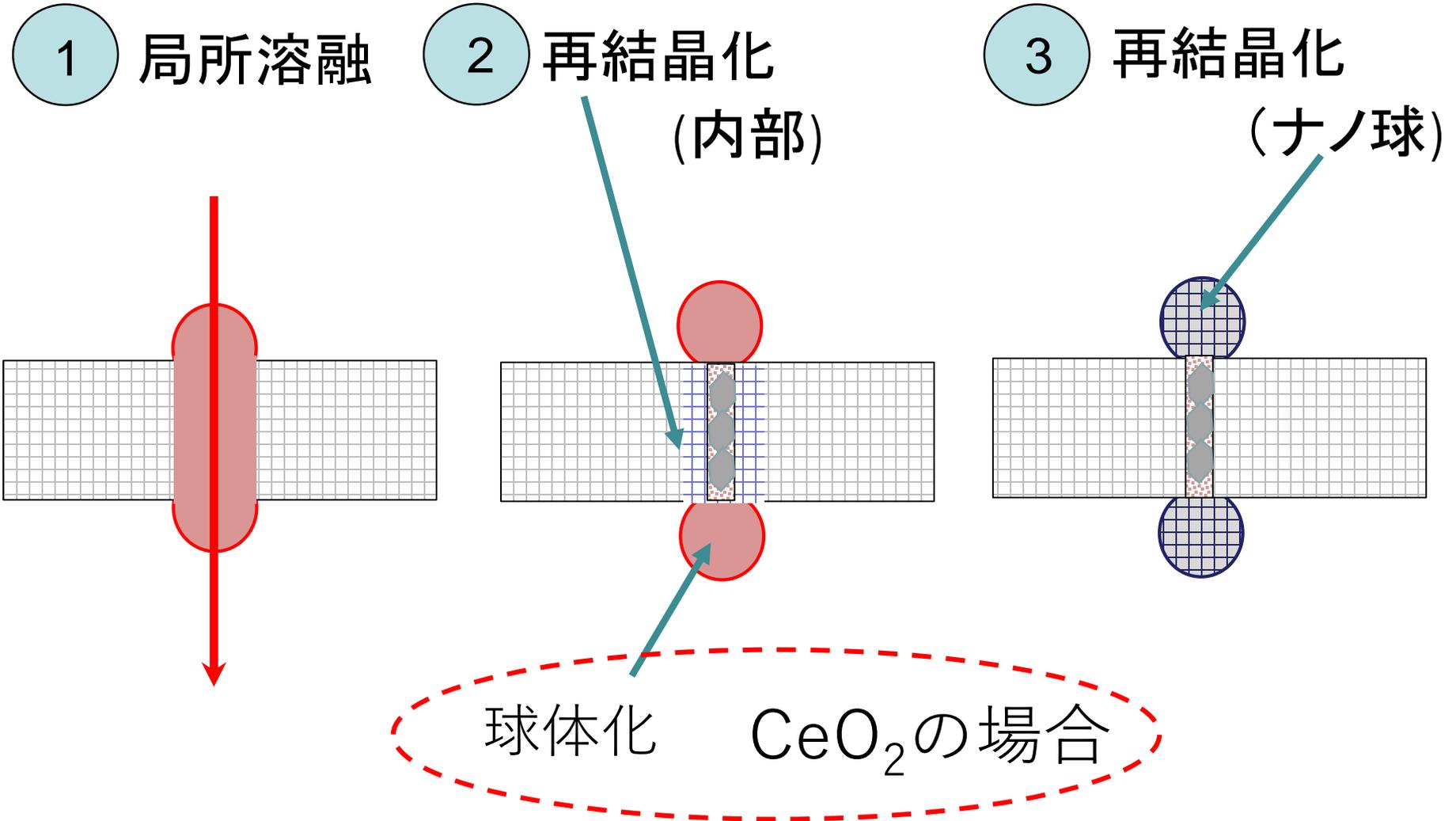


# 200 MeV Au $\rightarrow$ CeO<sub>2</sub>

- ✓ トラック直径 (小)
- ✓ ヒロック直径 (大)



# ヒロック形成プロセス(ver.2b)



# まとめ

