

X射线成像应用简介

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2013.11.21

1

主要内容

1. X射线成像及分类
2. 医学应用实例
3. 能源领域应用实例
4. 生物学应用实例
5. 材料领域应用实例
6. 其它应用



2

X射线成像及分类



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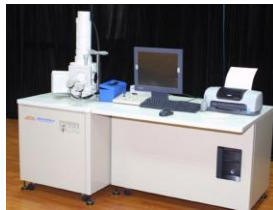
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3

常见成像手段



普通光学显微镜



扫描电子显微镜



医学CT



激光共聚焦扫描显微镜



透射电子显微镜



X射线显微镜



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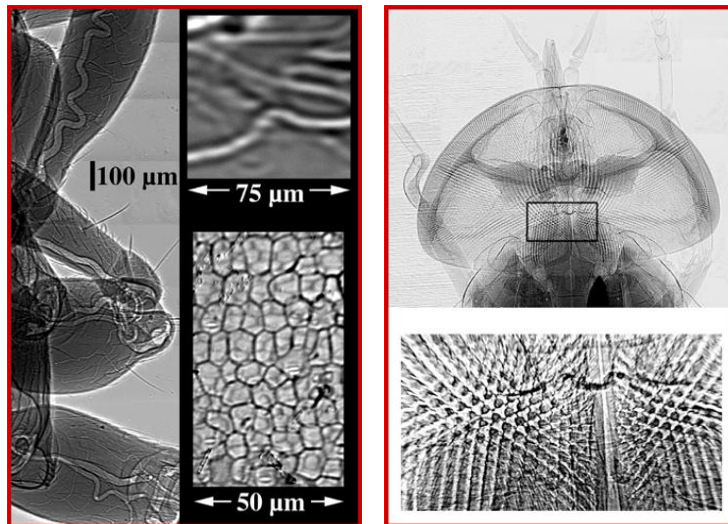
4

常见成像手段比较

成像方法	分辨率	样品尺寸	3D ?	实时 ?	破坏 ?
Optical microscope	λ (200~300nm)	Depth of focus <100 nm	N	Bio/Y	N
Confocal microscope	λ ; STORM/50nm	flexible	Y	Bio/Y	N
Medical X-ray CT	~mm	tens of cm	Y	Y	N
Neutron imaging	Tens of μm	~inch +	Y	Y	N
Synch. μ -CT	~ μm	mm to cm	Y	Y	N
TXM	~30 nm	tens of μm	Y	Y	N
AFM	~ \AA	tens of μm	N	N	N
SEM	~nm	~ μm +	With FIB	Difficult	2D/N; 3D/Y
TEM	~ \AA	<100 nm thick	Y	Difficult	N

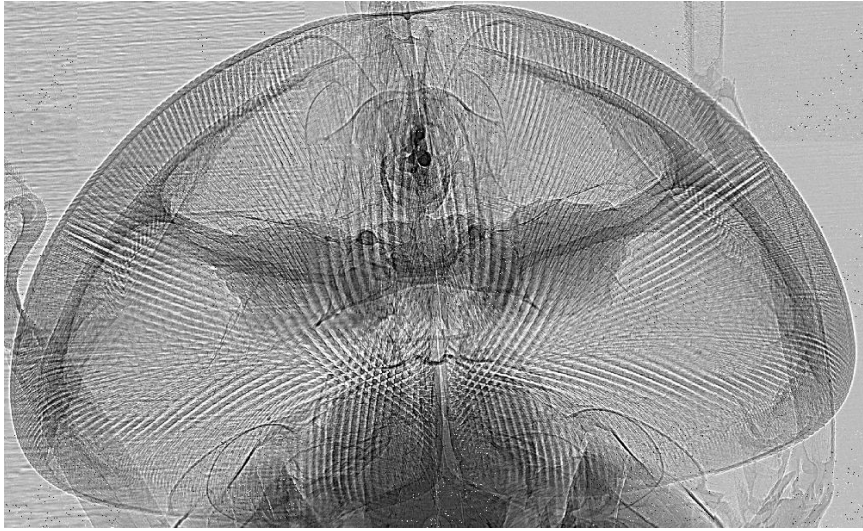


X射线成像可以干什么？



J. Phys. D35 (2002) R105, Y Hwu, Wen-Li Tsai, et al.



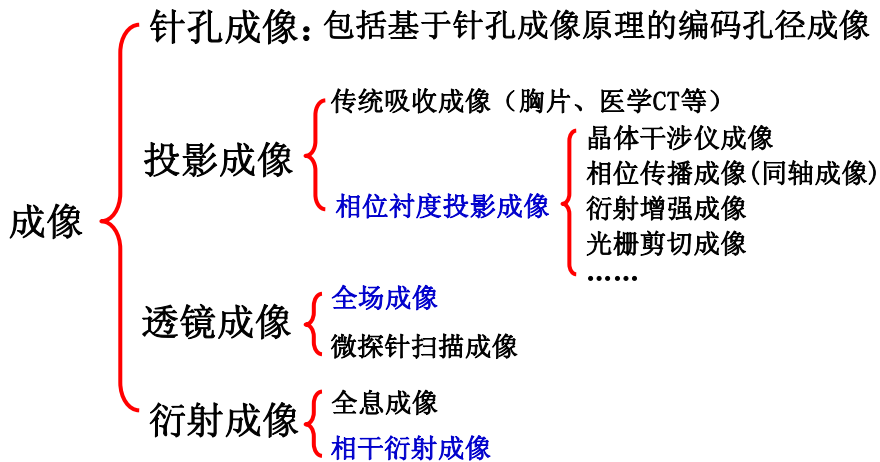
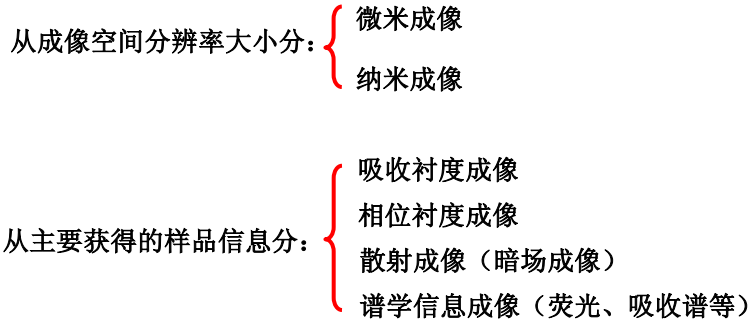


X射线成像的优点

1. 高空间分辨
2. 高穿透性的无创成像
3. 曝光时间短、成像速度快
4. 可外加各种环境条件
(磁场, 温度场, 电场, 压力等)
5. 丰富的衬度机制
(吸收、相位、散射、荧光、吸收边等)

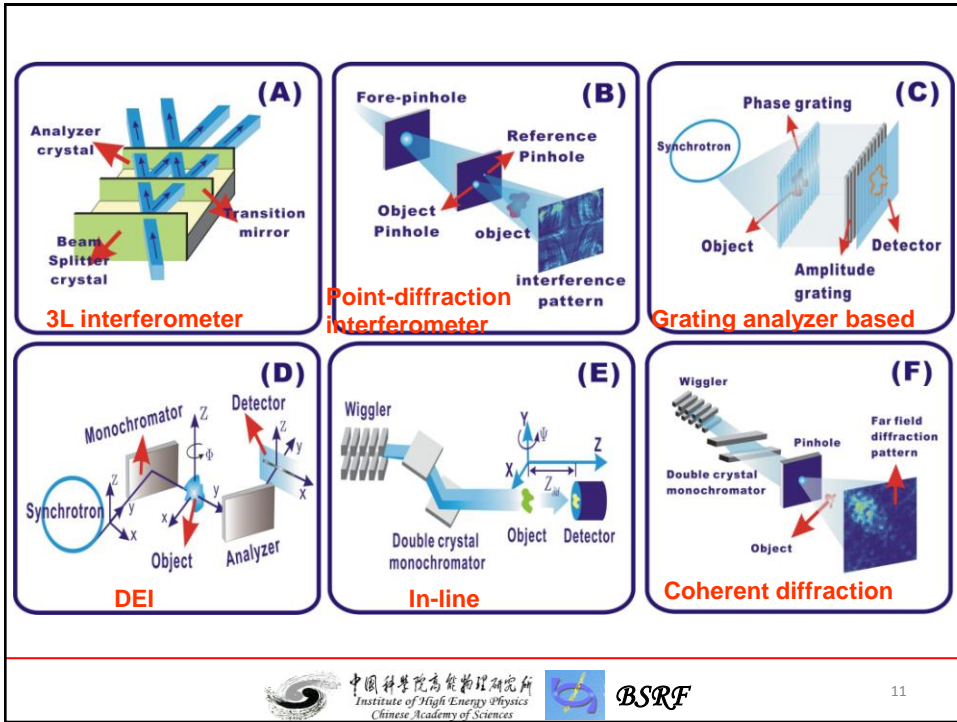


X射线成像分类



本报告所述应用实例主要围绕相位衬度投影成像、全场成像和相干衍射成像方法展开



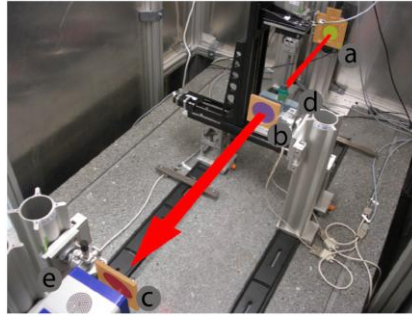


医学应用实例



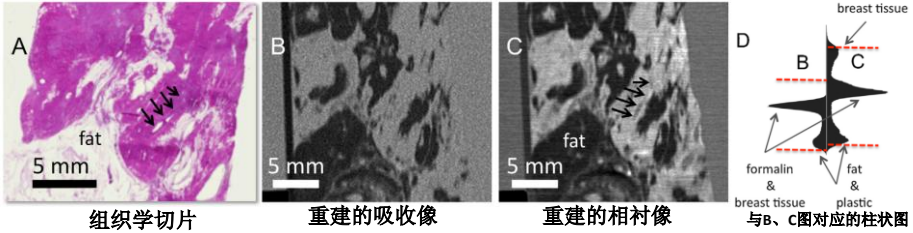
乳腺成像—1

实验室光源光栅成像
 Mo靶70 mA @ 35 - 40 kVp
 1200 p/360° & 11 steps
 曝光时间5s、总时间30h



- a) 源光栅;
- b) 相位光栅;
- c) 分析光栅;
- d) 样品台;
- e) 探测器

病例1



S. Grandl et al. / Z. Med. Phys. 23 (2013) 212–221

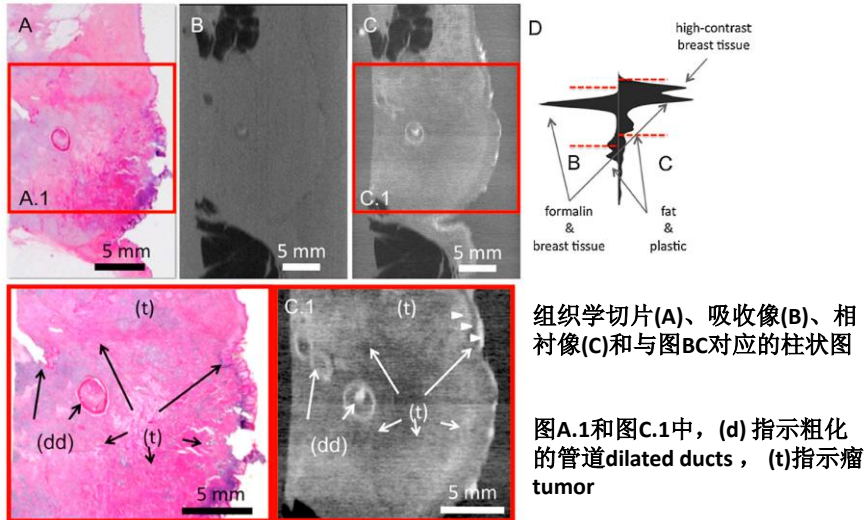


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病例2



组织学切片(A)、吸收像(B)、相衬像(C)和与图BC对应的柱状图

图A.1和图C.1中, (d) 指示粗化的管道dilated ducts, (t)指示瘤 tumor

S. Grandl et al. / Z. Med. Phys. 23 (2013) 212–221

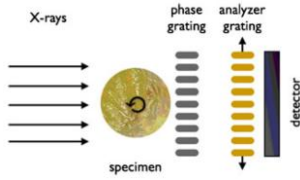


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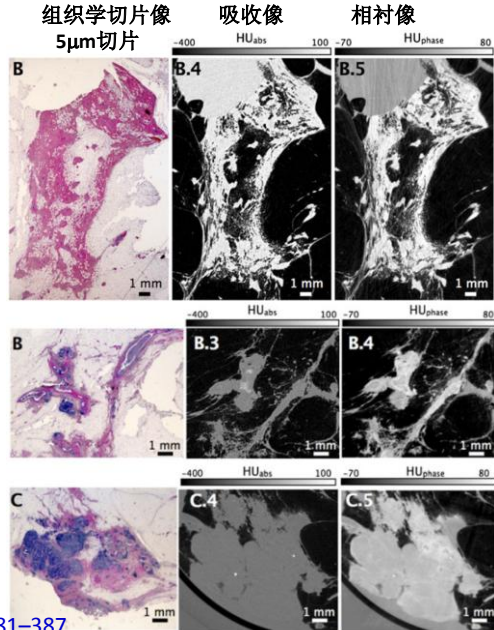
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乳腺成像—2



同步辐射光源光栅成像
23keV@ESRF-ID19
样品大小: $2 \times 2 \times 2 \text{cm}^3$
1199p/360° & 4 sets

基于光栅的相位衬度方法有可能实现从离体成像到活体成像



Anikó Sztróky et al. Eur Radiol (2013) 23:381–387



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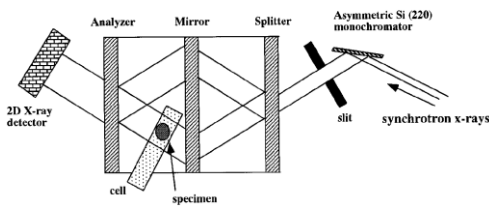


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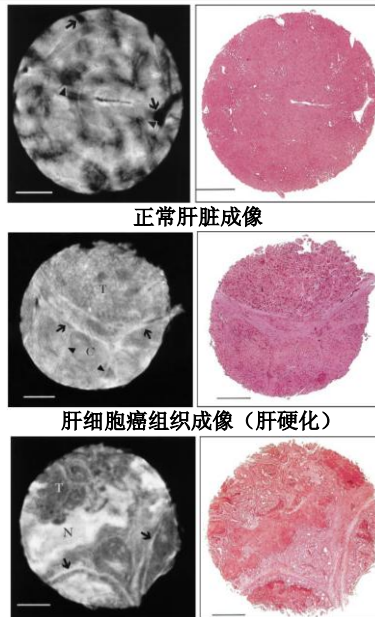
Hu—CT值, 表征密度大小的单位

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肝脏成像



视场: $100 \text{mm} \times 100 \text{mm}$
样品: 病理切片
样品厚度: 5cm
同步辐射光源17.7keV, 30keV
不使用衬度增强剂
福尔马林溶液固定



正常肝脏成像

肝细胞癌组织成像(肝硬化)

结肠癌转移的肝脏成像

光镜切片厚度 $10 \mu\text{m}$ 标尺1mm 16

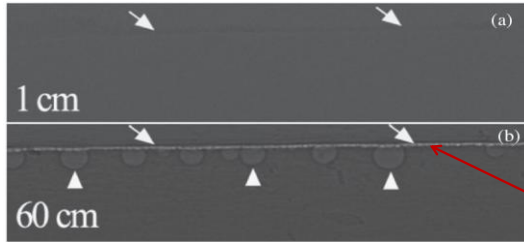
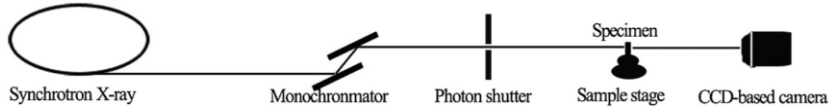
Tohoru Takeda et al. Radiology 214(1):298-301

微气泡作为脉管系统造影剂

小鼠活体实验（现场）

商业化的微气泡（超声，1-10 μm 平均2.5 μm ），自制微气泡（1-22 μm 平均9 μm ）
用0.5 ml BaSO₄(0.5 g ml⁻¹) 对照组

瘤组织尺寸~ 1cm，样品厚度5mm，19keV@SSRF-BL13W



活体成像

(a)吸收像（探测器距离1cm）

(b)相衬像（探测器距离60cm）

曝光时间：5S

箭头指示为商业化微气泡线

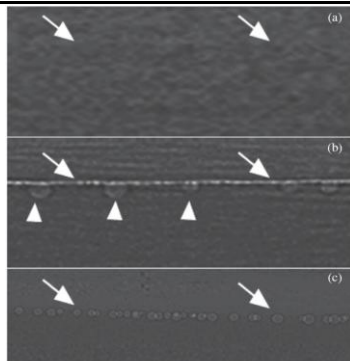
R. Tang et al. Phys. Med. Biol. 56 (2011) 3503–3512



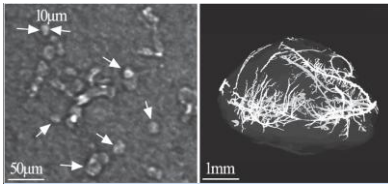
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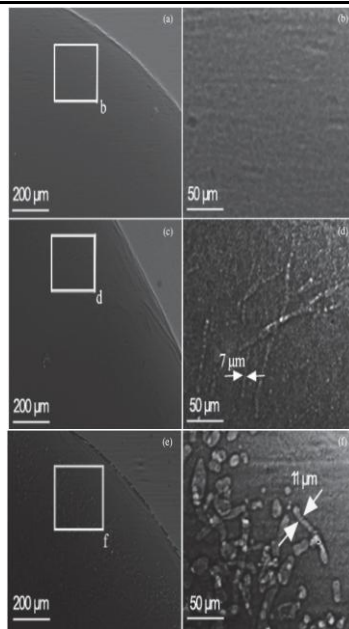
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(a)生理盐水, (b)商业微气泡, (c)自制微气泡
不同增强剂活体成像



活体肿瘤微气泡增强成像 肿瘤脉管系统CT



离体肾脏成像

(a)无气泡增强剂

(c)商业微气泡

(e)自制微气泡

R. Tang et al. Phys. Med. Biol. 56 (2011) 3503–3512

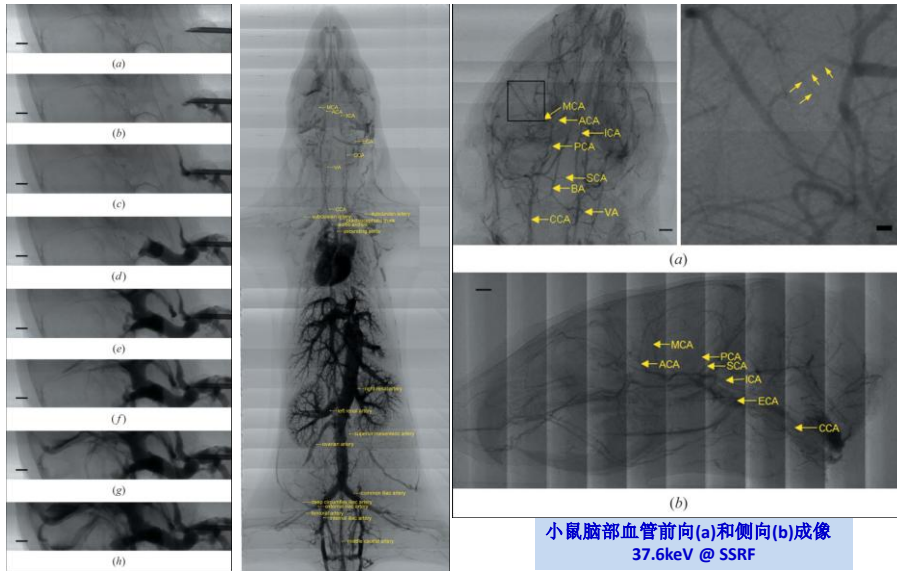


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同步辐射微血管成像



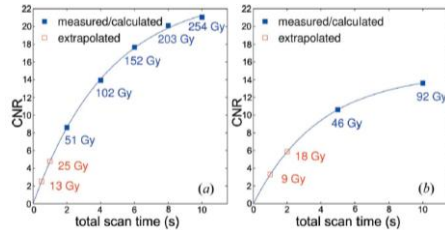
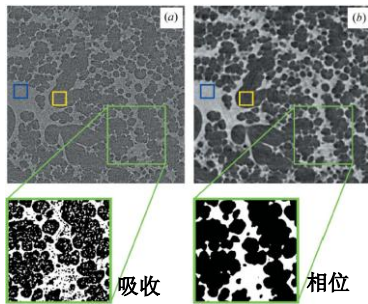
活体鼠脑血管造影过程
34keV @ SSRF(标尺1mm)

小鼠全身血管成像
34keV @ SSRF

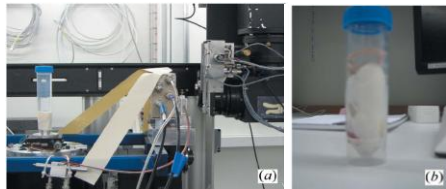
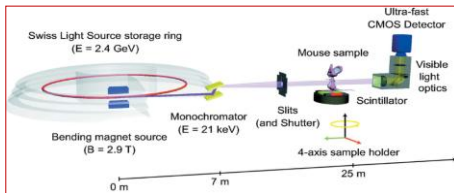
小鼠脑部血管前向(a)和侧向(b)成像
37.6keV @ SSRF

Ping Liu et al. J. Synchrotron Rad. (2010). 17, 517-521
造影剂: 碘、硫酸钡

肺泡快速CT



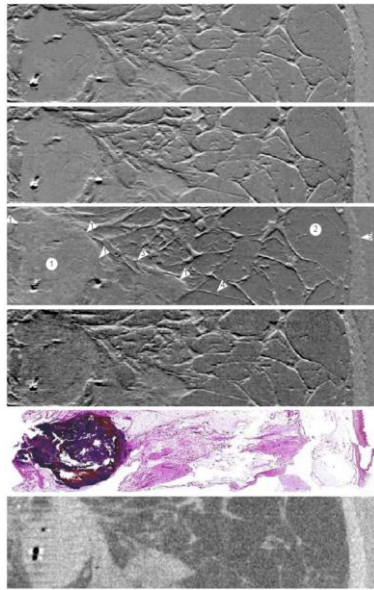
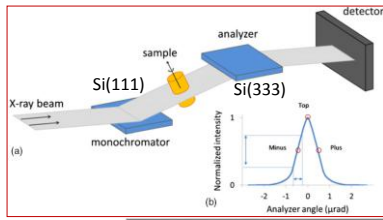
全套CT数据相应的辐照剂量:
(a)2.9 μm有效像素尺寸(b)1.1 μm有效像素尺寸成像



21keV, 2~13ms @ 901Projections, 总时间~10s

Goran Lovric et al.
J. Appl. Cryst. (2013). 46, 856-860

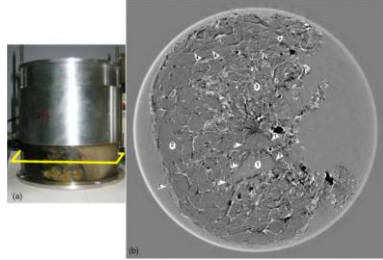
DEI乳腺CT



DEI-CT图像
(a) +90% of RC
(b) +70%
(c) -60%
(d) +40%

(e)组织切片图
(f)吸收CT图

C图中
(1)肿瘤及边界
(2)脂肪组织
(3)腺体组织
(4)胶原纤维
(5)皮肤

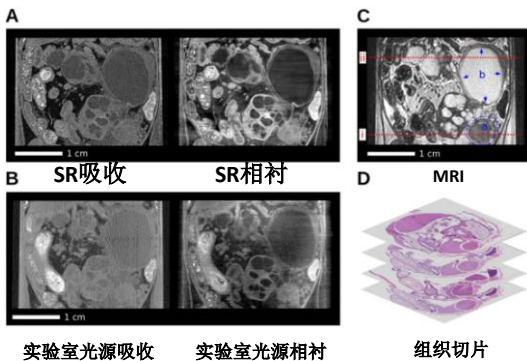


样品直径~15cm, 10%福尔马林溶液固定
70keV @ ID17 @ ESRF
有效像素尺寸: 92 μm×92 μm
四套CT数据(+90%, +70%, -60%, +40% of RC)

A Sztr' okay et al., Phys. Med. Biol. 57 (2012) 2931-2942

胰腺导管癌小鼠模型成像

不同CT模式的纵切面断层像

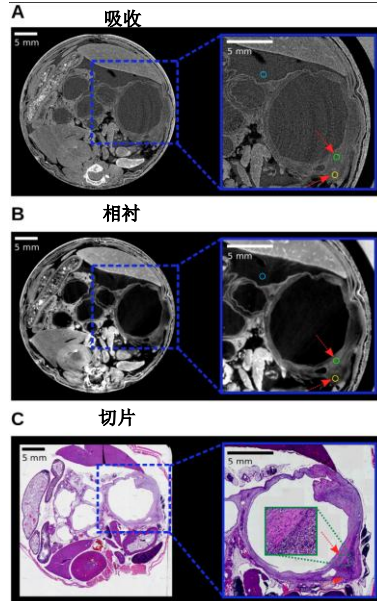


实验室光源吸收 实验室光源相衬

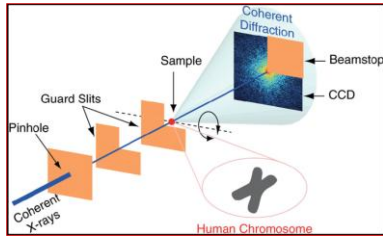
组织切片

光栅成像
SR: 35keV
Lab: 23keV @ 35kV

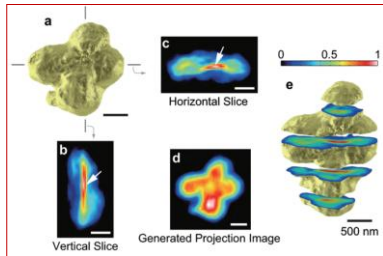
Arne Tapfer et al. PLOS One 8(2013)e58439



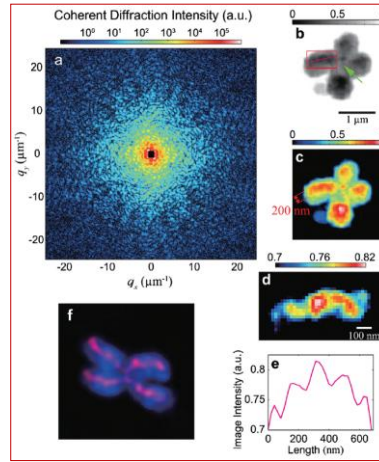
人类染色体相干衍射成像



5keV @ Spring-8 BL29XUL
 曝光时间: 2700s (部分3400s)
 28 or 56 projections @ -70°~70°



染色体电子密度三维重建结果



染色体CDI图和重建的投影图

Yoshinori Nishino et al. PRL 102, 018101 (2009)

能源领域应用实例

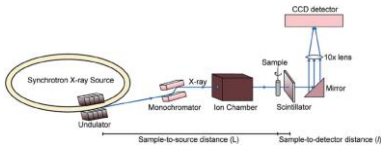


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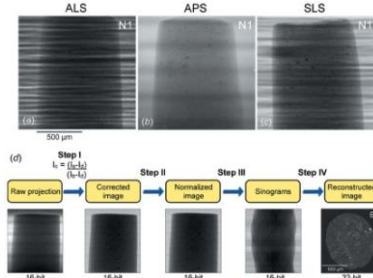


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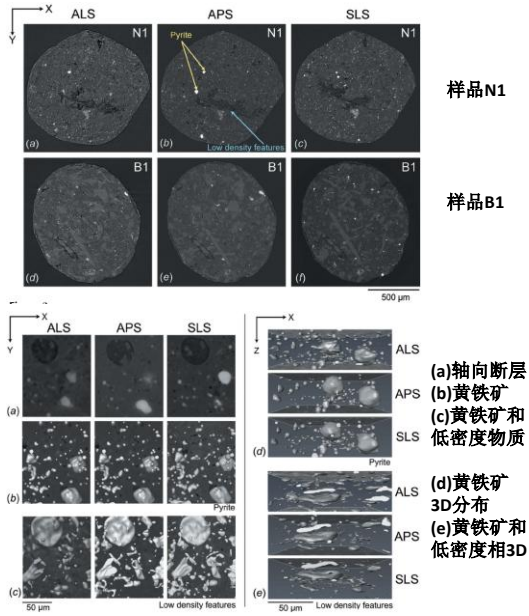
页岩同步辐射微米成像



18keV, 1500p/180°
样品: $\phi 1\text{mm} \times 5\text{mm}$



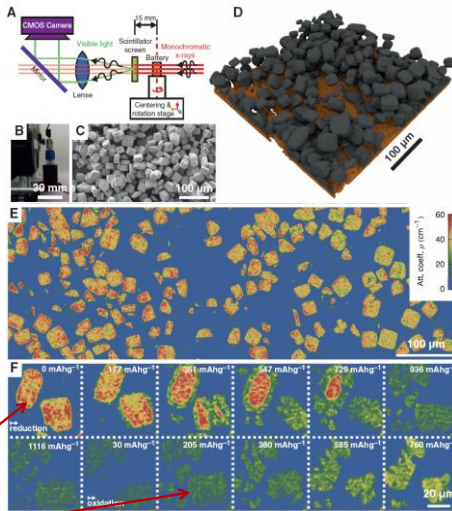
原始图及数据处理流程



Waruntorn Kanitpanyacharoen et al. *J. Synchrotron Rad.* (2013). 20, 172–180

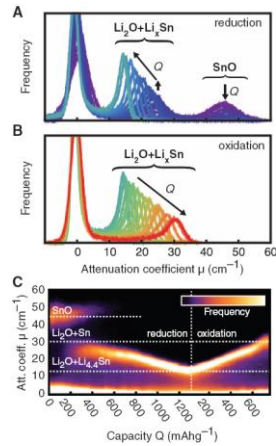
锂电池失效研究

Martin Ebner et al. *Science* 342, 716 (2013)

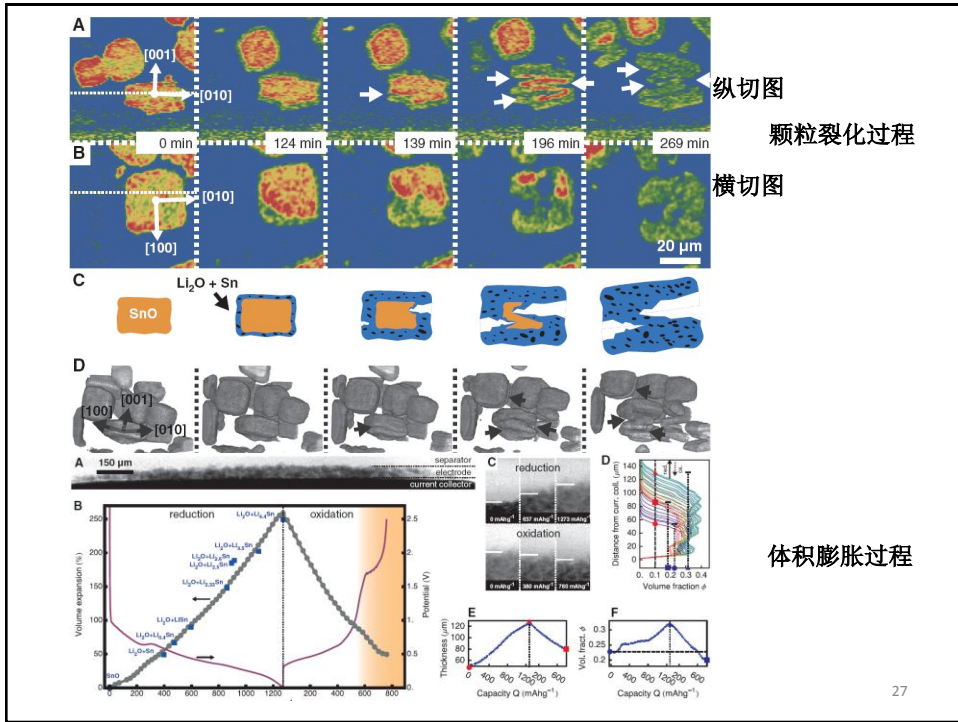


碳、粘接剂、电解相

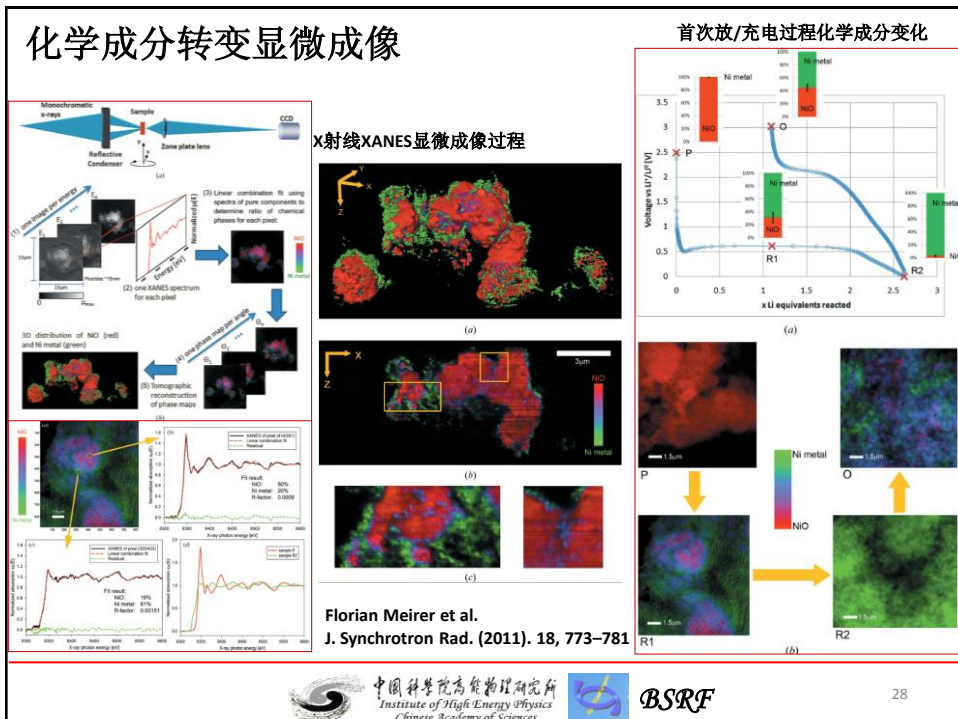
每隔15min采集一套CT数据
还原(锂化)过程: 110mAh/g @12h
氧化(去锂化)过程: 167mAh/g @5h



化学成分演变过程

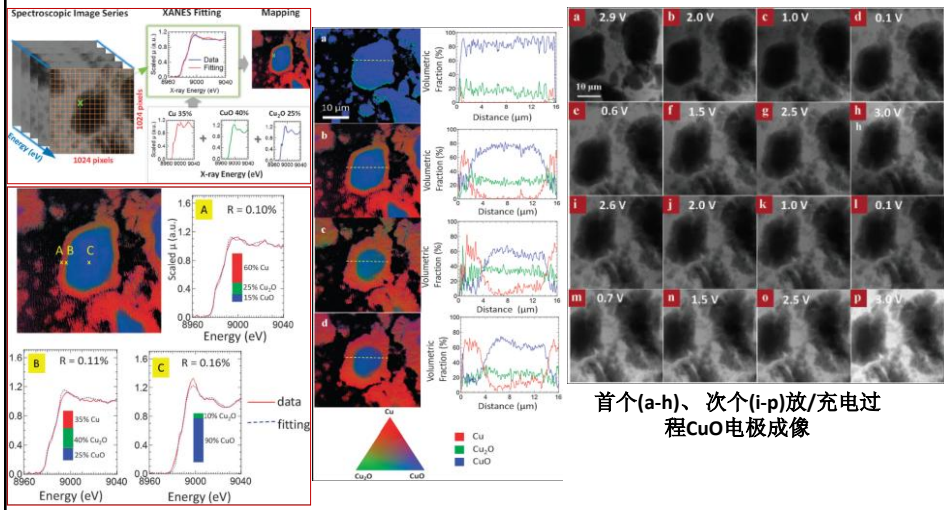


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锂电池实时化学成分成像

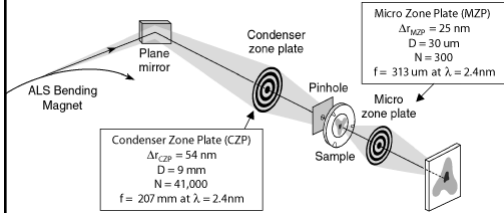


首个(a-h)、次个(i-p)放/充电过程CuO电极成像

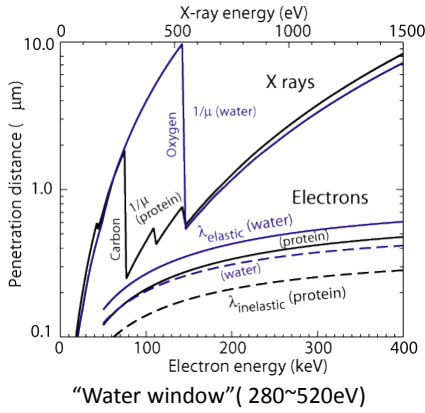
Jiajun Wang et al. Chem. Commun., 2013, 49, 6480–6482

生物学应用实例

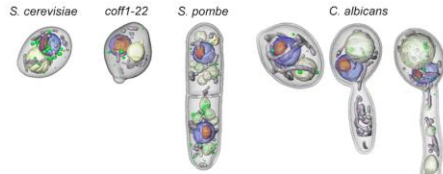
“水窗” TXM成像



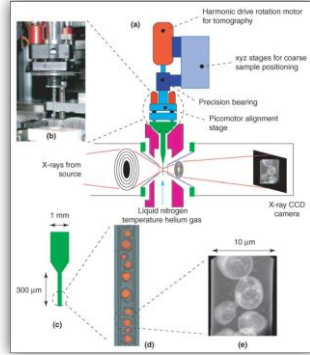
Schematic diagram of XM1 @ BL6.1.2 ALS



“Water window” (280~520eV)



M. Uchida et al., PNAS 106(46), 19375-19380 (2009)



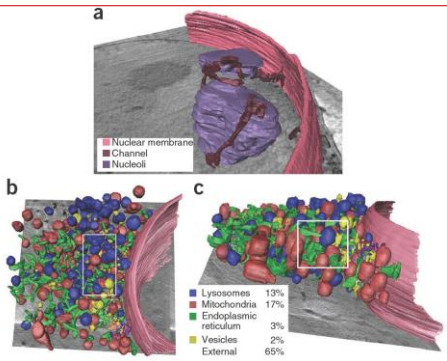
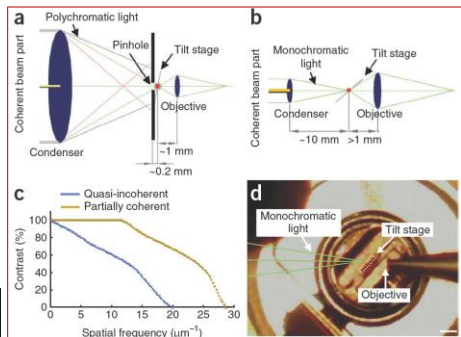
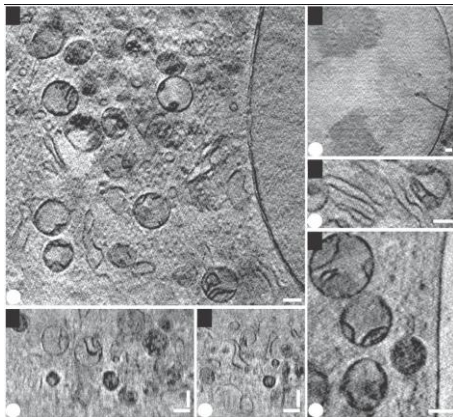
M. A. Le Gros et al., Curr. Opin. Struct. Biol. 15, 568-575 (2005)

细胞亚显微结构软X光成像

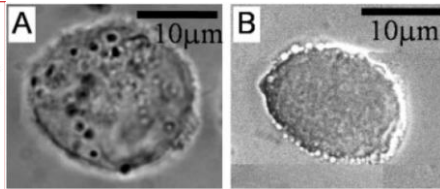
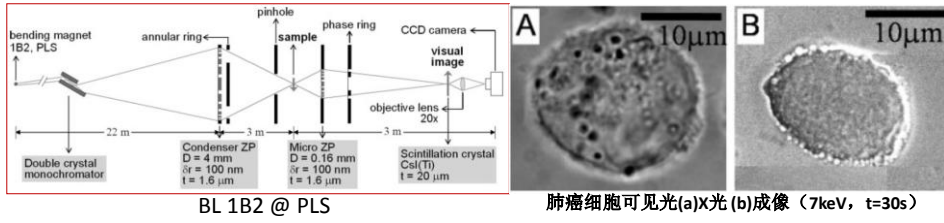
Gerd Schneider et al. Nature Methods 7(2013):985

U41-TXM @ BESSY II, HZB
250-800 eV

二维投影像@510eV, 标尺0.39 μm

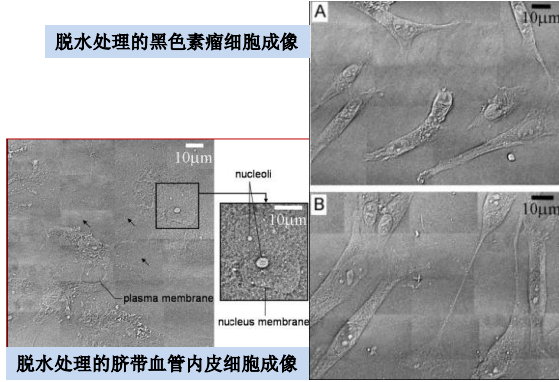


硬X射线相衬显微镜生物样品成像

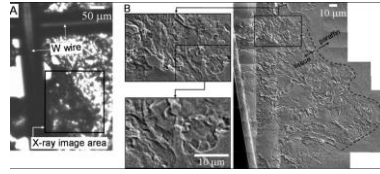


肺癌细胞可见光(a)X光(b)成像 (7keV, t=30s)

脱水处理的黑色素瘤细胞成像



脱水处理的脐带血管内皮细胞成像

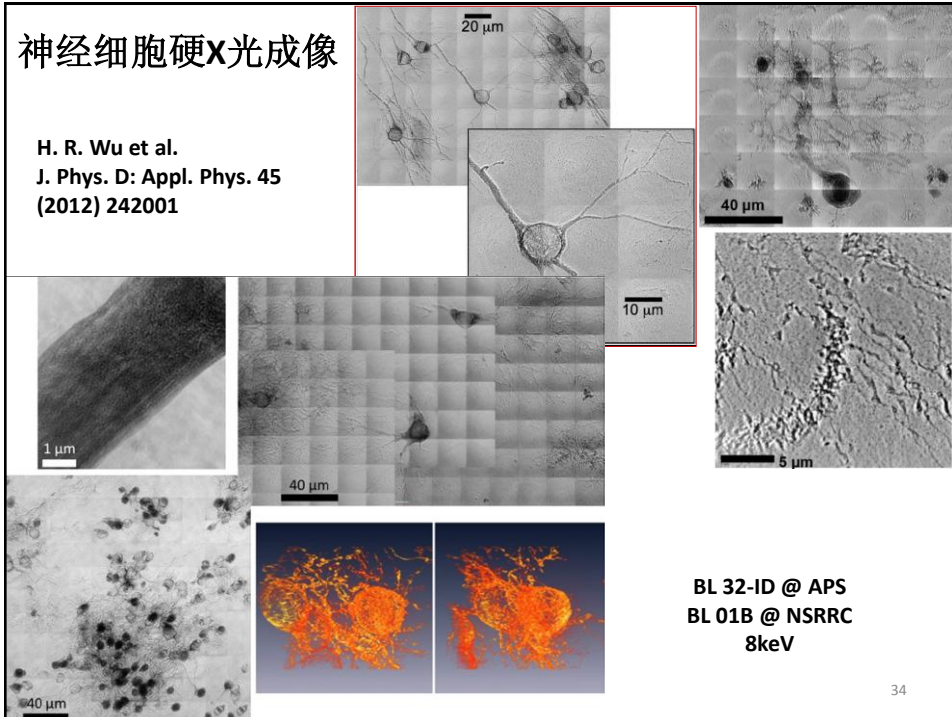


金属(铜)扩散的肺组织可见光(a)X光(b)成像

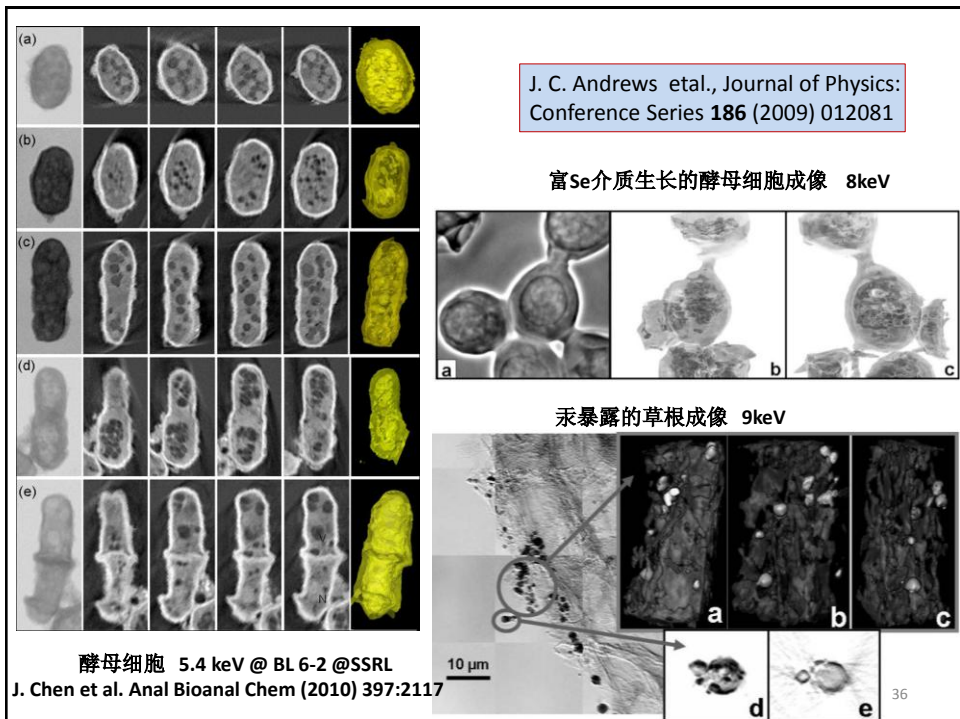
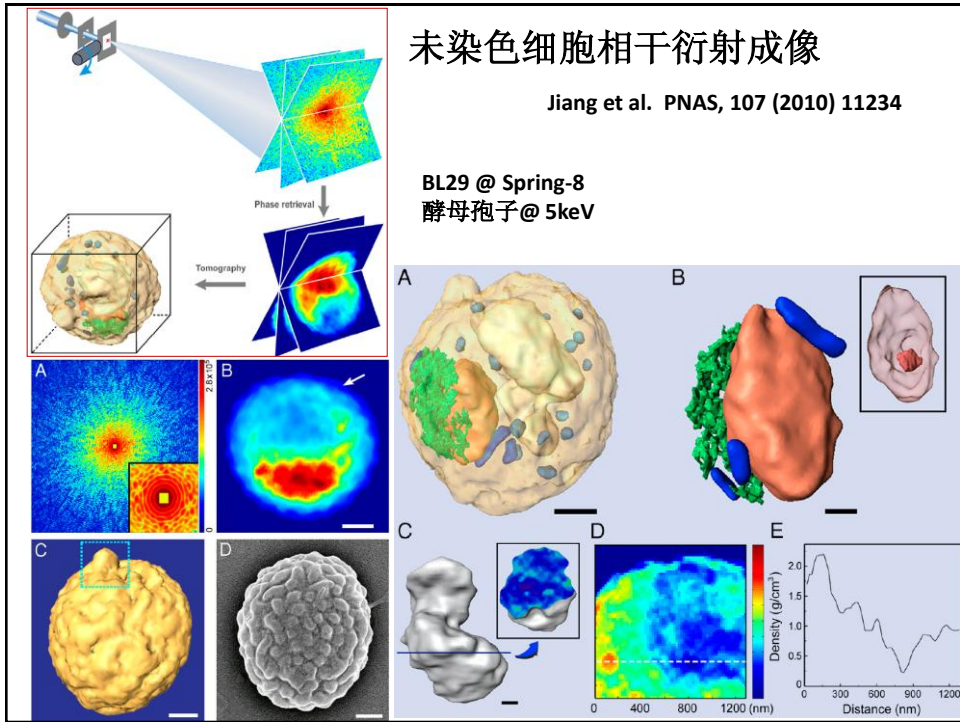
G.B. KIM et al.
 Microscopy Research And
 Technique 71:639-643 (2008)

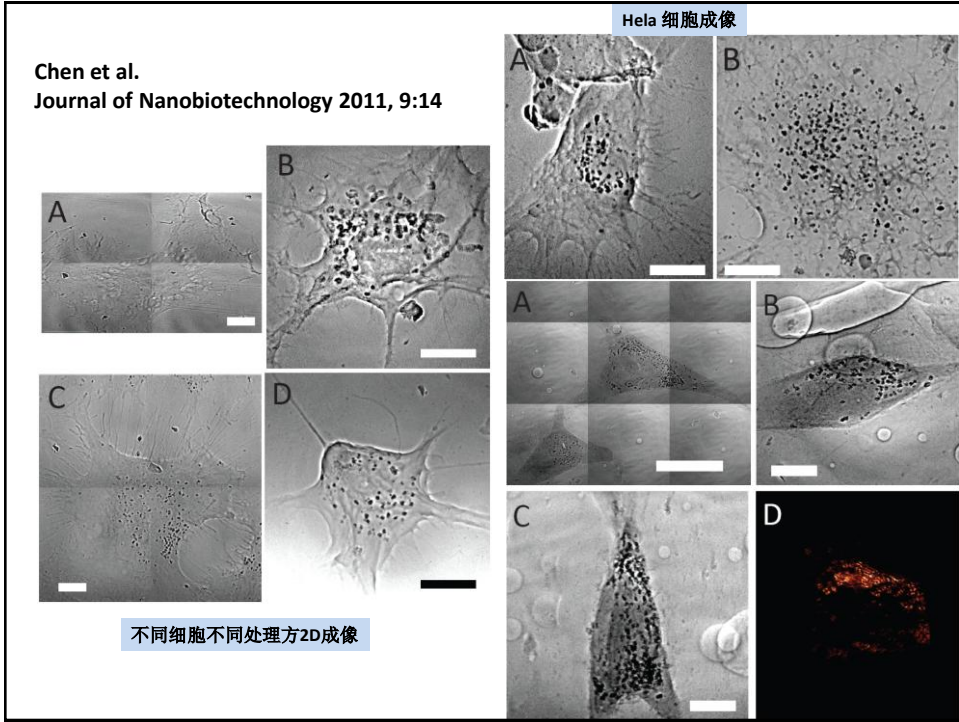
神经细胞硬X光成像

H. R. Wu et al.
 J. Phys. D: Appl. Phys. 45
 (2012) 242001



BL 32-ID @ APS
 BL 01B @ NSRRC
 8keV

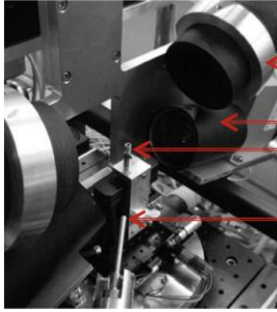




材料领域应用实例



加热条件下木材中微裂纹传播



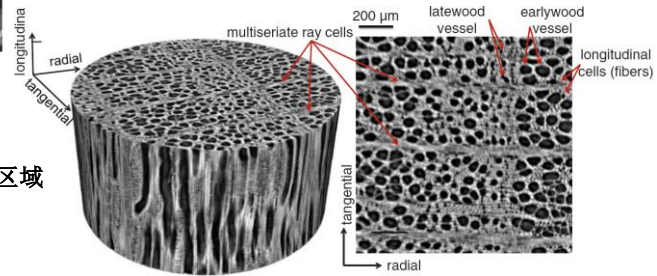
beam dump(s)
laser head(s)
sample holder
liquid nitrogen supply

激光加热装置

样品大小: $2 \times 2 \times 2 \text{mm}^3$

加热到 350°C 的过程中采集5套CT数据

3D重建图像的部分区域



Marjan Sedighi Gilani et al. Wood Sci Technol (2013) 47:889–896

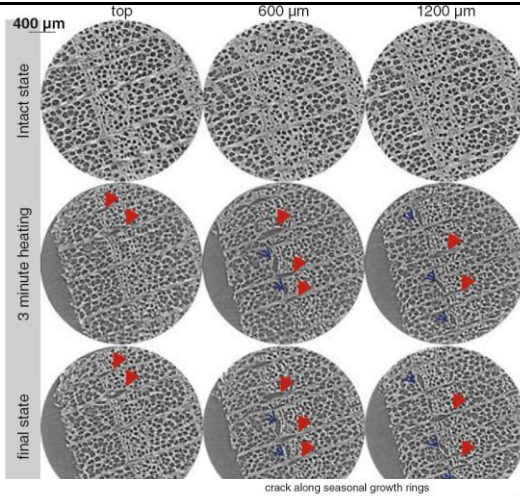


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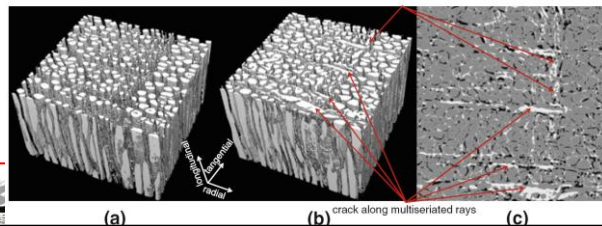


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裂纹形态及扩展



气孔、导管、裂纹3D分布

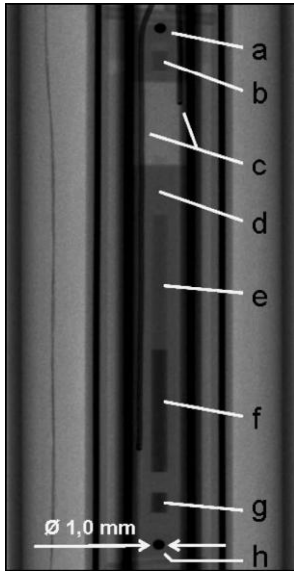


(a)

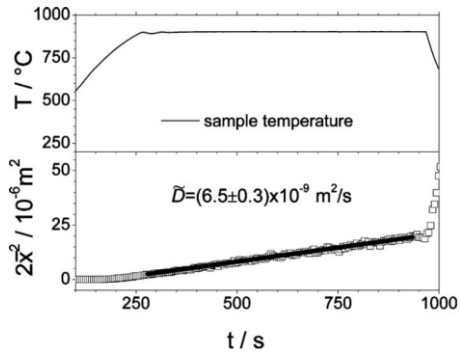
(b)

(c)

金属熔体中化学扩散成像



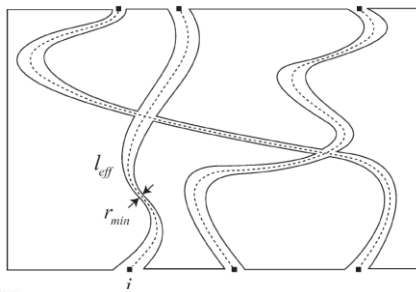
- a: 氧化锆圆柱
- b: Al
- c: 热电偶
- d: 石墨扩散
- e: Al
- f: AlNi10 at. %
- g: AlNi10 at. %



Al-AlNi10 at. %扩散温度-时间曲线 (900°C)及相应的渗透深度均方值

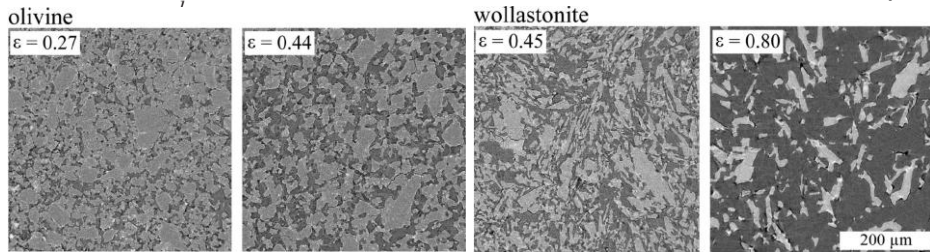
Griesche et al. Rev. Sci. Instrum. 81, 056104 2010

多孔陶瓷材料三维孔隙分布及离子导通性研究

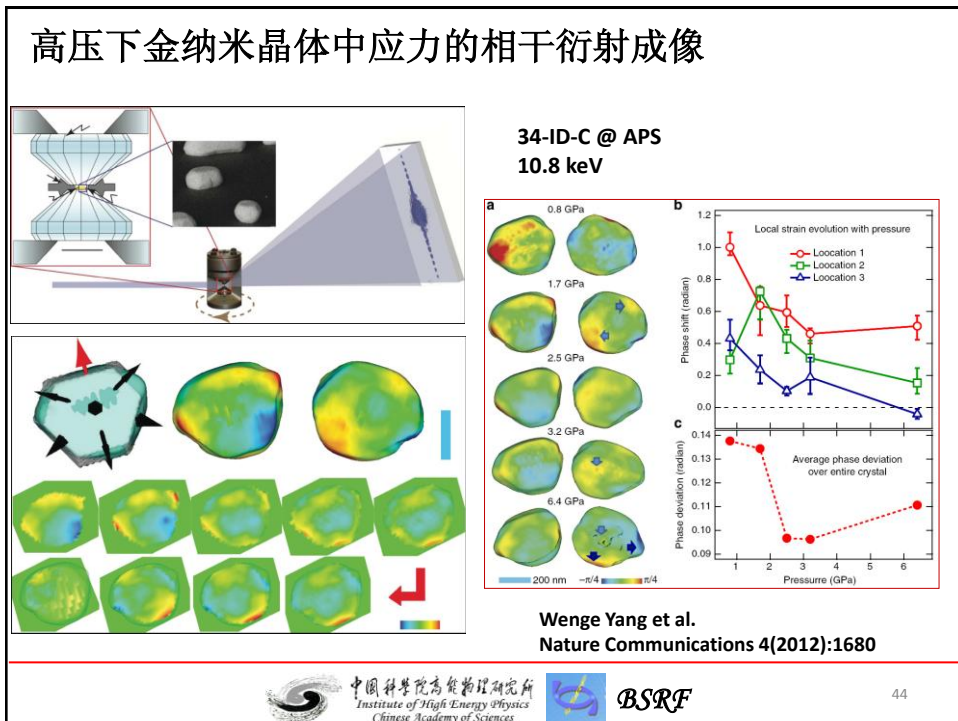
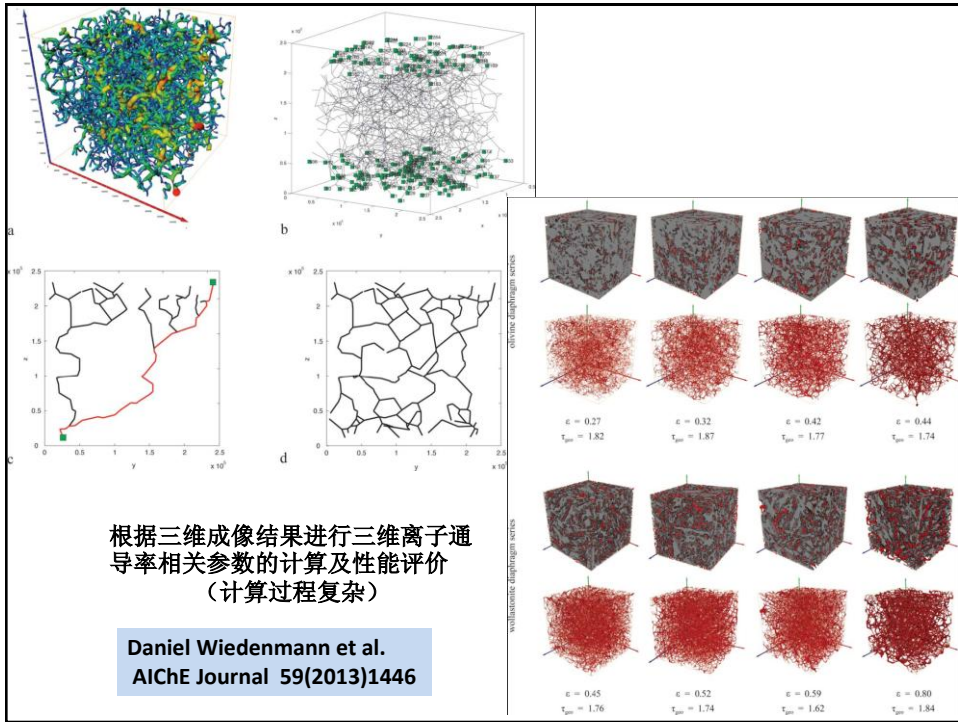


$$\tau = \frac{l_{eff}}{L}$$

重建的2D断层图 (15.5 keV, 1601p)

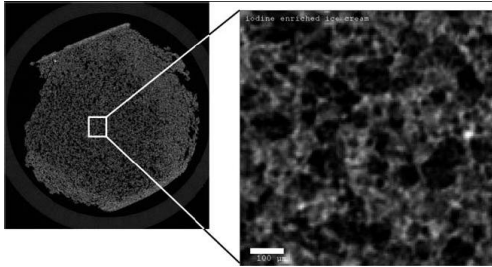


Daniel Wiedenmann et al. AIChE Journal 59(2013)1446



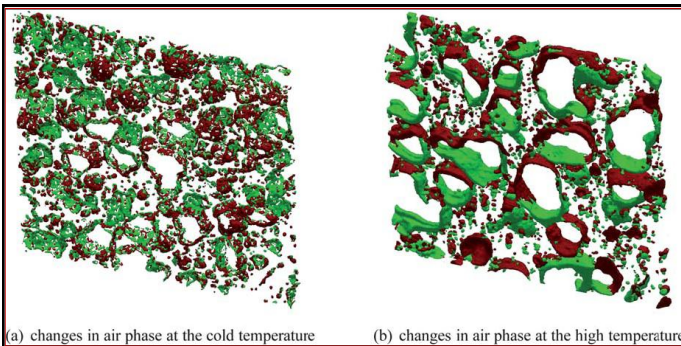
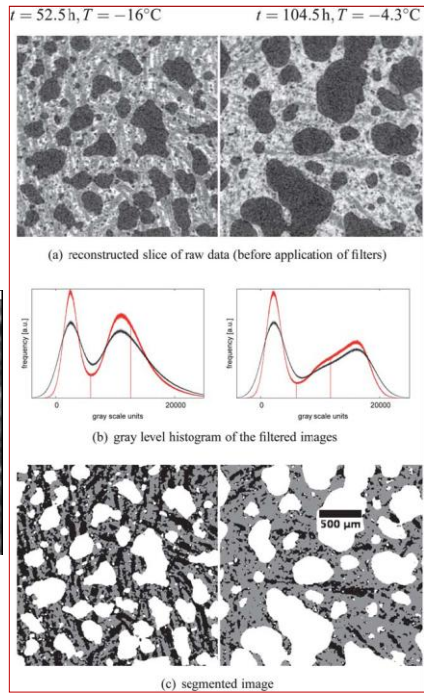
冰淇淋中微结构演变成像

实验设备: Scanco mCT40(微焦点光源)
 曝光时间: 900ms @ 75kV
 数据采集: 1000p/180°



重建的断层像

B. R. Pinzer et al. *Soft Matter*, 2012, 8, 4584

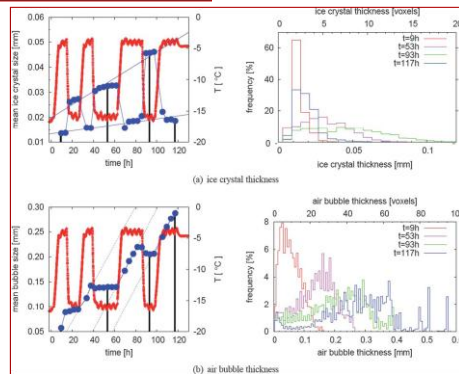


(a) changes in air phase at the cold temperature (b) changes in air phase at the high temperature

不同条件下
气相的结构演变

典型的结构尺寸随
温度变化的演变

B. R. Pinzer et al. *Soft Matter*, 2012, 8, 4584

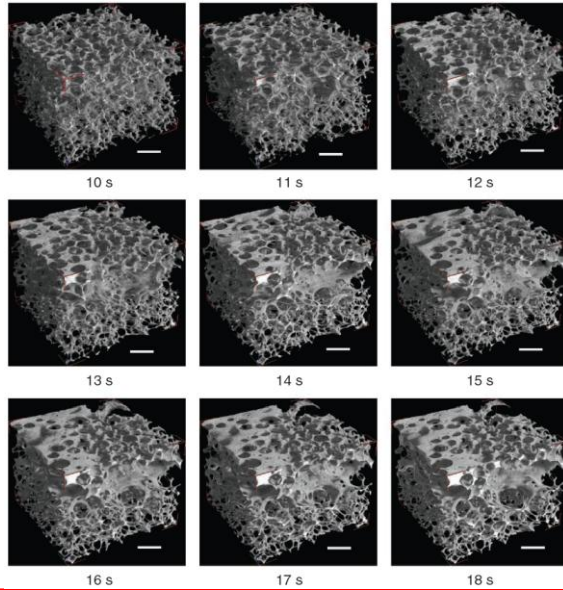


(b) air bubble thickness

玄武质泡状物中泡状结构演变成像

Nature Communications 3(2012):1135

高钾的玄武岩粉末制成的无定形样品
 激光加热~600°C (<30s), ~1200 °C
 t=1ms & 951 projections
 1 data set/S (共18套)
 像素尺寸: 2.98um×2.98um
 视场大小: 6.0mm ×6.0mm



玄武岩玻璃体中气泡的生长
 18套CT@18秒

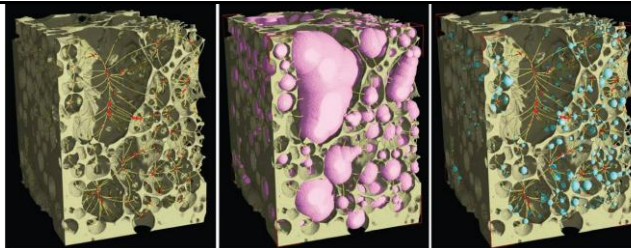


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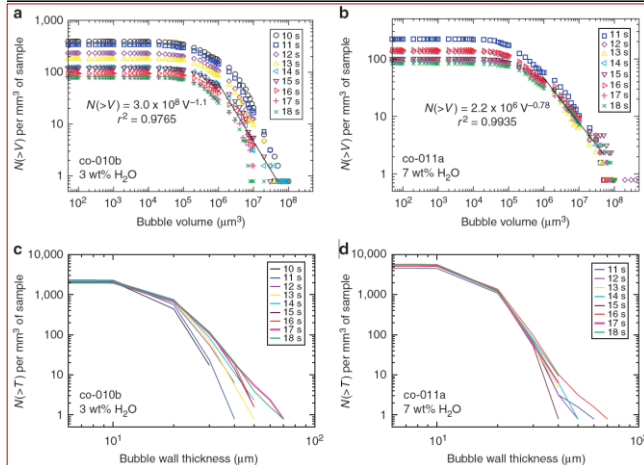


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骨架化方法测量气泡和孔隙尺寸实例



气泡生长过程中气泡总体积和壁厚演变

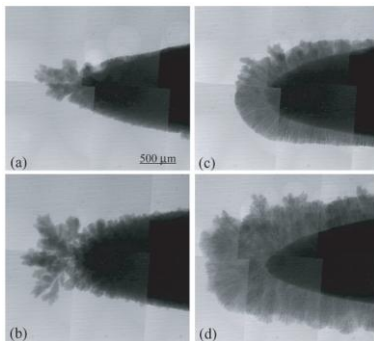


Don R. Baker et al.
 Nature Communications
 3(2012):1135

其它应用

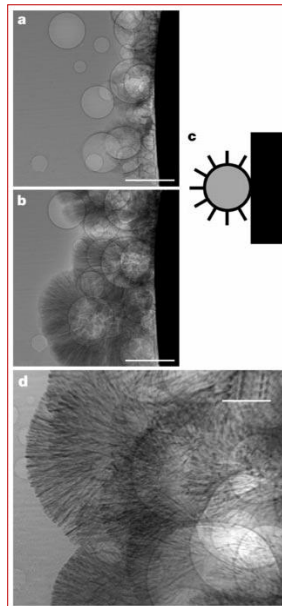
(化学、地学、环境等)

金属电镀过程成像



不同条件下
铜表面镀锌过程结构演变

Y Hwu et al.
J. Phys. D35 (2002) R105,

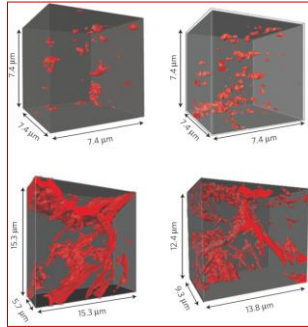


铜表面镀锌过程中
锌在氢气泡上生长

W. L. Tsai et al.
Nature
417(2002)139

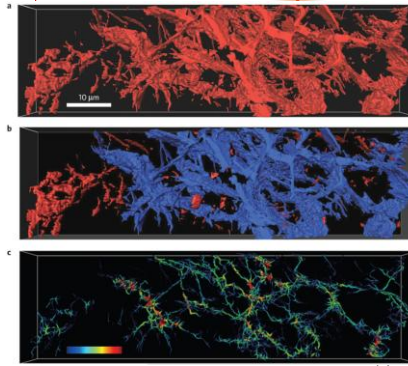
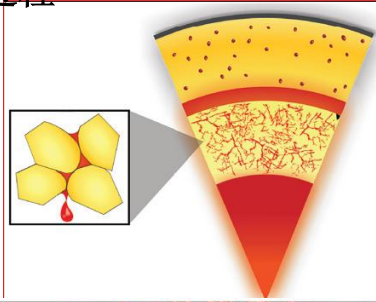
下地幔条件下金属铁网络的生成过程

高温高压模拟地球下地幔条件
TXM成像@SSRL

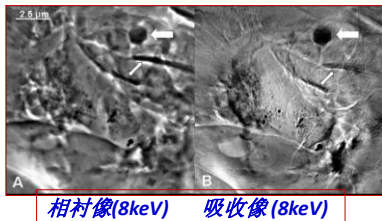
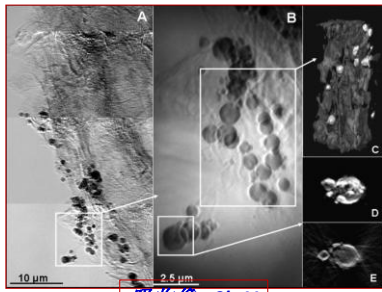


硅酸盐钙钛矿中铁熔体合金的三维分布
25GPa(2300K)、39GPa(2800k)、
52GPa(3100K)、64GPa(3300K)

Crystal Y. Shi et al. Nature Geoscience
(2013) doi:10.1038/ngeo1956

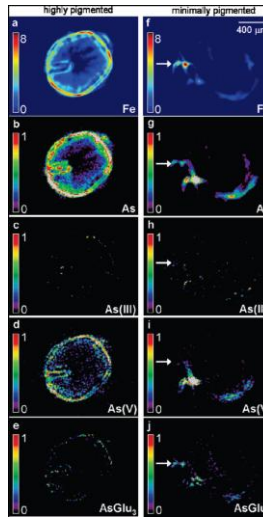


绳草的根部富集汞成像



Environ. Sci. Technol. 2009, 43, 7397-7402

水稻根部砷的生成、传输



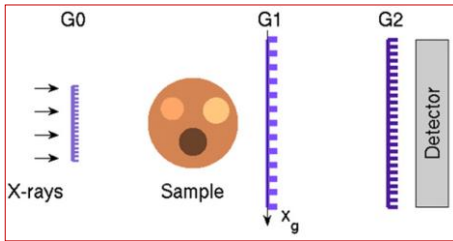
荧光/μXANES/显微成像
水稻根部覆盖的铁被认为是砷向上传输的阻碍

结果显示铁并不直接组织砷的吸收和传输，而是起到清理砷的作用



Environ. Sci. Technol. 2010, 44, 8108-8113

食品中有机异质体的检测（散射信息光栅成像）

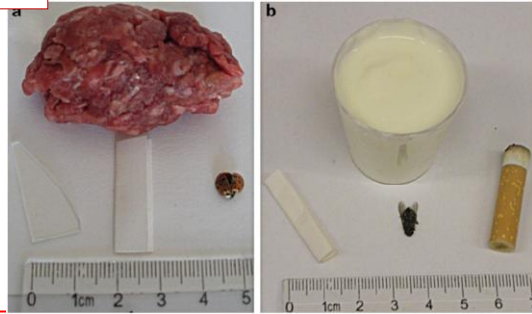


实验室光源光栅成像
铜靶 @ 40kV & 150mA
光源点尺寸: 1mm×1mm

样品1: 碎牛肉、玻璃、4层纸张、单层纸包裹的瓢虫

样品2: 塑料杯、发酵的奶酪、8层纸张、苍蝇、烟头

M.S. Nielsen et al.
Food Control 30 (2013) 531

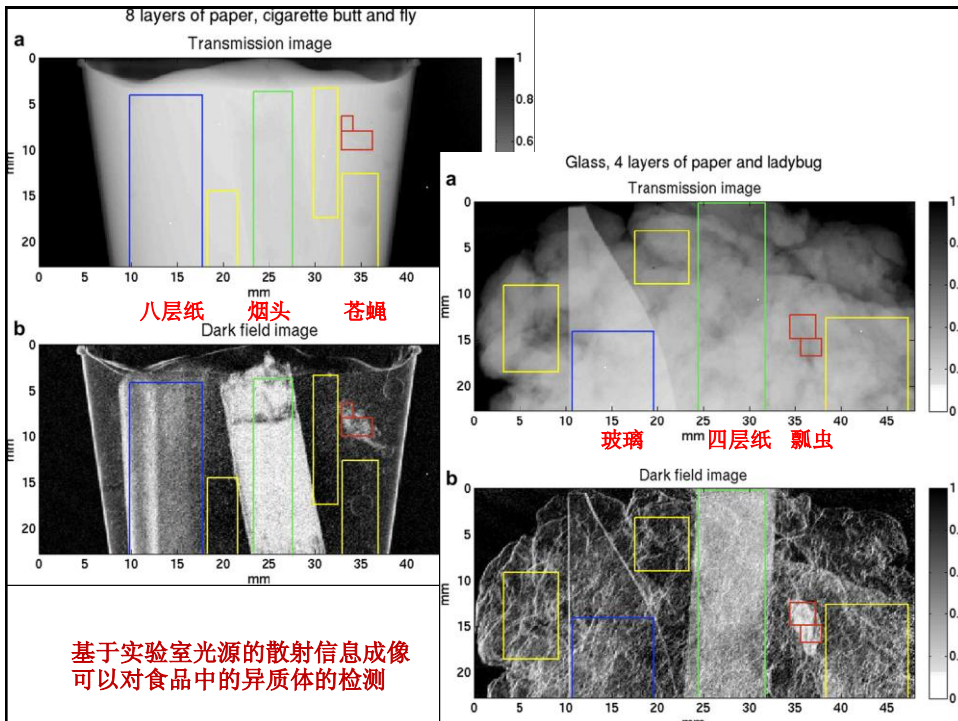


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小 结

- 发现好的成像科学问题
- 获取好的成像实验结果
- 把实验结果更好地展示出来



谢谢大家！

