

如何选择合适的AFM探针

“成功的AFM成像始于探针”

主讲人：F. Ted Limpoco，化学博士
牛津仪器Asylum Research应用科学家

AFM探针网络讲座 – 概要

OXFORD
INSTRUMENTS

The Business of Science[®]

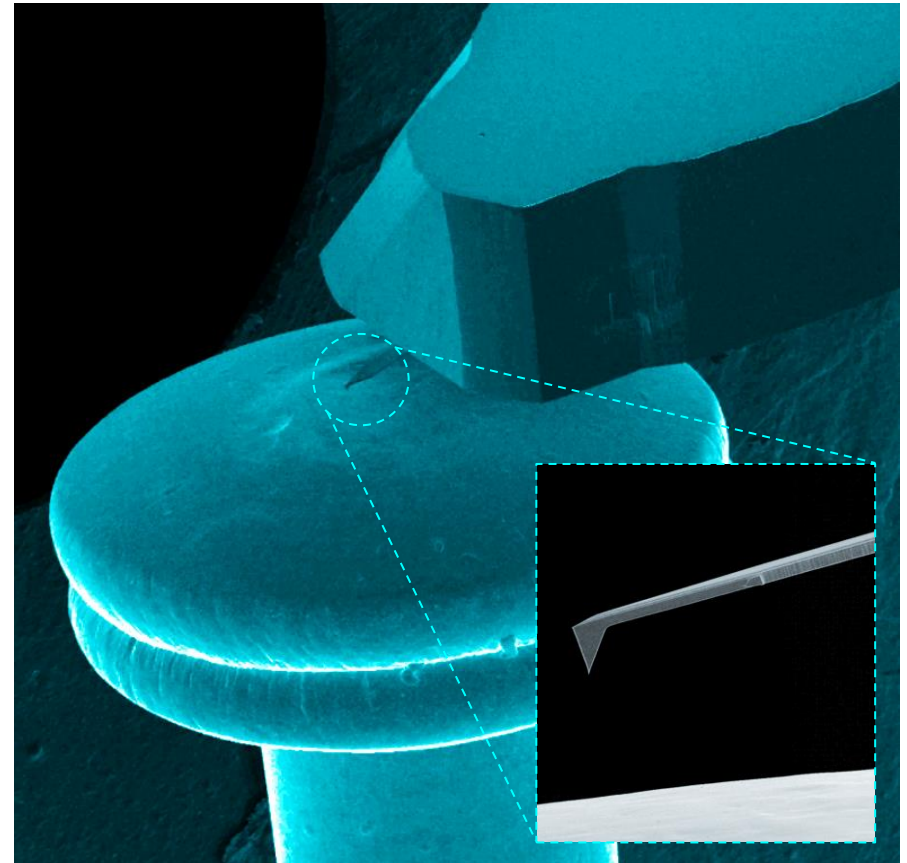
引言

探针的基本知识

探针的关键参数

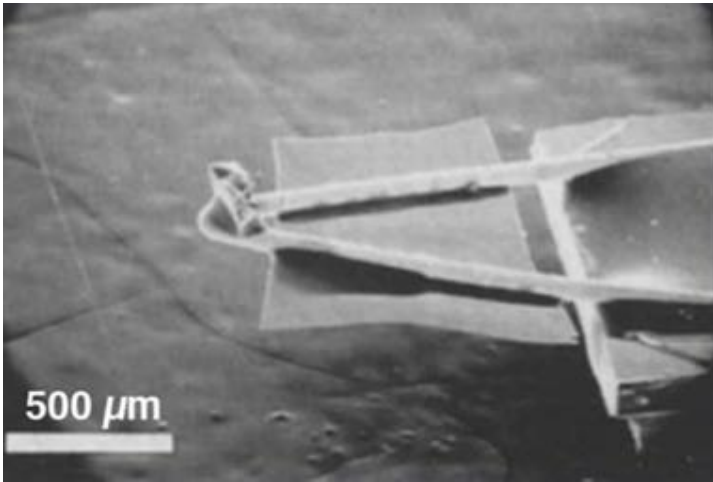
探针的选择指南

应用实例



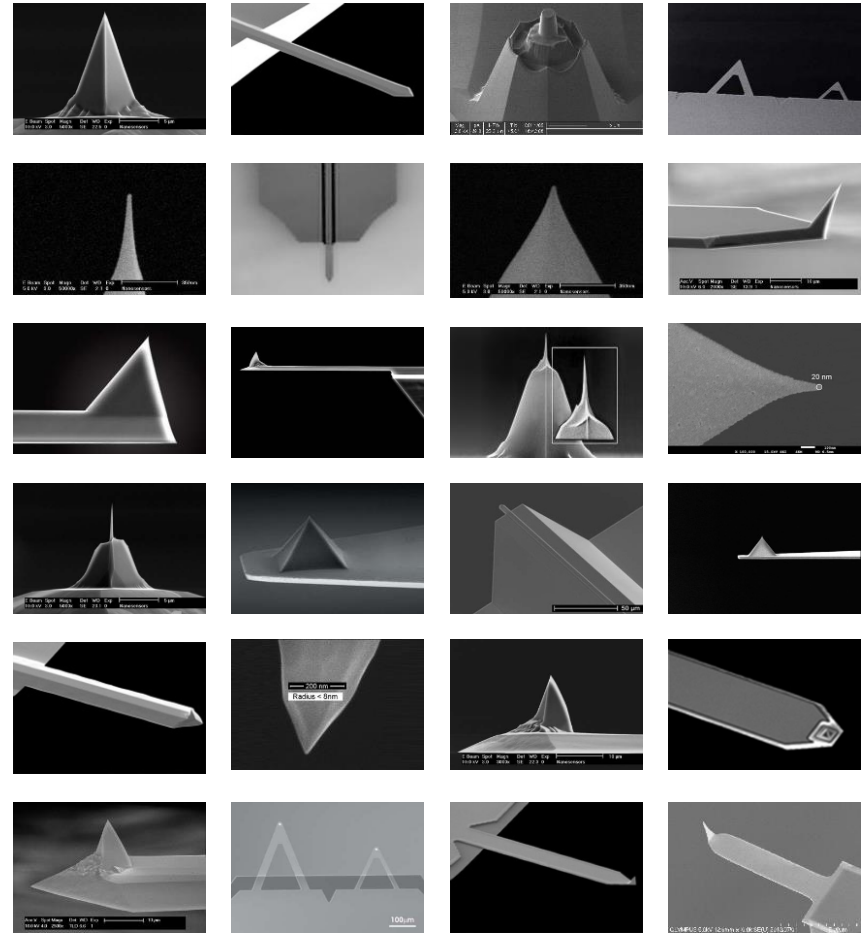
引言:

那么多种类的探针，如何选择.....



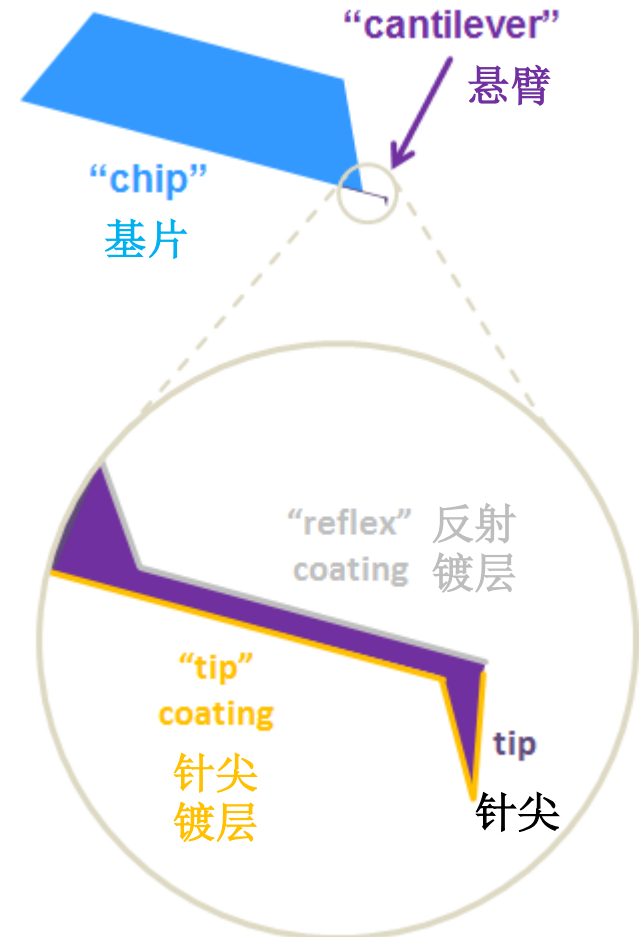
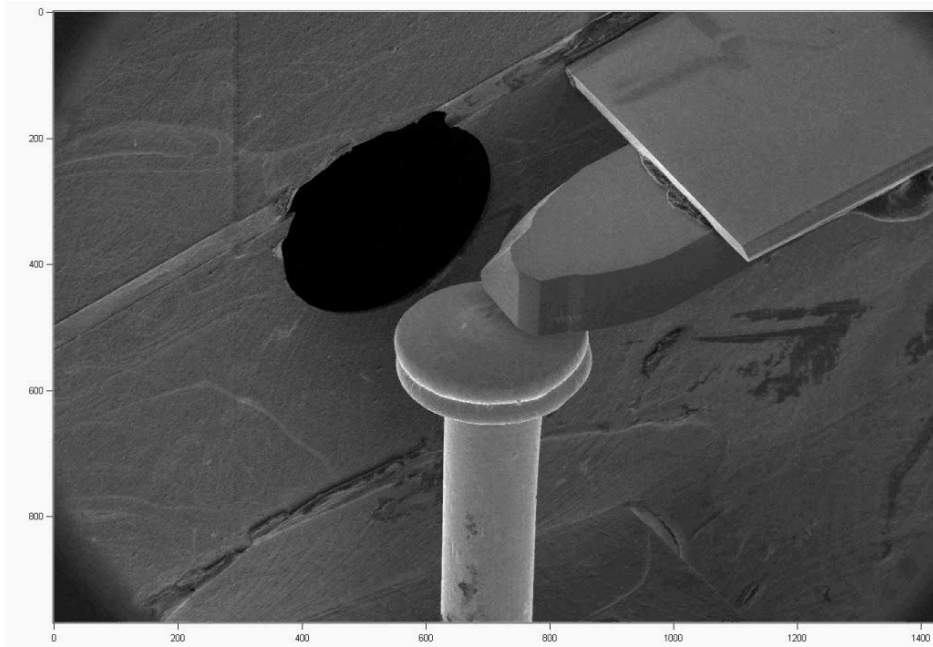
最初的AFM探针 (1986-1990)

- 细丝弯折后粘到基片上，作为悬臂
- 玻璃镀金属，作为反射面
- 钻石碎片粘到悬臂末端，作为针尖



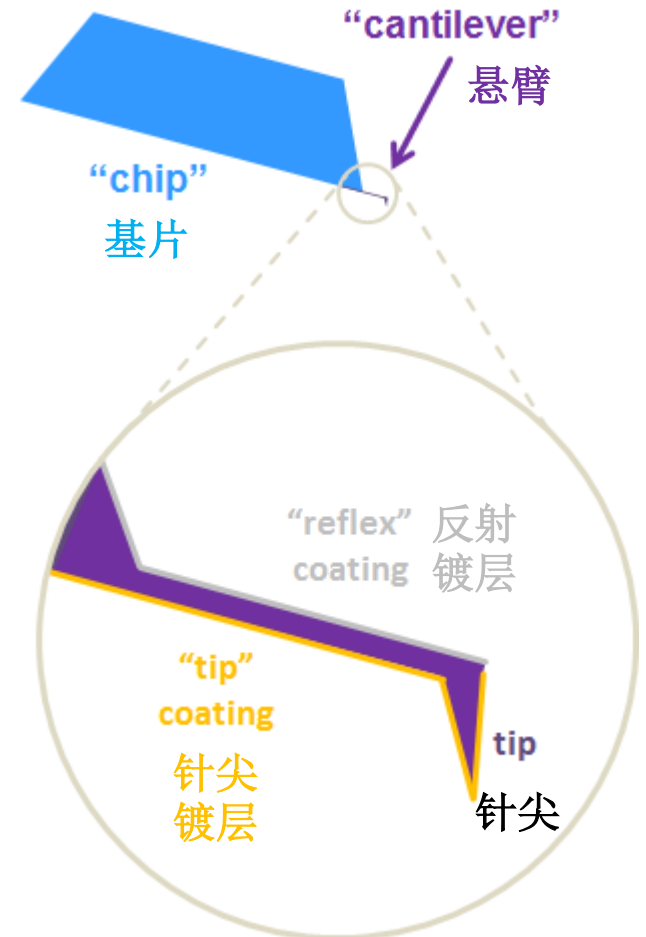
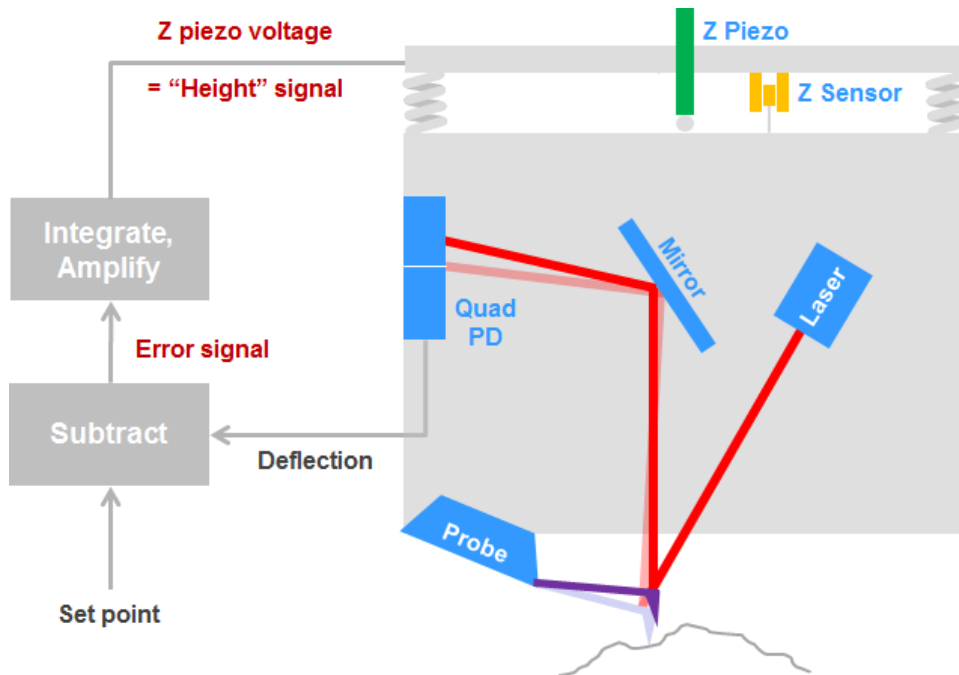
什么是AFM探针?

- 探针可以视为一种力传感器，用来“感知”样品
- 通常由硅或者氮化硅加工而成
 - **硅 (silicon)**：针尖较尖锐，悬臂较硬，共振频率较高
 - **氮化硅 (silicon nitride)**：针尖较耐磨，悬臂较软
- 针尖会随着使用而变钝，或者被污染
 - 通常不值得花时间清洁，可以视为消耗品



什么是AFM探针?

- 探针可以视为一种力传感器，用来“感知”样品
- 通常由硅或者氮化硅加工而成
 - 硅 (**silicon**)：针尖较尖锐，悬臂较硬，共振频率较高
 - 氮化硅 (**silicon nitride**)：针尖较耐磨，悬臂较软
- 针尖会随着使用而变钝，或者被污染
 - 通常不值得花时间清洁，可以视为消耗品



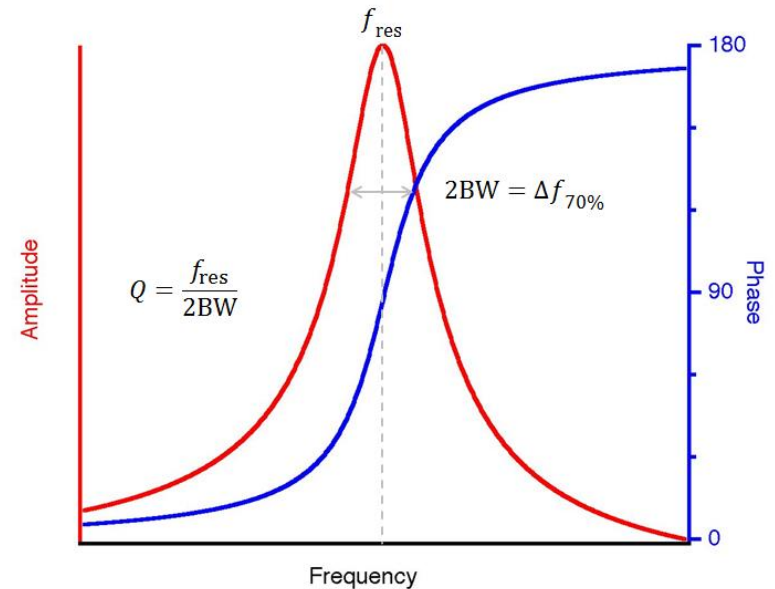
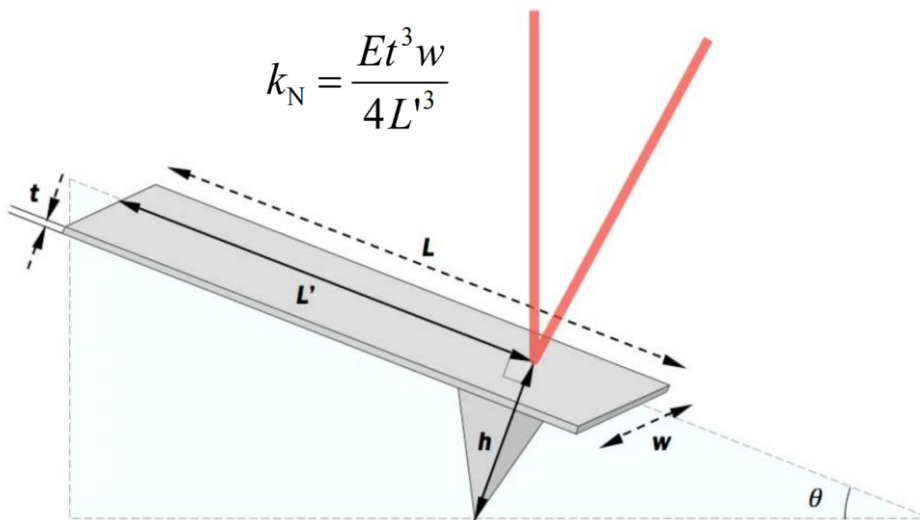
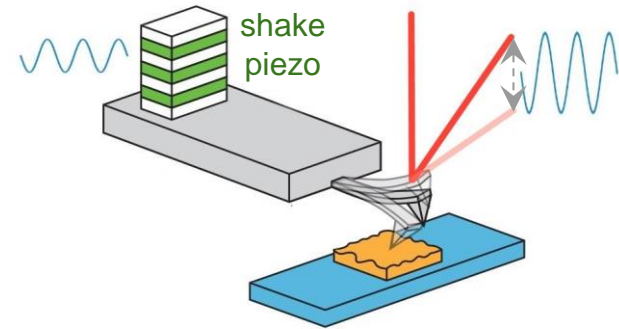
探针的基本知识:

探针的关键参数

OXFORD
INSTRUMENTS

The Business of Science®

弹性系数 - k	扫描力
针尖锐度 - r	横向分辨率
共振频率 - f	扫描速度
品质因子 - Q	扫描速度



AFM探针网络讲座 – 概要

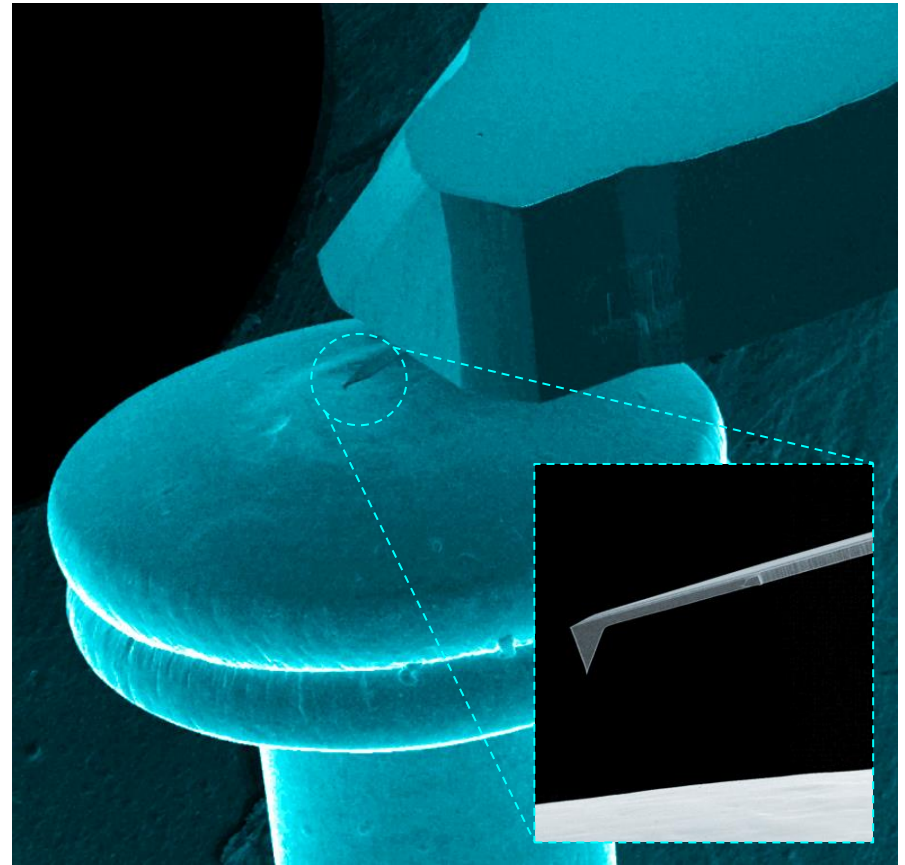
引言

探针的基本知识

探针的关键参数

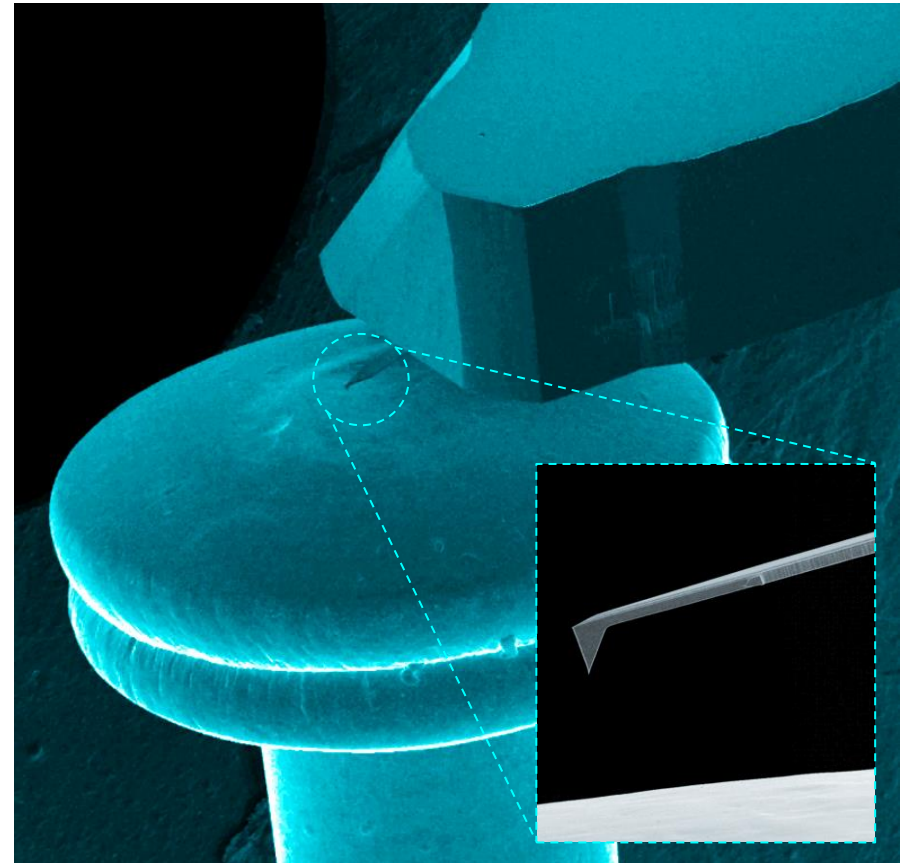
探针的选择指南

应用实例



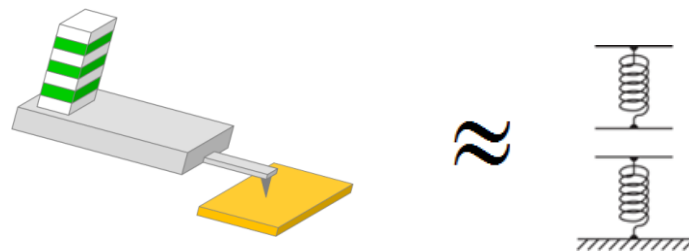
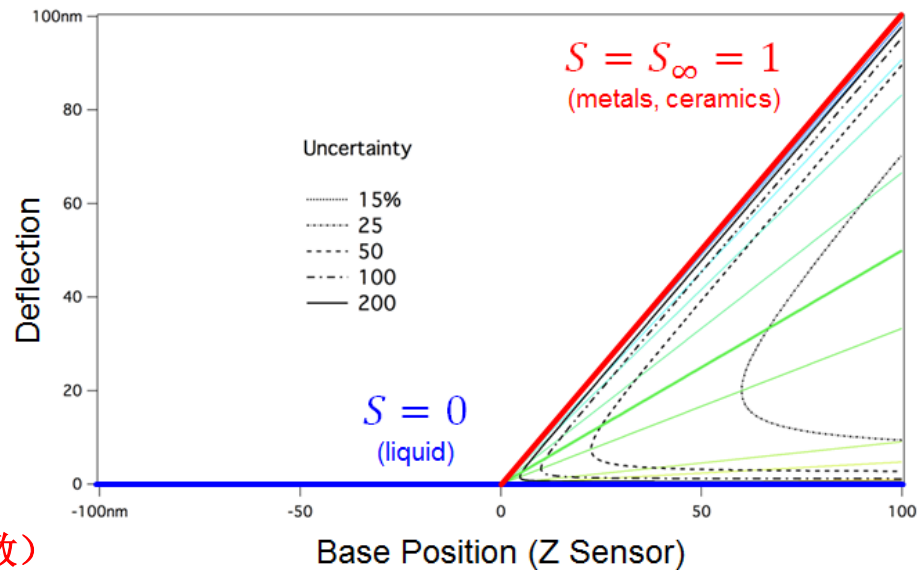
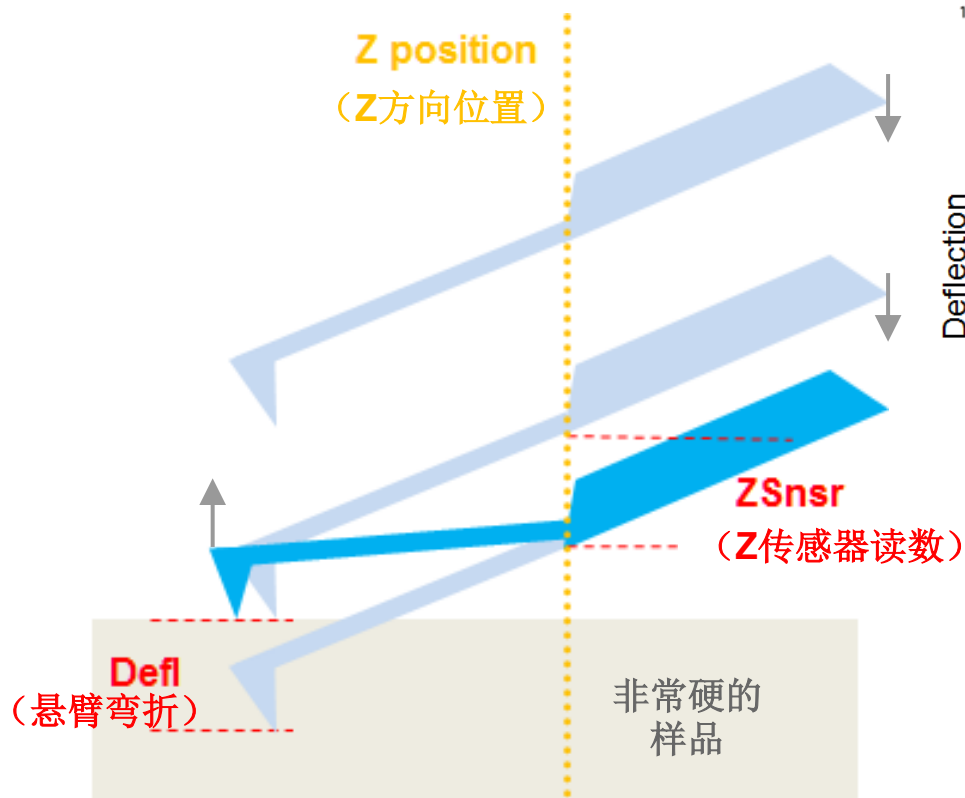
探针的关键参数

- 弹性系数 (k)
- 针尖锐度 (针尖曲率半径 r)
- 共振频率 (f)
- 品质因子 (Q 因子)



探针参数:

弹性系数 (spring constant)



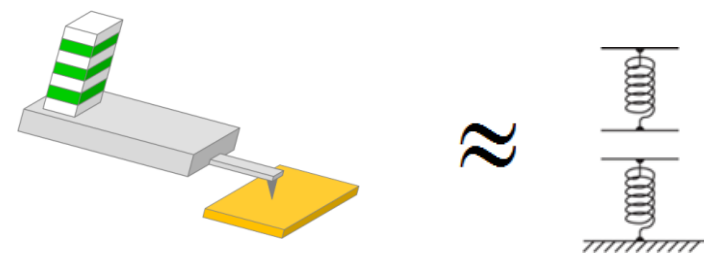
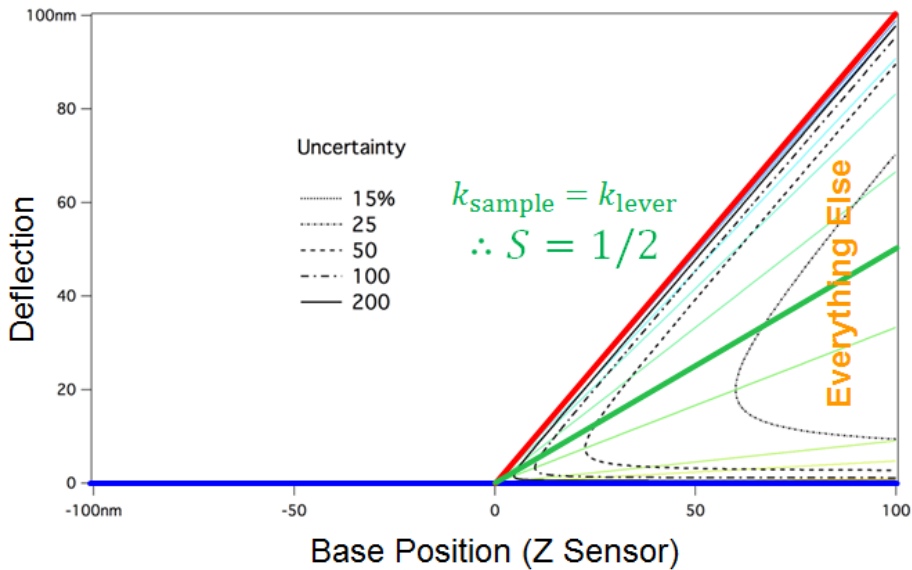
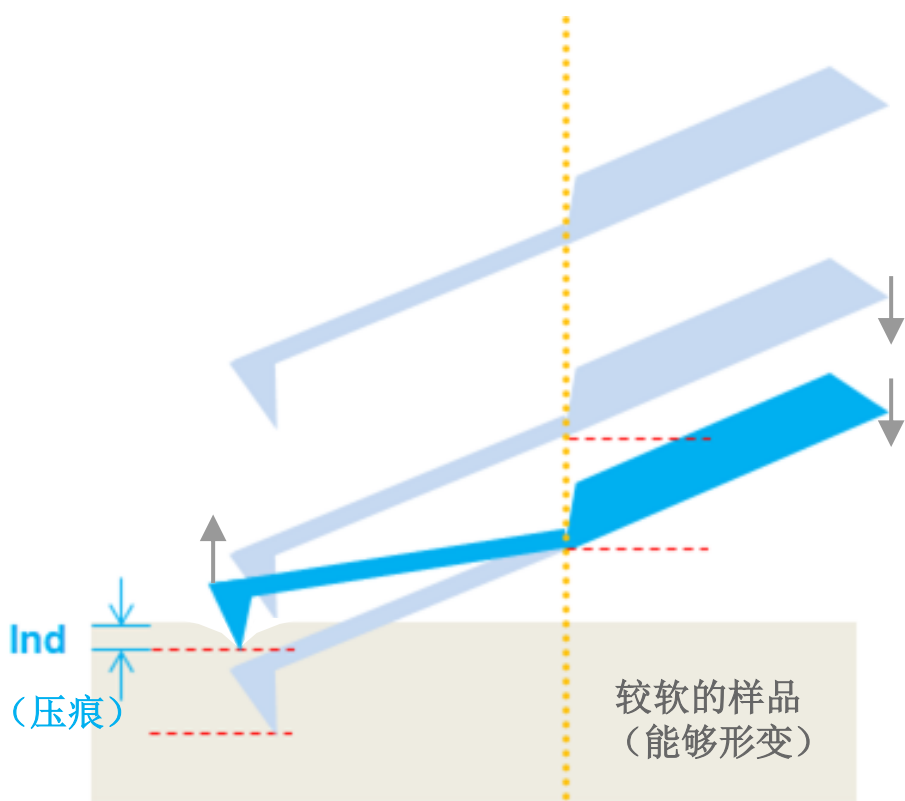
如果 $k_{\text{样品}} \gg k_{\text{悬臂}}$, 探针的向下移动会导致悬臂同等幅度的弯折

如果 $k_{\text{样品}} \ll k_{\text{悬臂}}$, 针尖会穿透样品, 而悬臂不会有明显的弯折

$$k_{\text{sample}} = k_{\text{lever}} \left(\frac{S_{\text{sample}}}{S_{\infty} - S_{\text{lever}}} \right)$$

探针参数:

弹性系数 (spring constant)



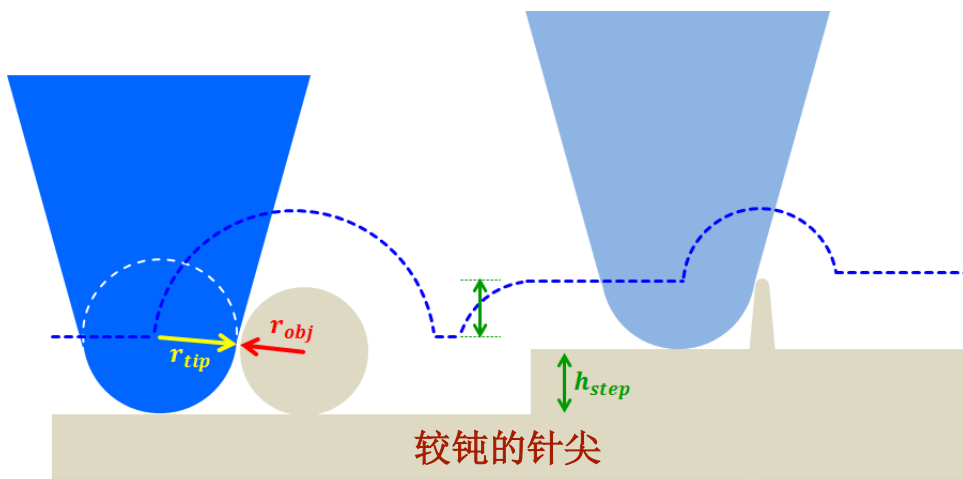
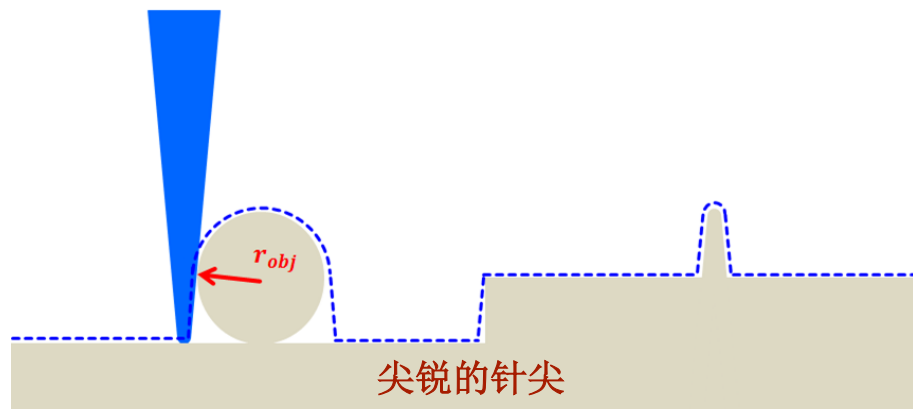
如果要用AFM测量样品的刚度，在样品和探针接触时，需要保证样品产生一定的形变（纳米压痕），而探针产生一定程度的弯折（用于测量力的大小）

压痕深度 = Z方向向下的移动 - 探针向上的弯折

$$k_{\text{sample}} = k_{\text{lever}} \left(\frac{S_{\text{sample}}}{S_{\infty} - S_{\text{lever}}} \right)$$

探针参数:

针尖曲率半径 (tip radius)



AFM图像反映了样品形貌和针尖形状的相互作用 (convolution)

- 针尖的曲率半径决定了AFM的**横向分辨率**
- 若使用较钝的针尖（针尖的曲率半径和样品的形貌尺寸处于同一个数量级），AFM图像中的样品形貌看上去会比实际的大
- 若使用较钝的针尖扫描尖锐的形貌，AFM图像实际上显示的是针尖的形状
- **纵向分辨率**不会受到针尖曲率半径的影响，而是取决于Z传感器和Z压电体的噪声
- AFM不能观察到悬垂的形貌
- 若针尖很尖锐细长，那么针尖的侧面可能会和样品形貌接触

探针参数:

针尖曲率半径 (tip radius)

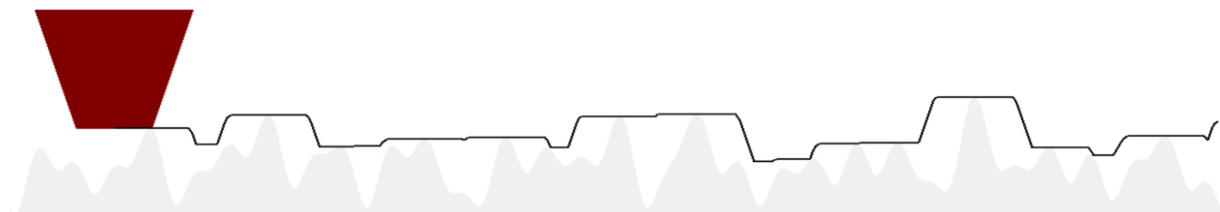
细金字塔形
("超尖锐针尖")



宽金字塔形
("典型针尖")



截顶金字塔形
("破损的针尖")



细抛物面形
("典型针尖")

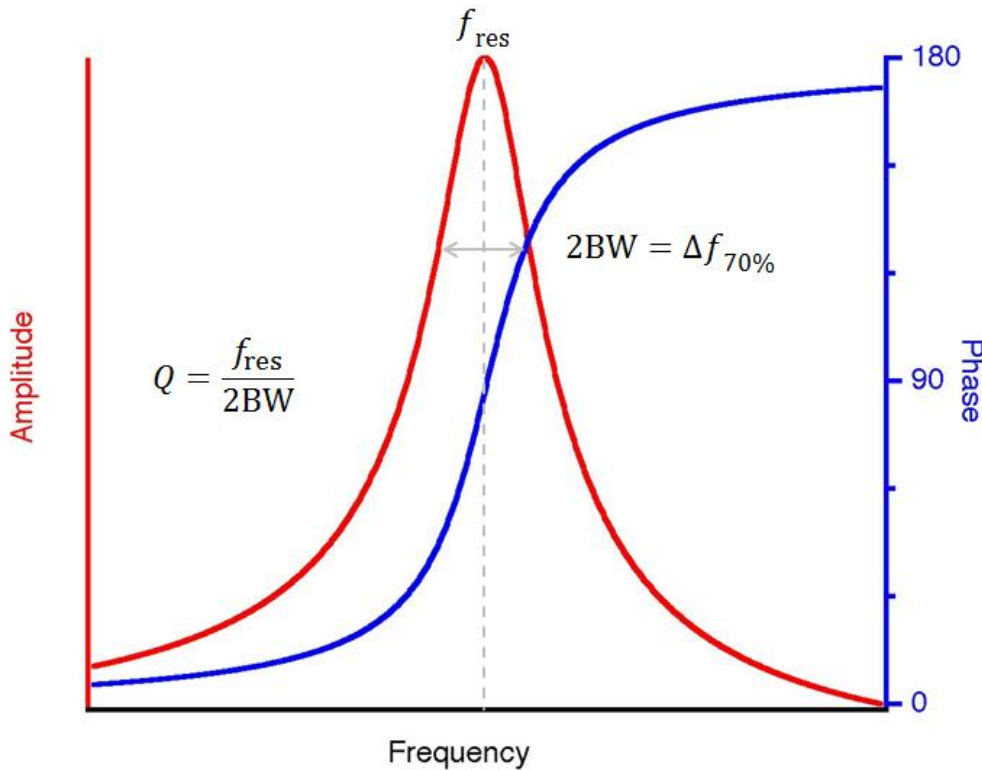


宽抛物面形
("磨圆了的钝针尖")

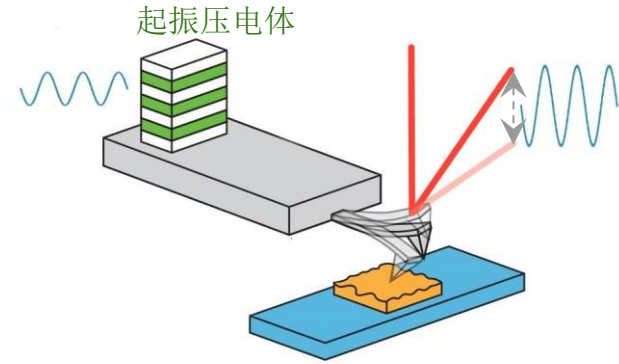


探针参数:

共振频率和Q因子 (freq. and Q factor)



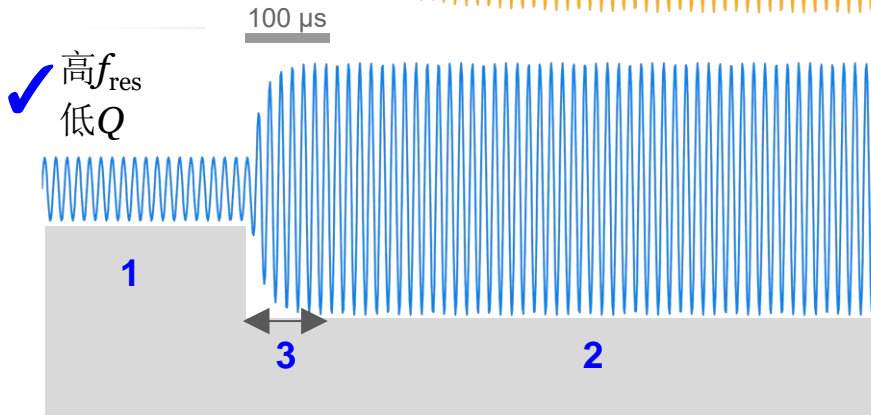
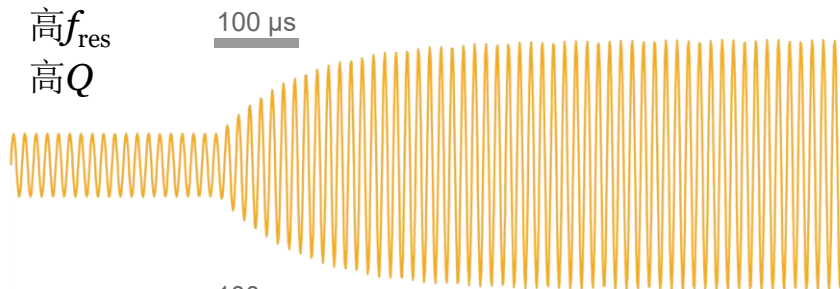
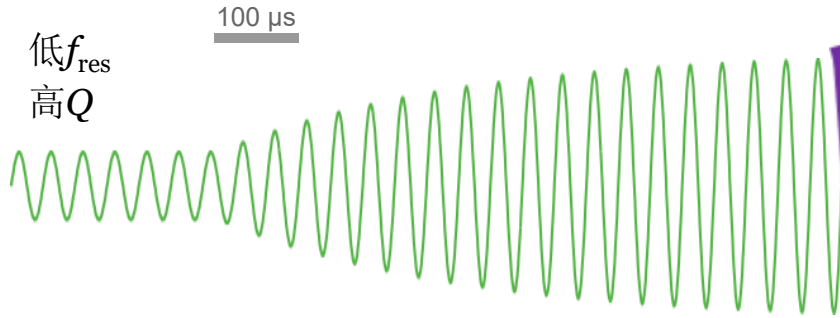
探针悬臂的振动曲线



探针悬臂的动态特性:

- 在AC电压的作用下，起振压电体开始振动，并带动探针悬臂的振动
- 探针的振动频谱近似于一个简谐振子
- 探针的振动特性可以由两个参数来描述：
 - 共振频率 f_{res}
 - Q因子
- 以上两个参数决定了探针的振动带宽 **BW**，具体而言决定了：
 - 探针的响应时间 τ
 - 扫描速度

共振频率和Q因子 (freq. and Q factor)



1. 首先, 探针悬臂在一块平面上振动, 处于动态平衡的状态
2. 然后, 探针需到了一个向下的台阶 (扰动), 振幅因此**变大**
3. **响应时间 τ** : 受到扰动后, 探针振幅达到新的平衡振幅的70%所需的时间

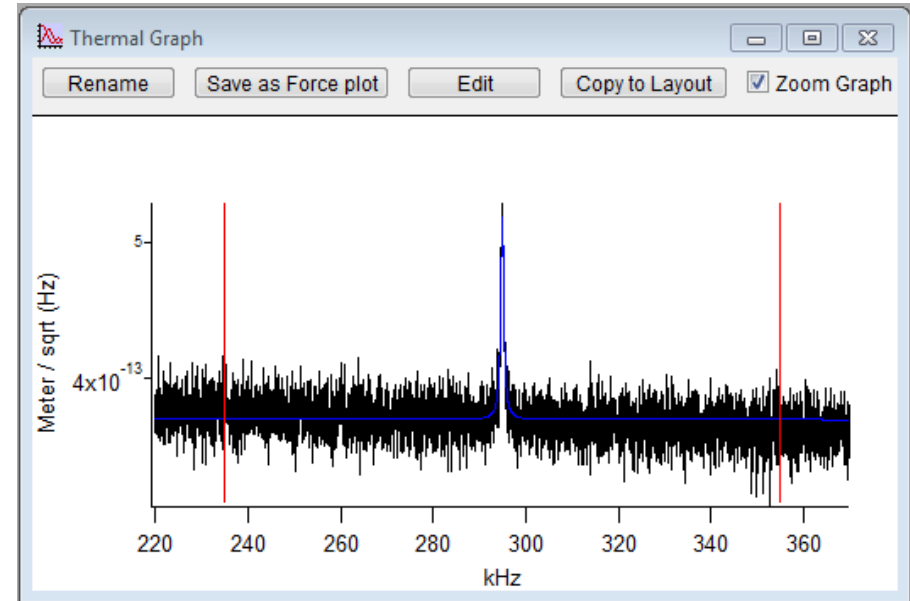
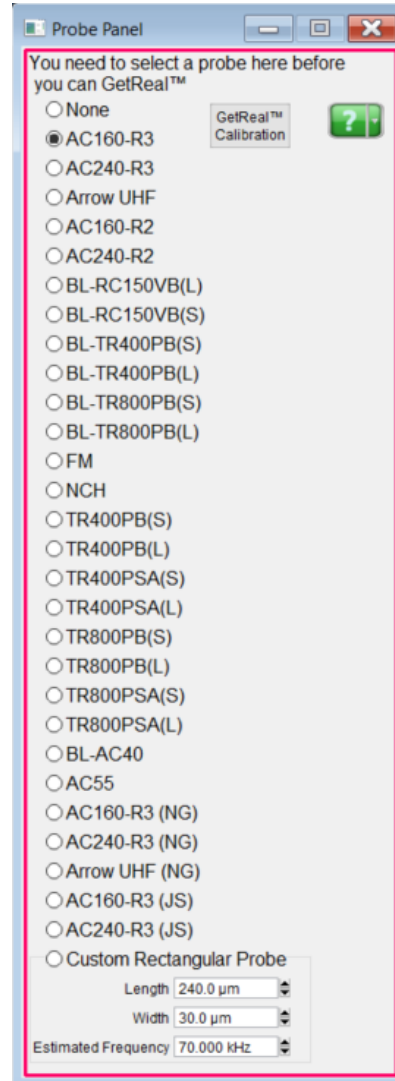
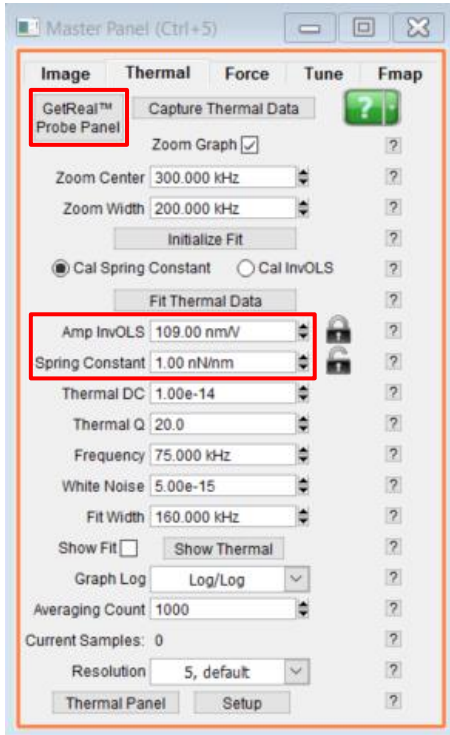
$$BW = \frac{f_{res}}{2Q} \quad \tau = \frac{1}{2\pi BW} = \frac{Q}{\pi f_{res}}$$

- **Q因子**: 达到新的平衡状态所需的振动周期数
- **共振频率 f_{res}** : 达到新的平衡状态的速率

对于快扫描:

- 若共振频率不变, **降低**探针的**Q因子**意味着达到平衡状态所需的振动周期数变少
- 若Q因子不变, **提高**探针的**共振频率**意味着可以更快地达到平衡状态

GetReal™ 校准



无需接触样品就可以对探针进行原位校准:

- **S**: 光杠杆敏感度
- **k**: 弹性系数

$$k = k_{ref} \left(\frac{Q}{Q_{ref}} \right) \left(\frac{f}{f_{ref}} \right)^{1.3}$$

$$\frac{1}{2} k_B T = \frac{1}{2} k \langle (SA)^2 \rangle$$

Q, f, A 参数可以从探针的热噪声频谱中获得

Reference 参数由工厂的激光多普勒测振仪测得

AFM探针网络讲座 – 概要

OXFORD
INSTRUMENTS

The Business of Science®

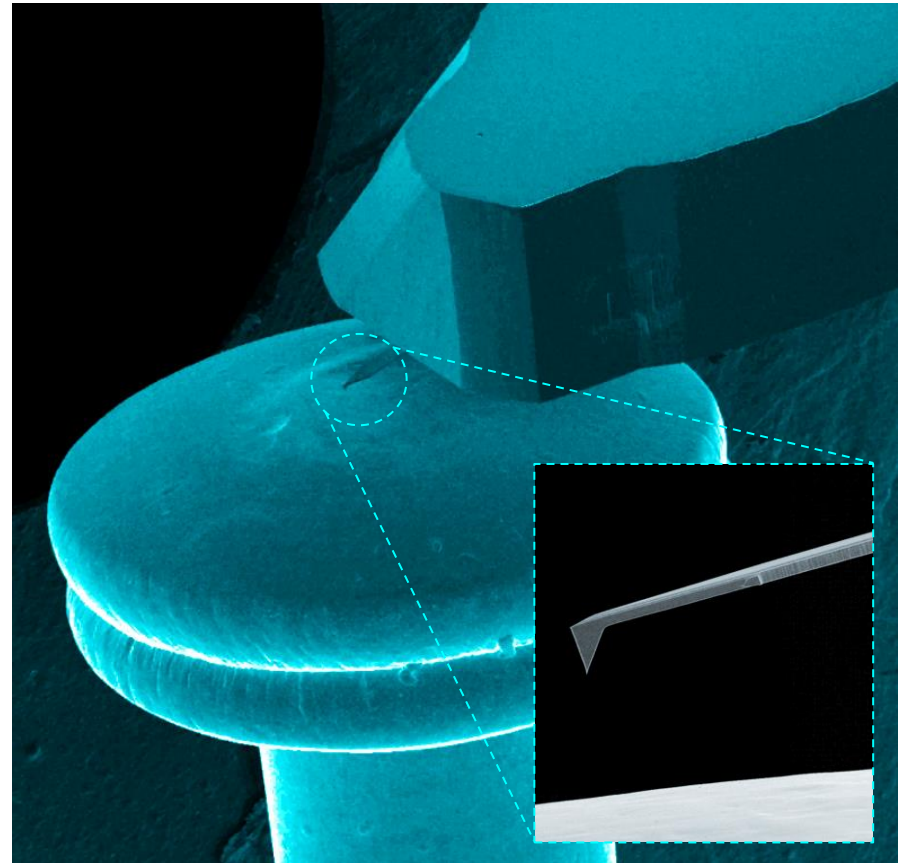
引言

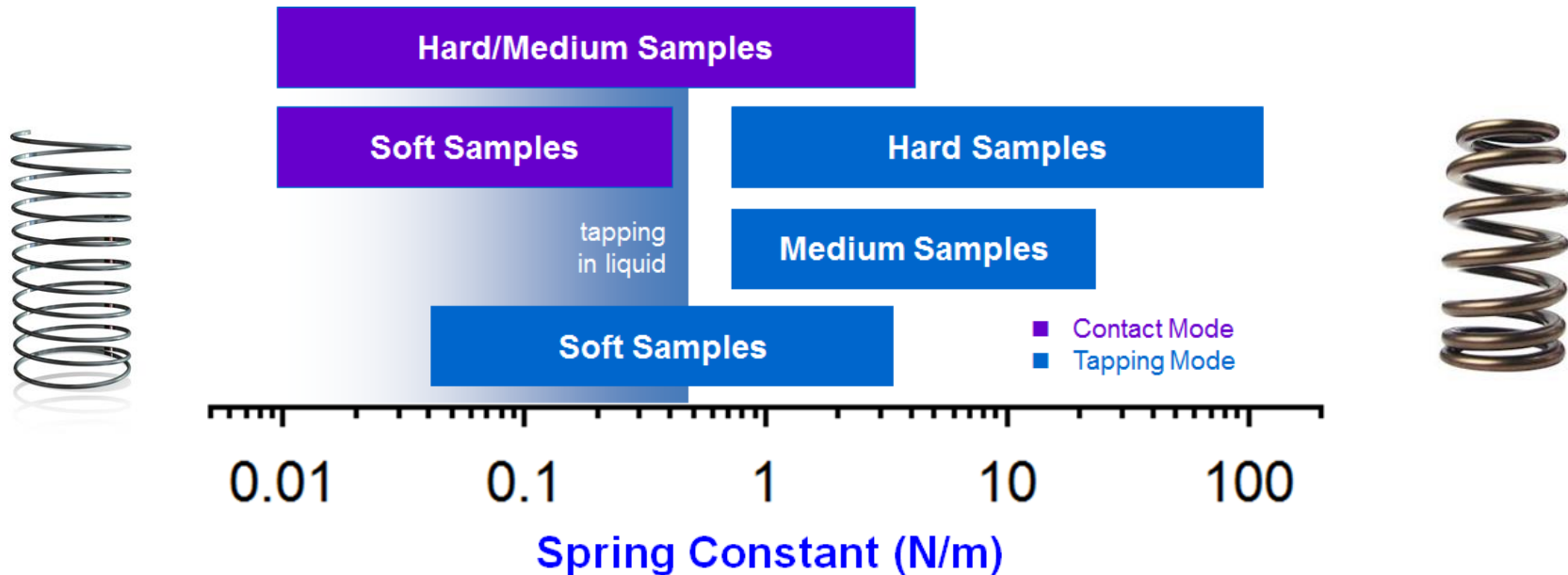
探针的基本知识

探针的关键参数

探针的选择指南

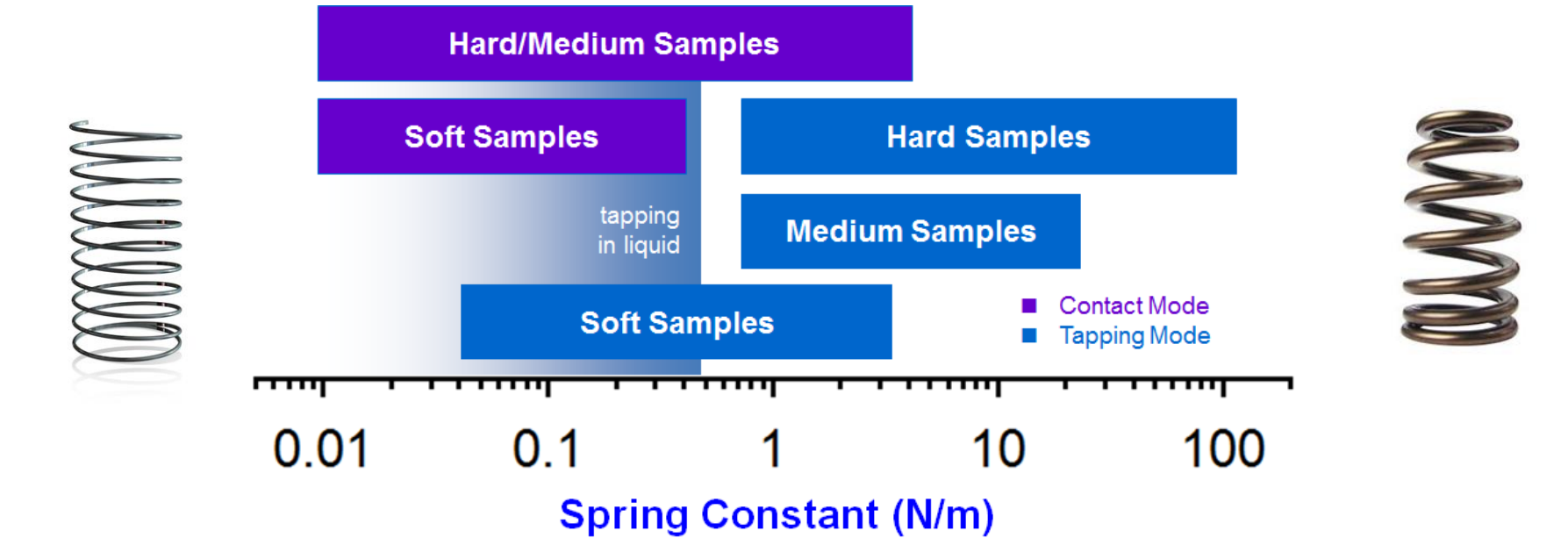
应用实例





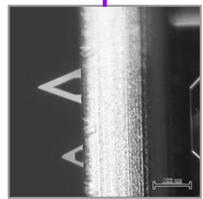
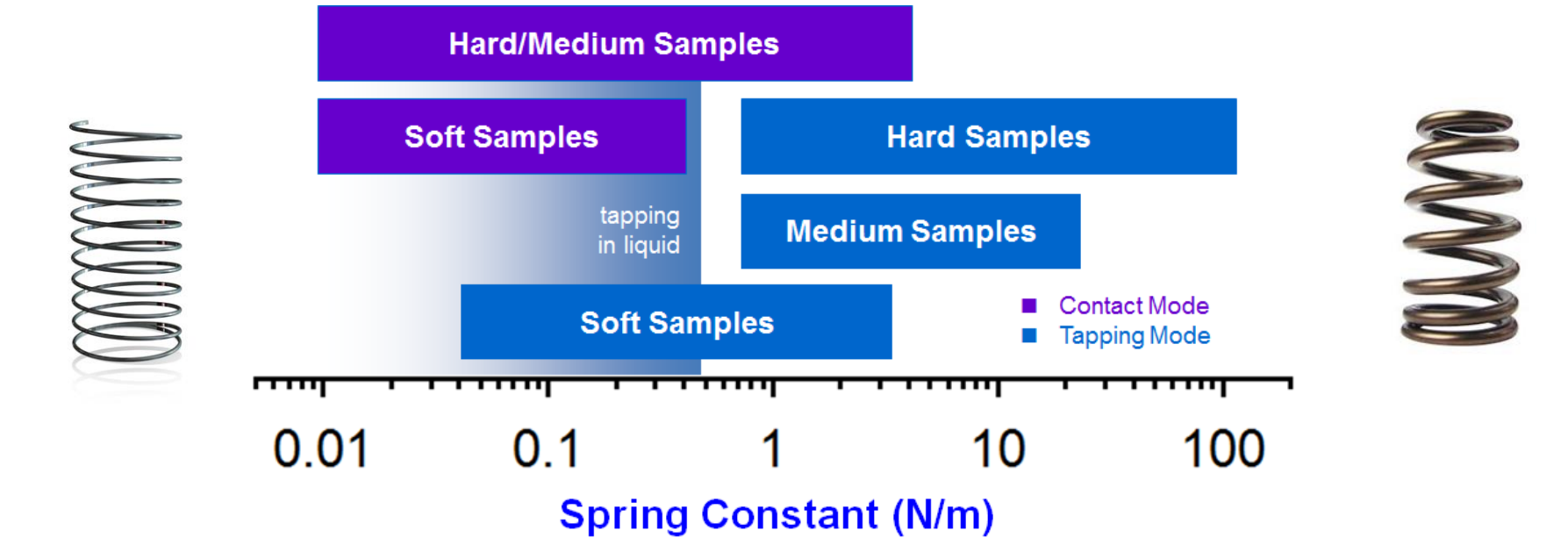
- 悬臂越软，针尖磨损得越慢。
- 若样品没有很牢靠地固定在基底上，选择小的 k ，避免样品被探针拖动。
- 在空气中使用轻敲模式时，为了避免探针吸附在样品表面，可选择 $k > \sim 0.5$ N/m的探针。
- 若样品的粘性很大，选择大的 k
- 探针的刚度应匹配样品的刚度；这对于纳米力学测量而言尤为重要。

弹性系数 k



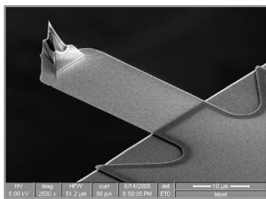
TR400 long	Biolever Mini (BL-AC40)	TR800 short	AC240	Arrow UHF	AC160	AC55
细胞	DNA, 蛋白质	蛋白质	薄膜 聚合物	方解石 (碳酸钙)	薄膜 聚合物	薄膜 聚合物

弹性系数 k



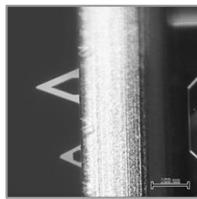
TR400 long

细胞



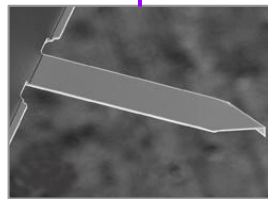
Biolever Mini (BL-AC40)

DNA, 蛋白质



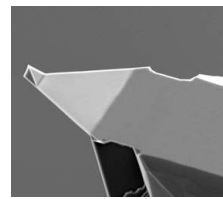
TR800 short

蛋白质



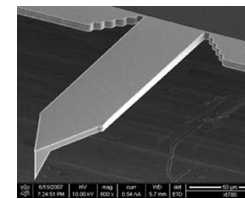
AC240

薄膜
聚合物



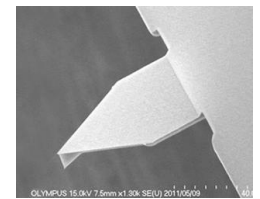
Arrow UHF

方解石 (碳
酸钙)



AC160

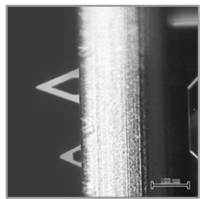
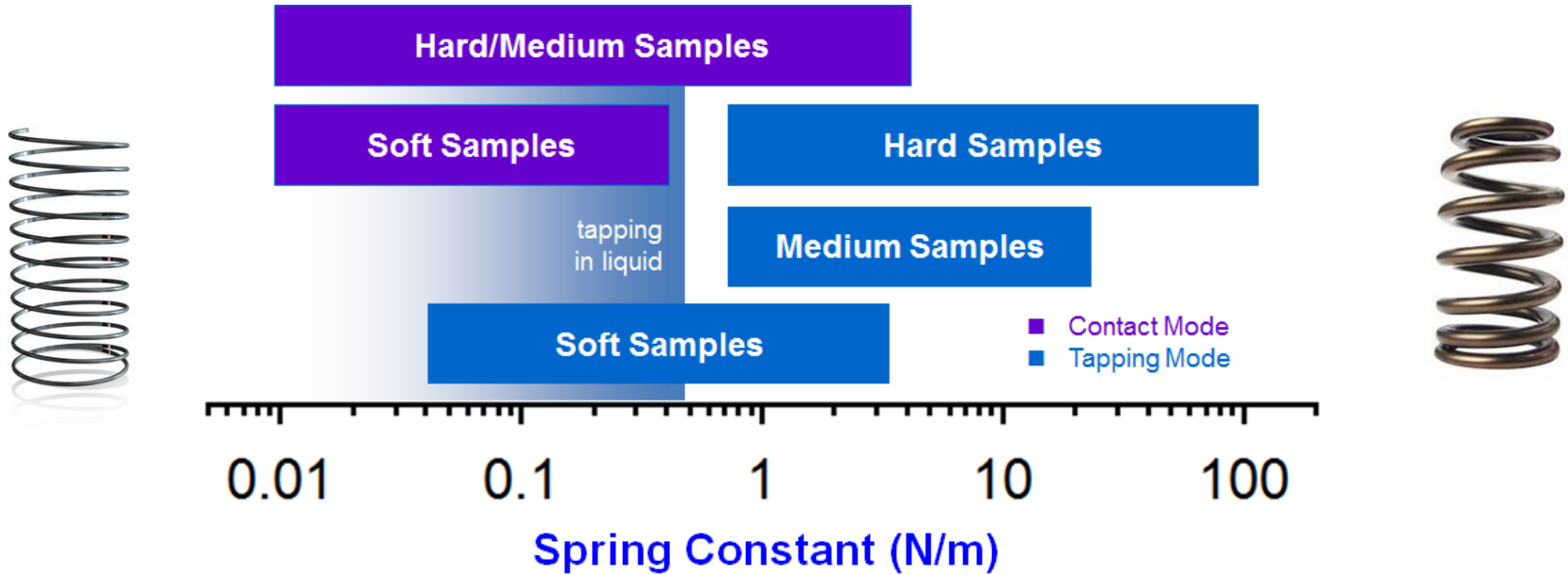
薄膜
聚合物



AC55

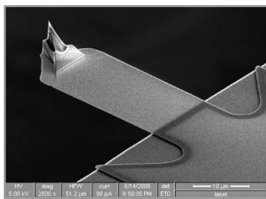
薄膜
聚合物

弹性系数 k



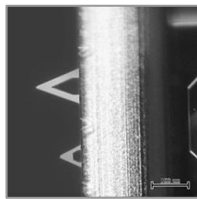
TR400 long

细胞



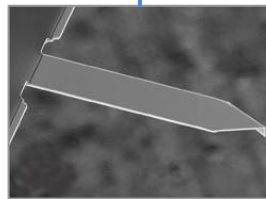
Biolever Mini (BL-AC40)

DNA, 蛋白质



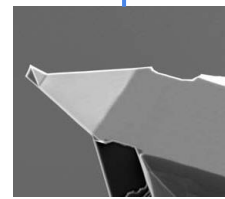
TR800 short

蛋白质



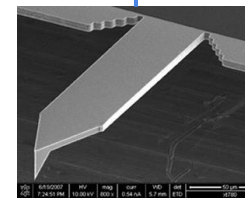
AC240

薄膜
聚合物



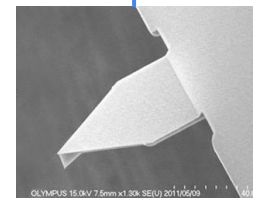
Arrow UHF

方解石 (碳
酸钙)



AC160

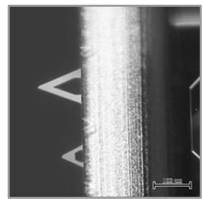
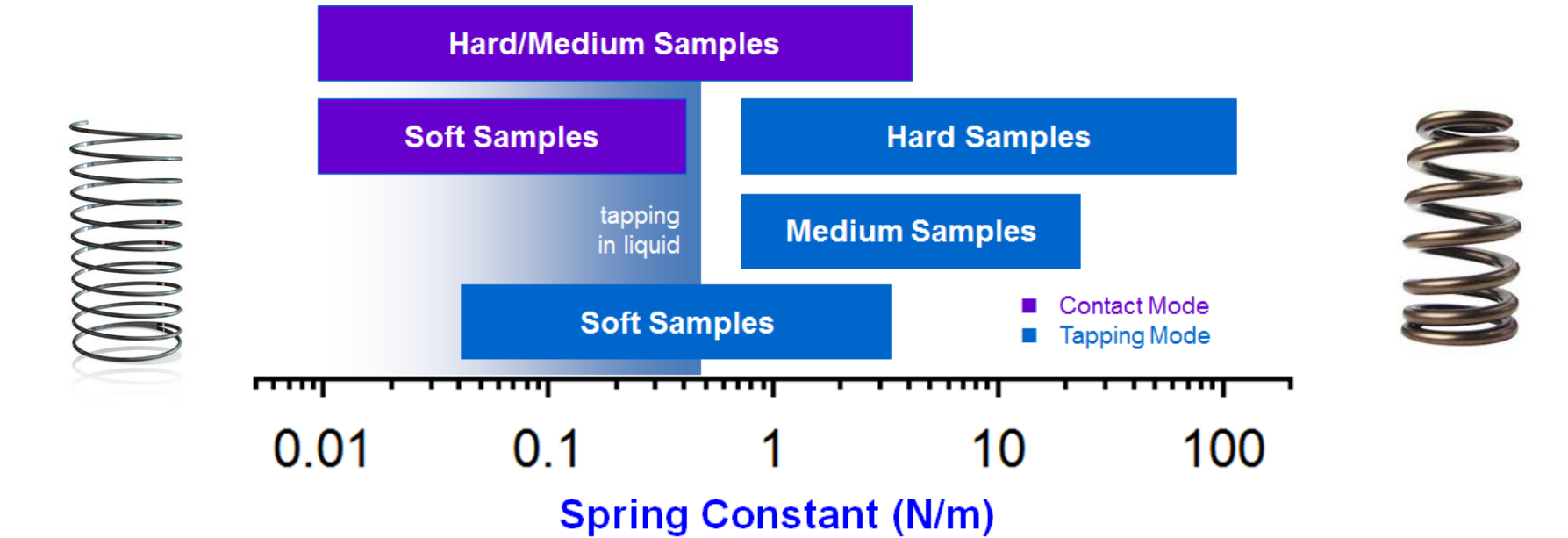
薄膜
聚合物



AC55

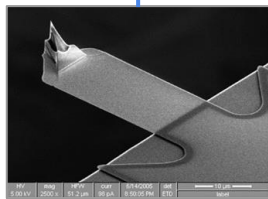
薄膜
聚合物

弹性系数 k



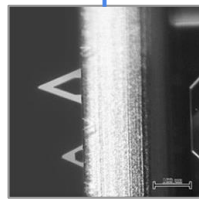
TR400 long

细胞



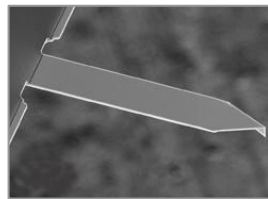
Biolever Mini (BL-AC40)

DNA, 蛋白质



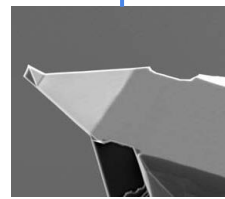
TR800 short

蛋白质



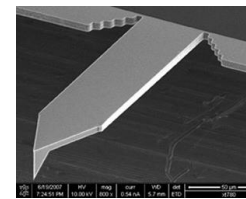
AC240

薄膜
聚合物



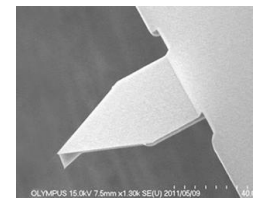
Arrow UHF

方解石 (碳
酸钙)



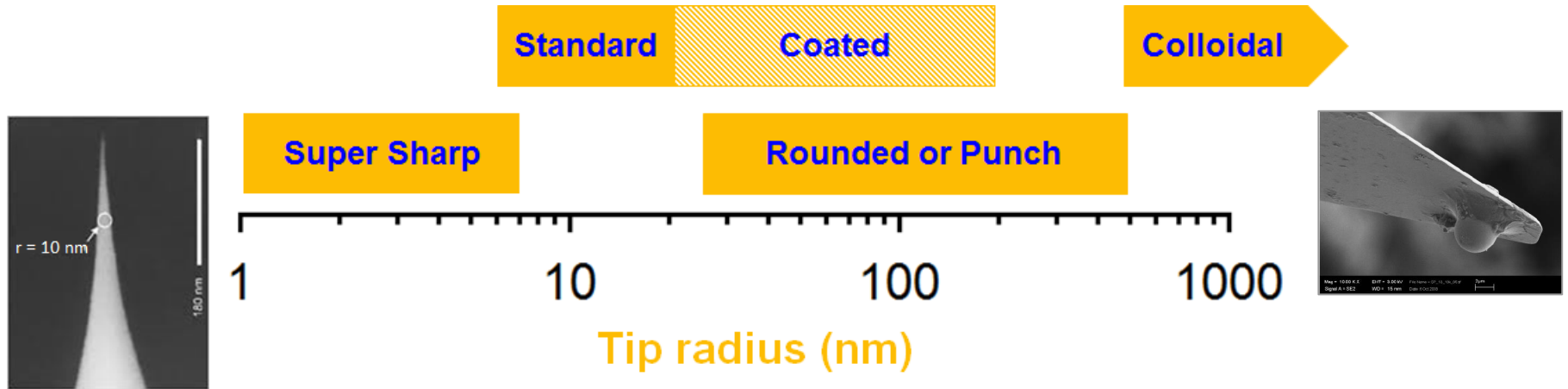
AC160

薄膜
聚合物



AC55

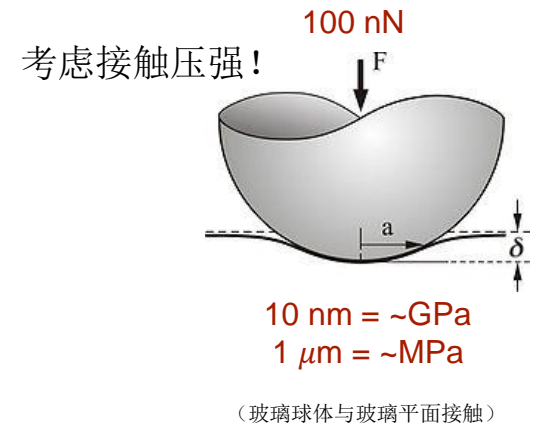
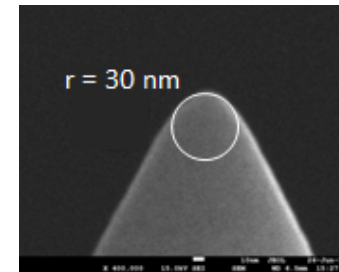
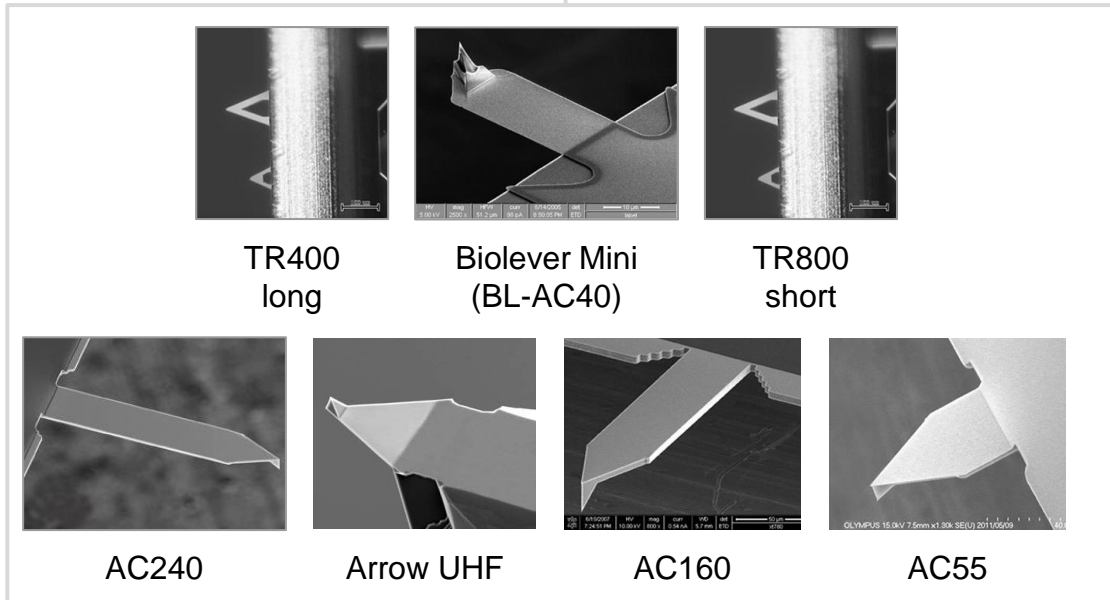
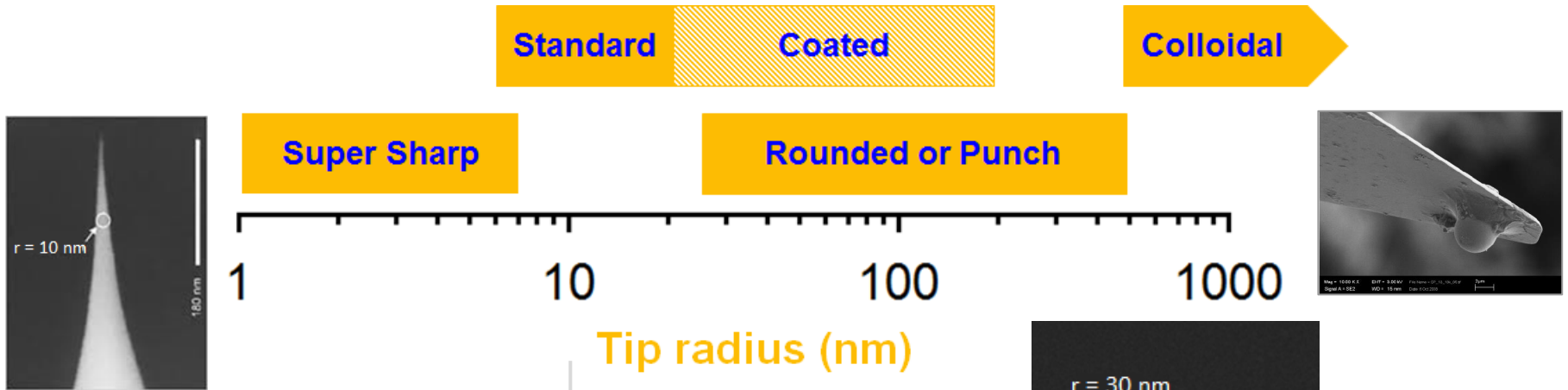
薄膜
聚合物



- 针尖的尖锐度限定了AFM图像的横向分辨率
- 超尖锐针尖 ($r \approx 1\text{-}2 \text{ nm}$) 非常昂贵, 按需使用
- 由于针尖的尖端总有原子级别的粗糙度, AFM图像是有可能获得分子或者原子缺陷级别的分辨率的
- 对于某些柔软的生物样品(例如细胞膜), 较大的针尖 ($r > 20 \text{ nm}$) 或许更合适, 可以避免针尖扯坏样品
- 对于纳米机械测量而言, 尺寸较大且形状确定的针尖或许更合适
- 在液相中扫描时, 避免使用有铝镀层的探针

选择指南:

针尖曲率半径 r



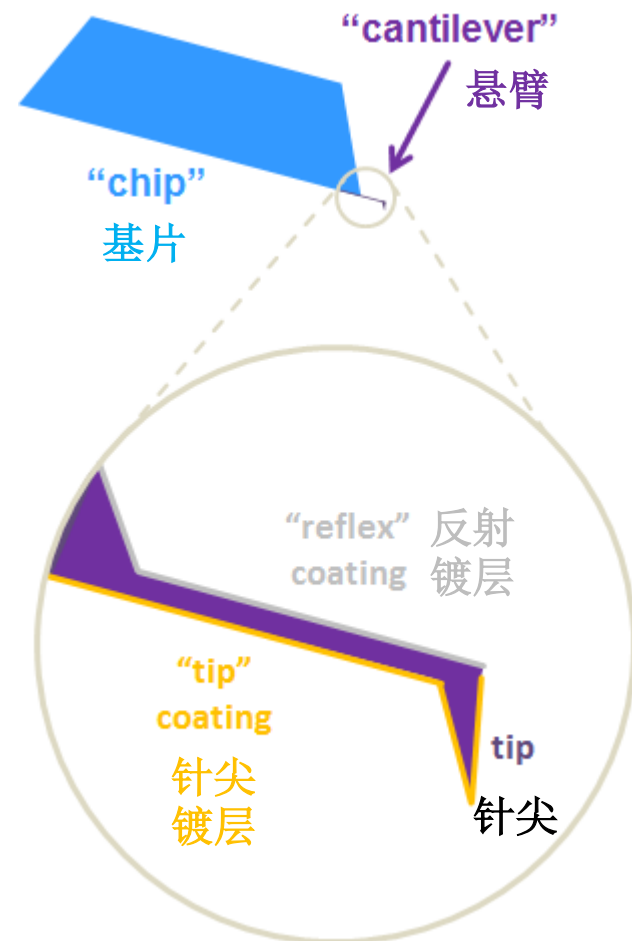
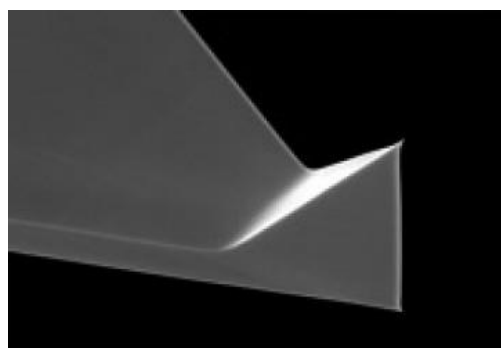
针尖参数:

针尖曲率半径 – 针尖镀层的影响

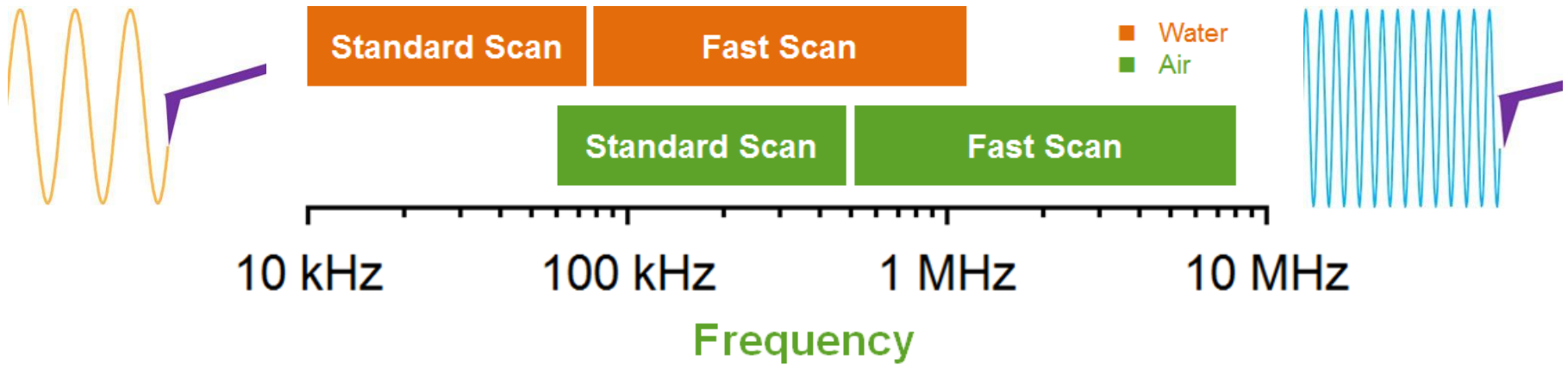
OXFORD
INSTRUMENTS

The Business of Science®

型号	类型	针尖镀层	曲率半径
AC240TS	标准硅针尖	无	7 nm
AC240TM	导电针尖	Ti/Pt	<25 nm
ASYELEC-01	导电针尖	Ti/Ir	28 nm
ASYMFMLC	低矫顽力	permalloy	32 nm
ASYMFMHC	高矫顽力	CoPt/FePt	32 nm
ASYMFMLM	低磁矩	CoCr	20 nm
ASYMFMHM	高磁矩	CoCr	84 nm



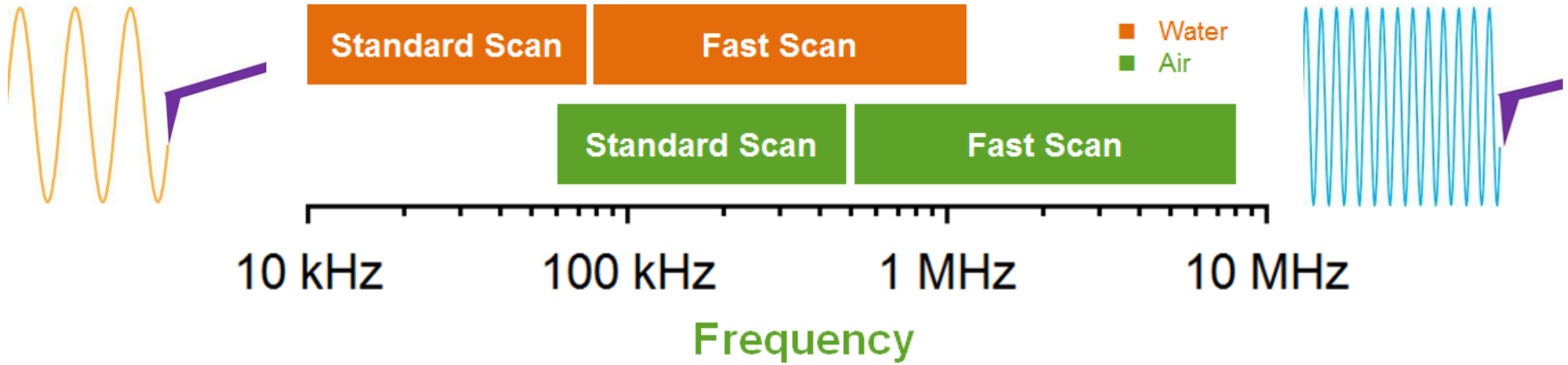
共振频率 f 和 Q 因子



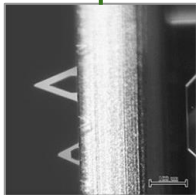
- 通常只有当需要进行快扫描时，才考虑 f 和 Q
- 探针的带宽 ($f/2Q$) 限定了扫描速度
- 大部分的探针制造商不说明探针的 Q 因子，只说明共振频率
- 不过，不同的AFM探针的 Q 因子通常只相差2至3倍，而共振频率可以相差几个数量级
- 在液体中， Q 因子和共振频率都会降低
- 若要进行快扫描，通常需要 $f > 500$ kHz

选择指南:

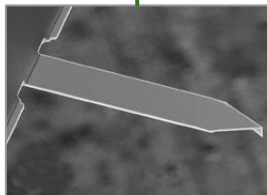
共振频率 f 和 Q 因子



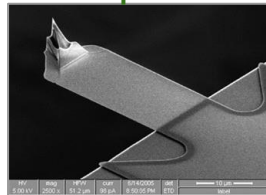
BL-RC150VB
short



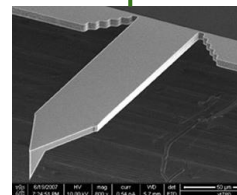
TR800
short



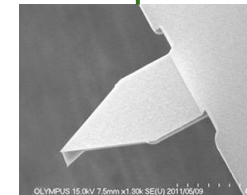
AC240



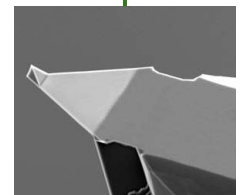
Biolever Mini
(BL-AC40)



AC160



AC55

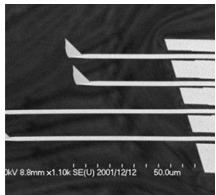
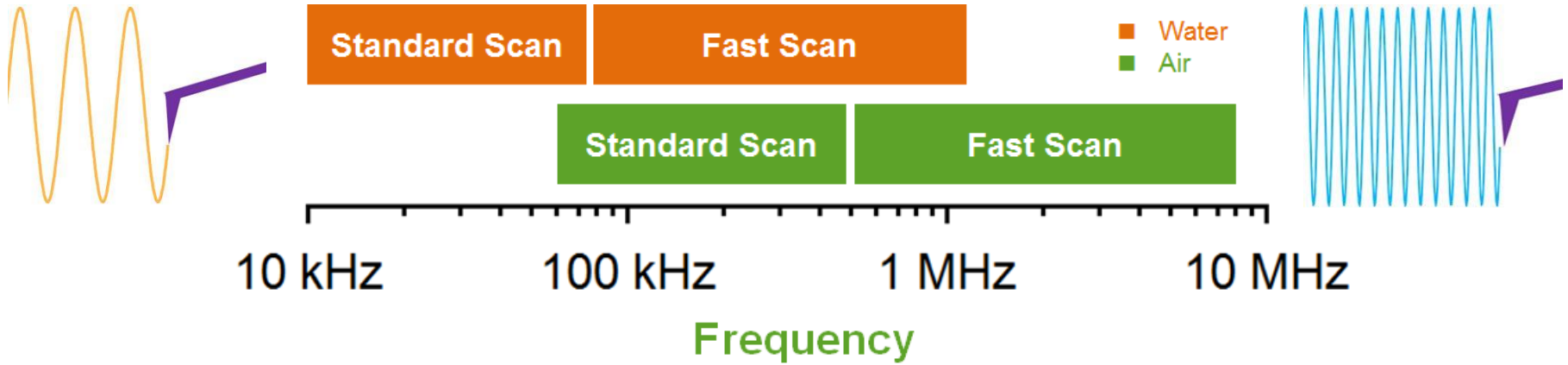


Arrow UHF

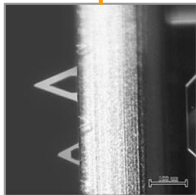
蛋白质
拉伸

选择指南:

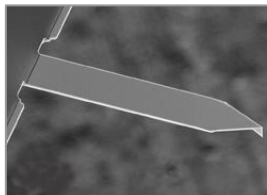
共振频率 f 和 Q 因子



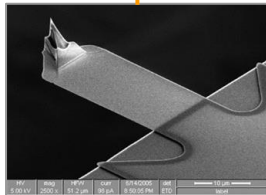
BL-RC150VB
short



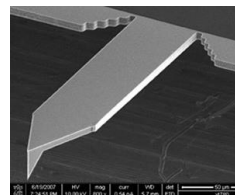
TR800
short



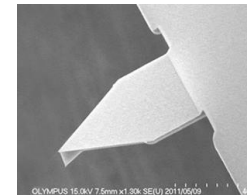
AC240



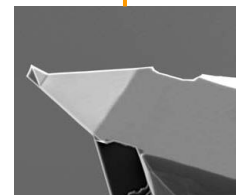
Biolever Mini
(BL-AC40)



AC160



AC55



Arrow UHF

蛋白质
拉伸

AFM探针网络讲座 – 概要

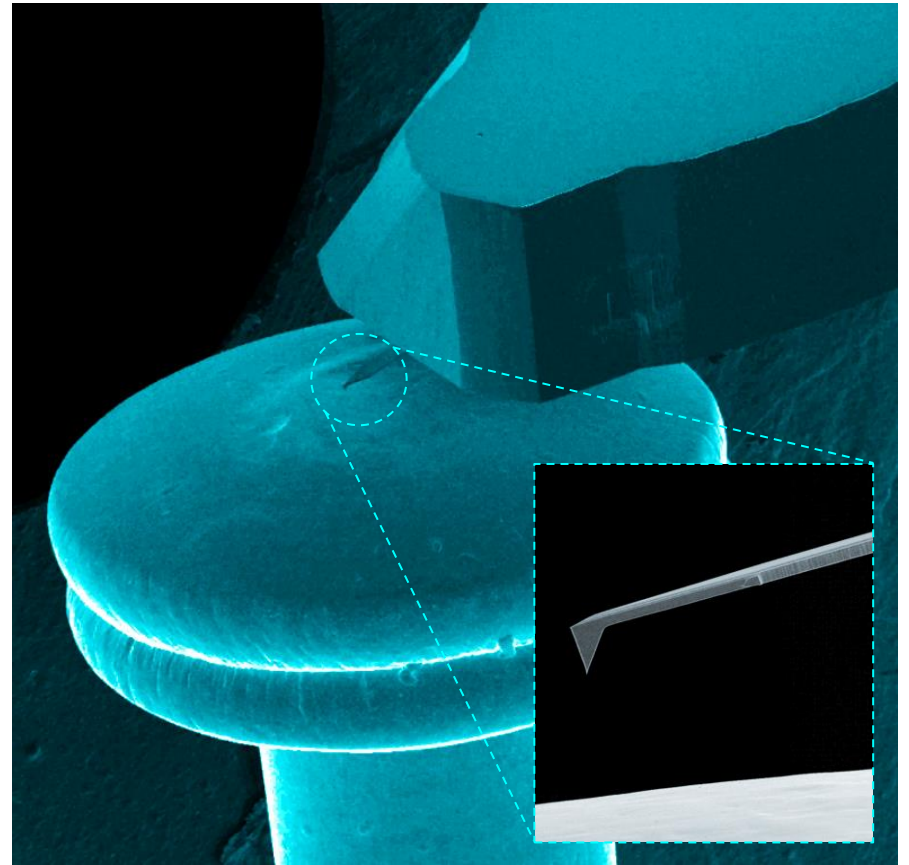
引言

探针的基本知识

探针的关键参数

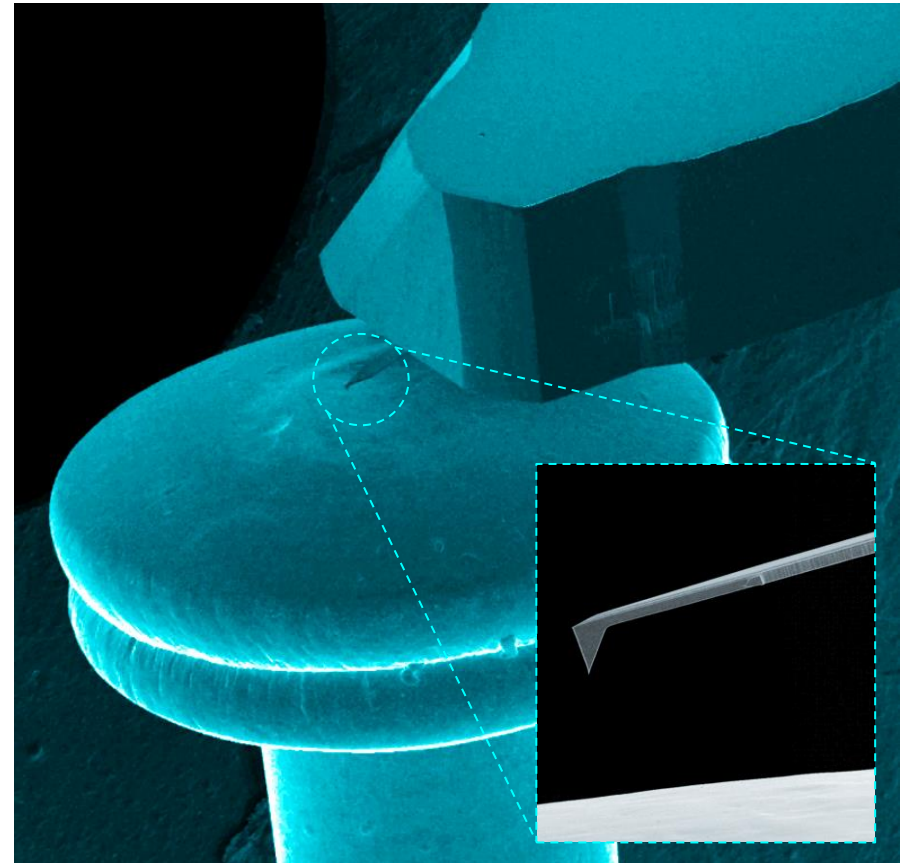
探针的选择指南

应用实例



应用实例

- 基本形貌
- 原子级分辨率（轻敲模式）
- 晶格级分辨率（接触模式）
- 快扫描
- 生物样品
 - 生物分子成像
 - 高分辨率
 - 力拉伸
 - 生物细胞
- 纳米力学测量
 - **Fast Force Mapping**
 - **AM-FM**
- 电学表征
 - **Conductive AFM**
 - **EFM和KPFM**
 - **DART PFM**
- 磁性材料
- 特殊应用

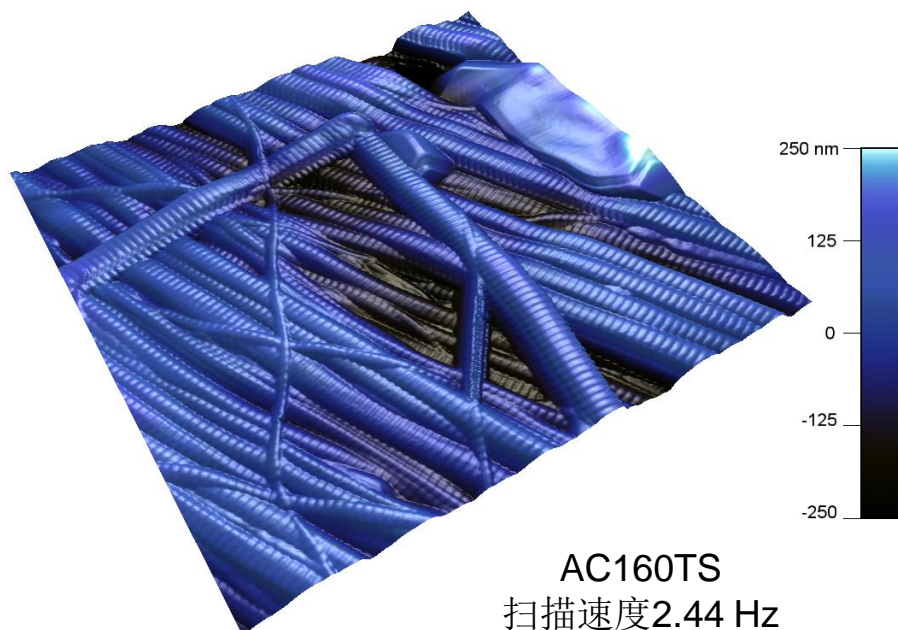


应用：轻敲模式成像

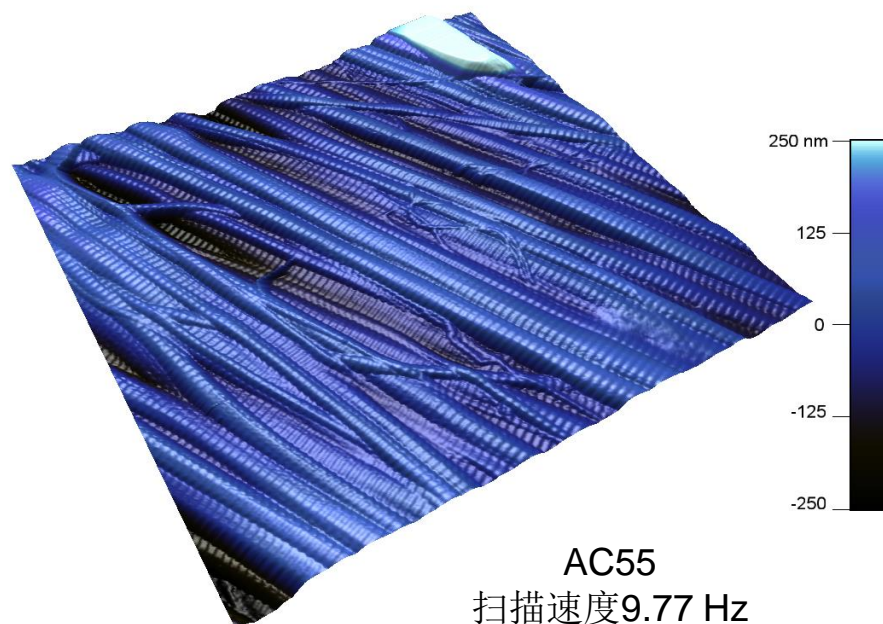
胶原蛋白

OXFORD
INSTRUMENTS

The Business of Science®

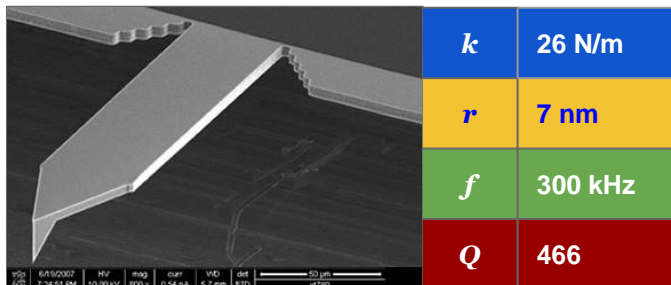


AC160TS
扫描速度2.44 Hz
扫描范围5 μm

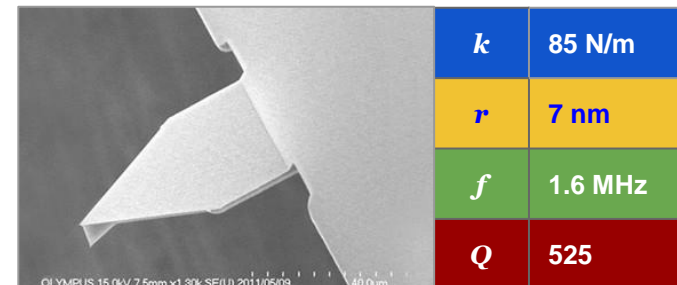


AC55
扫描速度9.77 Hz
扫描范围5 μm

AC160TS-R3



AC55TS

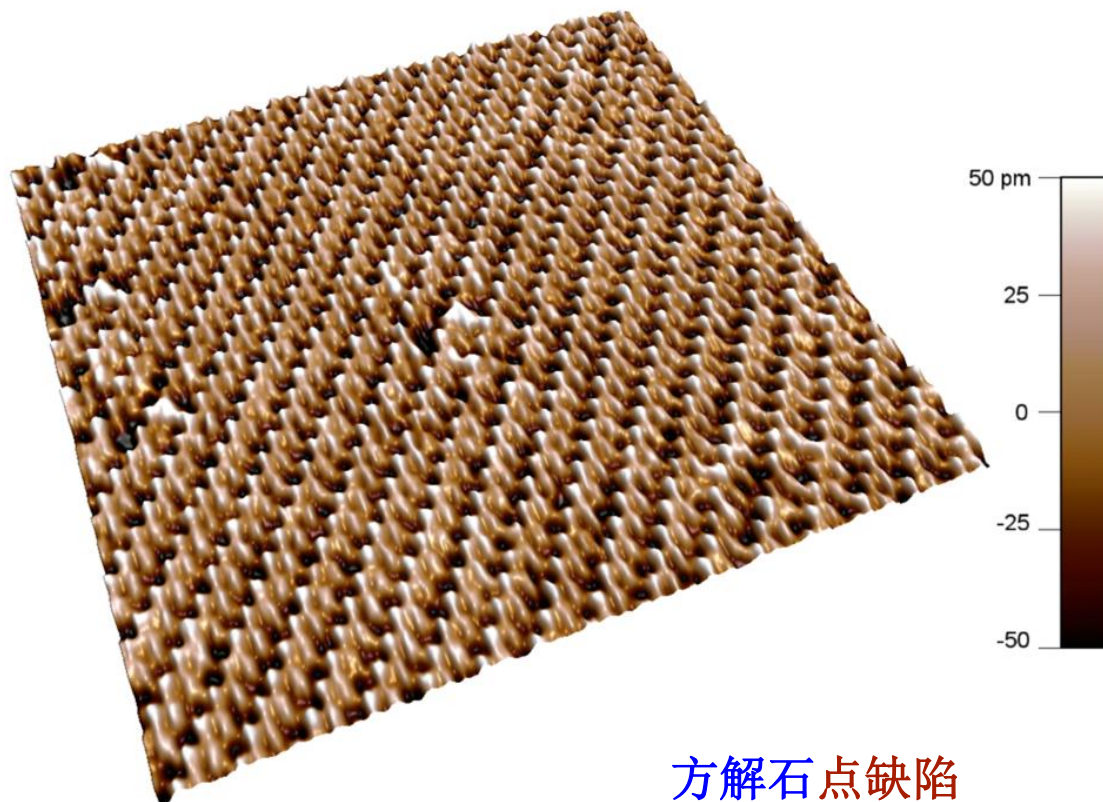


应用：原子级分辨率（轻敲模式）

方解石点缺陷

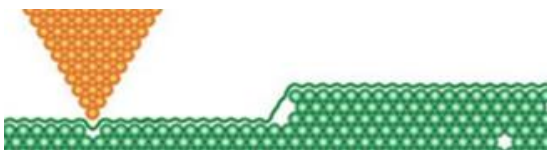


The Business of Science®

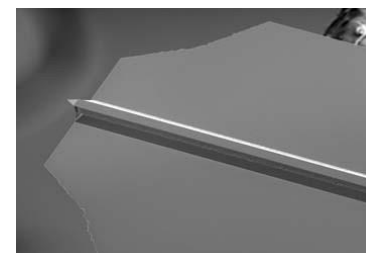


方解石点缺陷
扫描范围15 nm

针尖有原子级粗糙度



对于轻敲模式下的快扫描，选择共振频率高的小探针



注：Arrow UHF AuD探针也可用于blueDrive

Arrow UHF

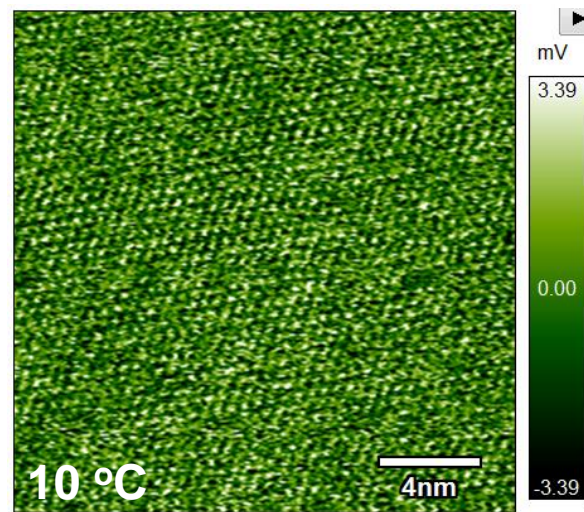
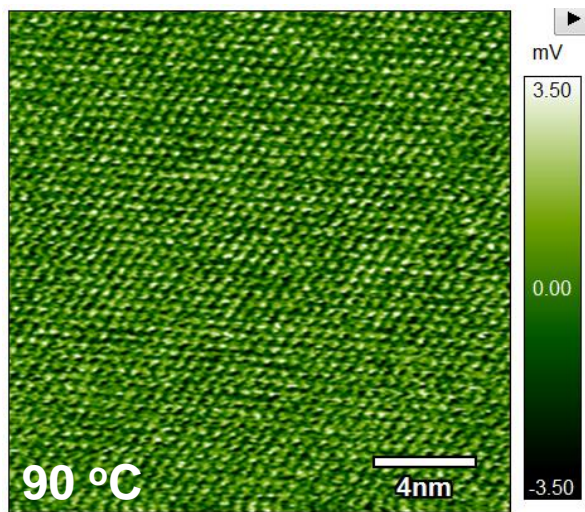
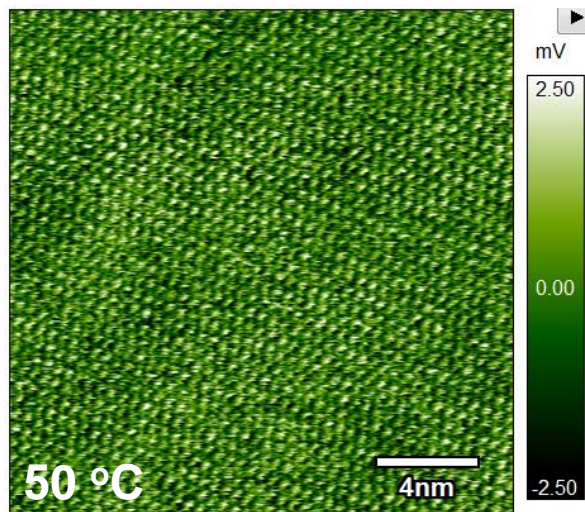
k	6 N/m
r	10 nm
f	2 MHz
Q	183

应用：晶格级分辨率（接触模式）

云母原子晶格



The Business of Science®



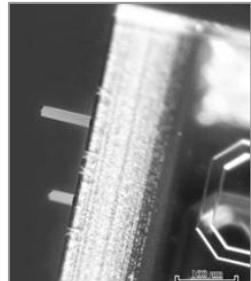
云母晶格图像
水中的LFM模式
扫描范围20 nm
Cypher ES



对于接触模式扫描，选择较软、较小的探针

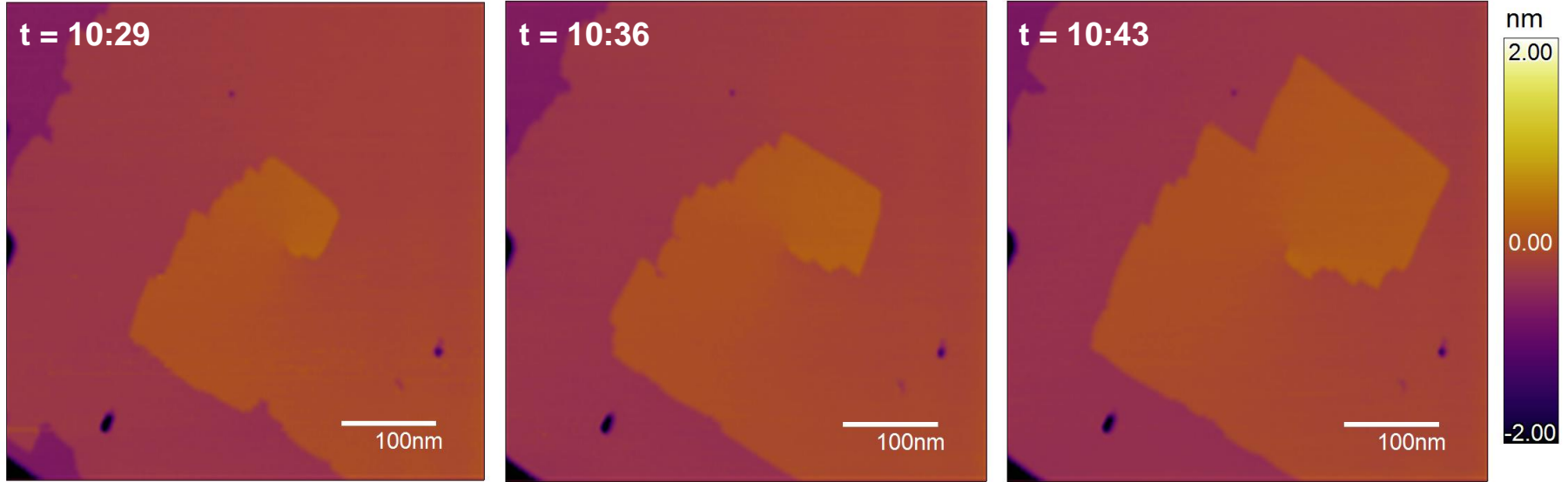
注： $k_{\text{横向}} \gg k_{\text{纵向}}$

RC800PSA

	k	0.76 N/m
	r	15 nm
	f	71 kHz
	Q	--

应用：快扫描 (>10 Hz)

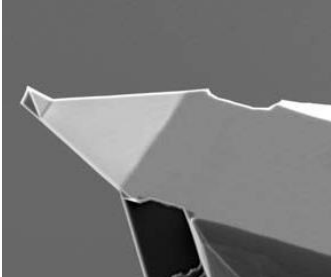
方解石螺旋位错



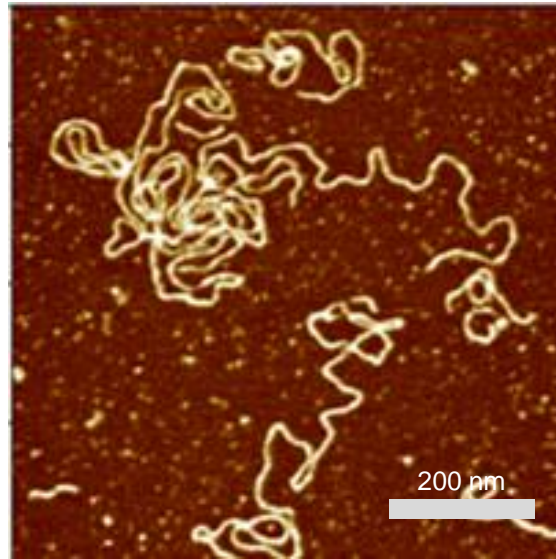
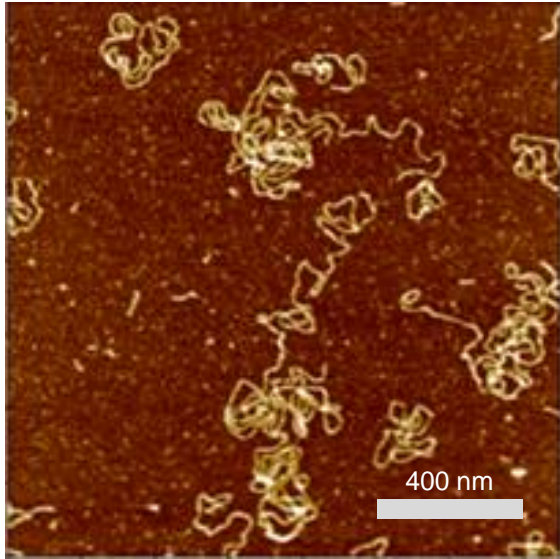
方解石螺旋位错视频
扫描范围500 nm
19.5行每秒
(~7秒每帧)

对于轻敲模式下的快扫描，选择共振频率高的探针

Arrow UHF AuD

	k	6 N/m
	r	10 nm
	f	2 MHz
	Q	183

DNA

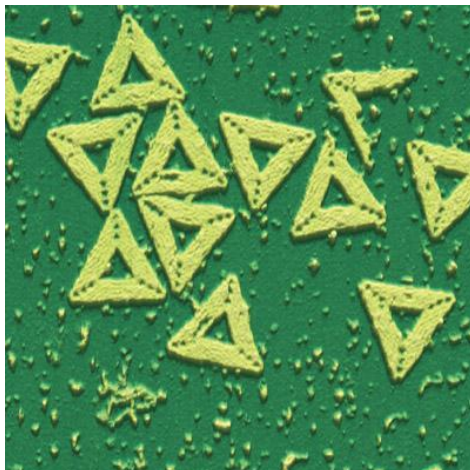


云母上的DNA链
扫描速度2 Hz

**MFP-3D-BIO
TR400PB**

液相中的轻敲模式可使用低弹性系数的氮化硅悬臂

注：针尖镀层和反射镀层均使用金，可减少探针在液体中的弯曲漂移

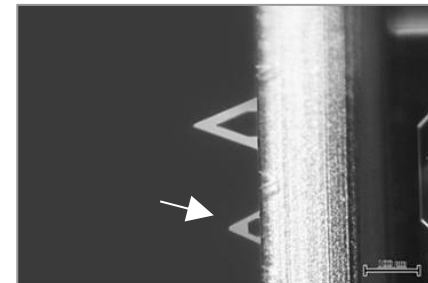


DNA折叠
扫描范围1 μm

**MFP-3D-BIO
Biolever Mini
(BL-AC40TS)**

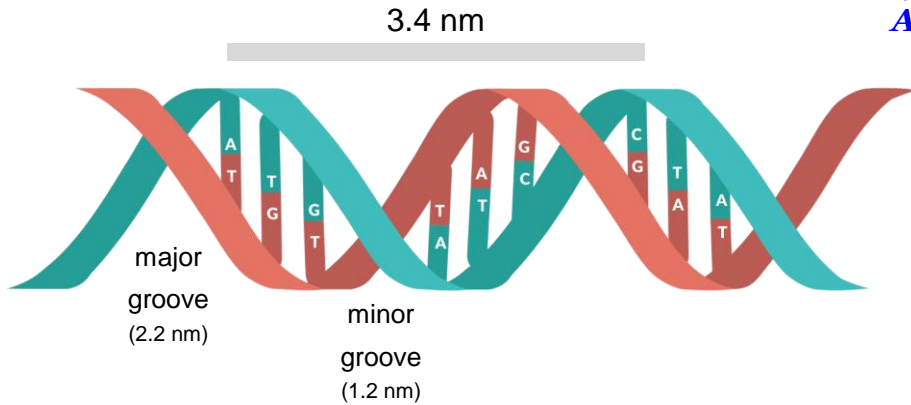
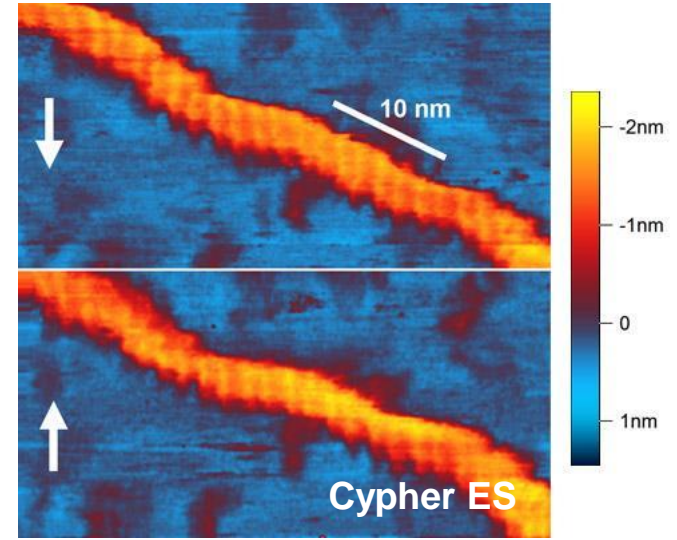
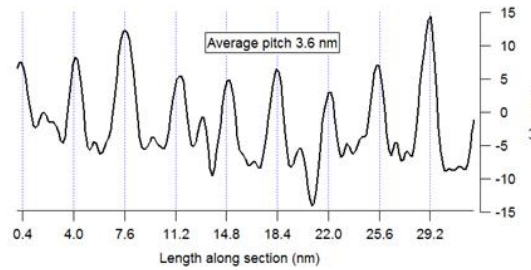
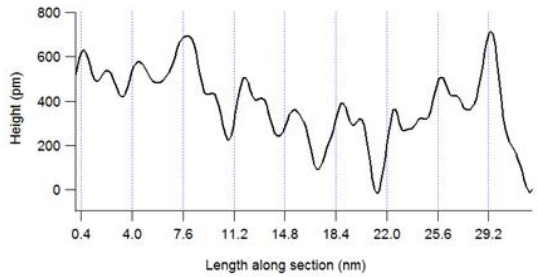
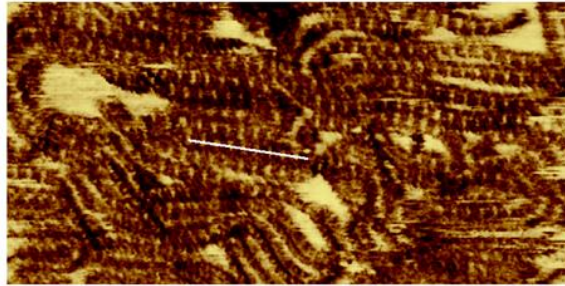
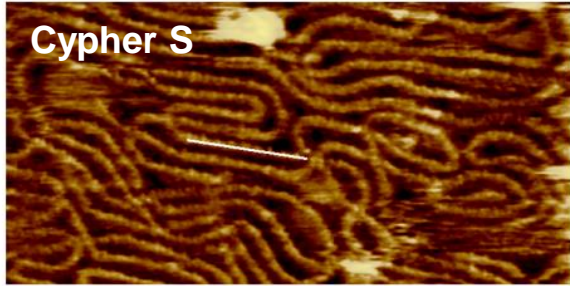
告知：在MFP-3D-BIO上使用需要技巧

TR400PB (Short)



k	0.09 N/m
r	32 nm
f	32 kHz
Q	41

DNA双螺旋结构



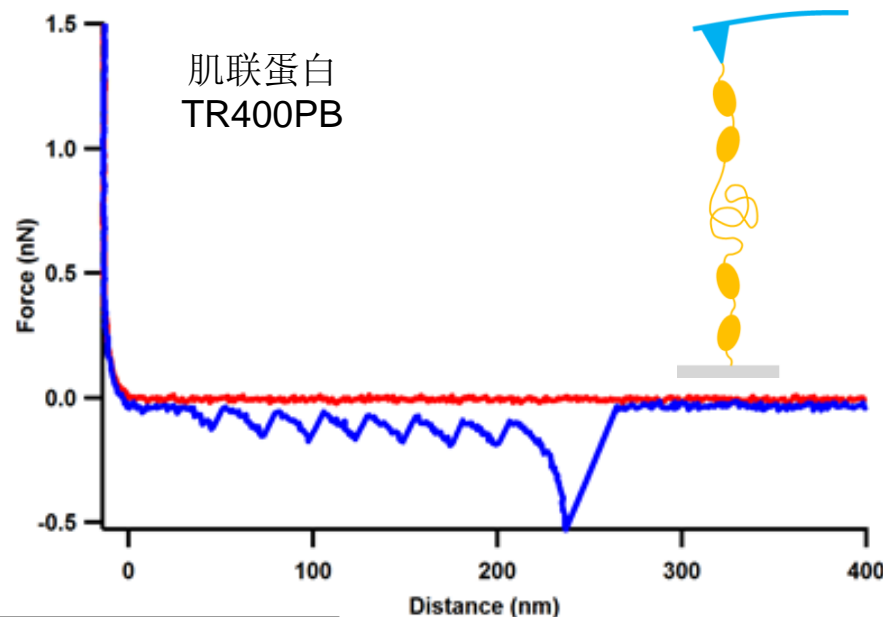
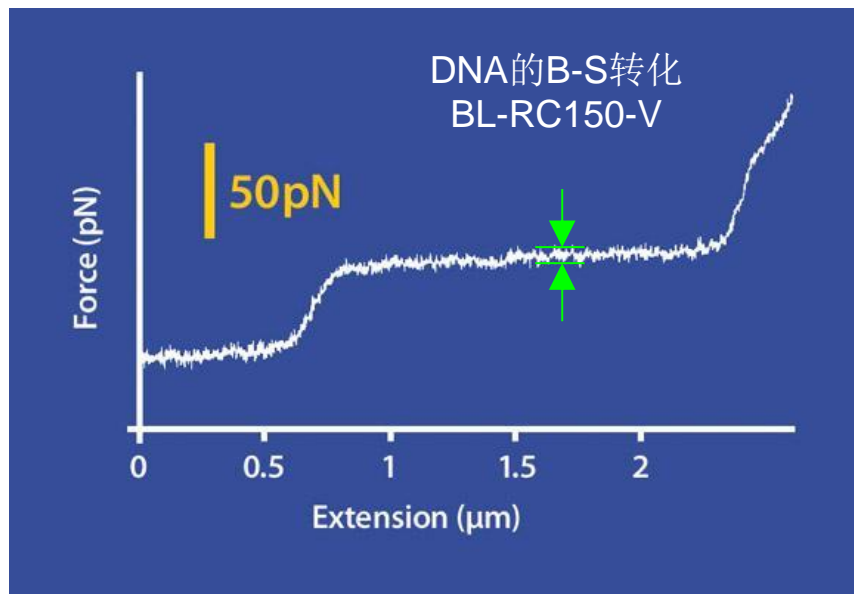
$f_{\text{fluid}} = 42 \text{ kHz}$
 $A = 0.8 \text{ nm}$

液相中的低振幅轻敲模式可使用低弹性系数的氮化硅悬臂和尖锐的硅针尖

Biolever Mini
(BL-AC40TS)

k	0.25 N/m
r	8 nm
f	130 kHz
Q	40

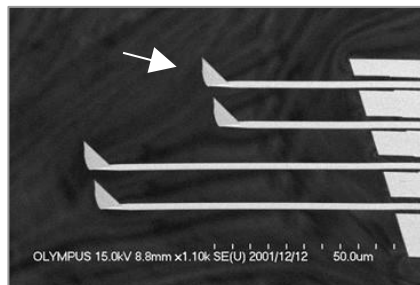
DNA和肌联蛋白



$$F_{min} = \sqrt{4k_b T b f_{BW}} \quad b = \frac{k_N}{2\pi f_{res} Q}$$

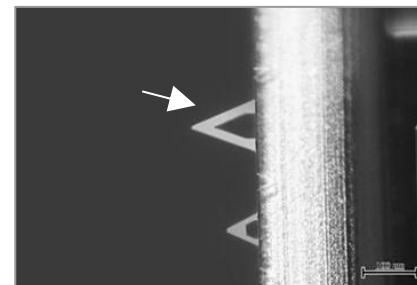
BL-RC150-VB (Short)

TR400PB (Long)



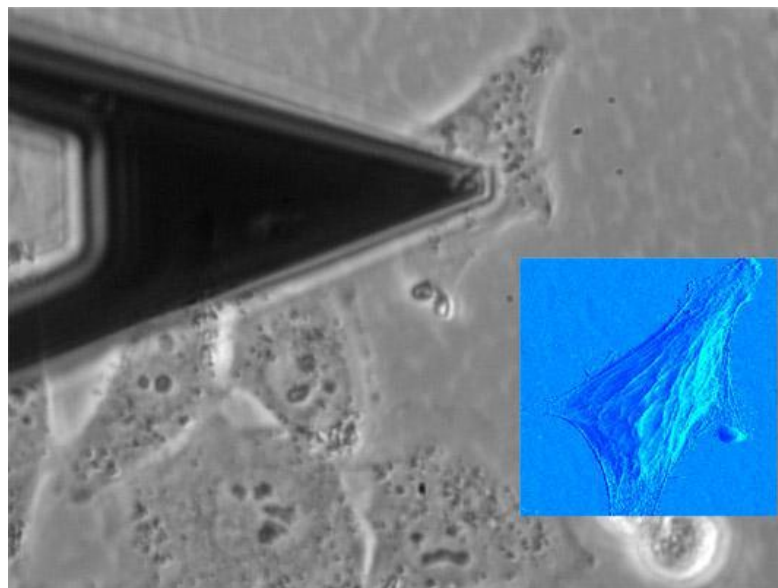
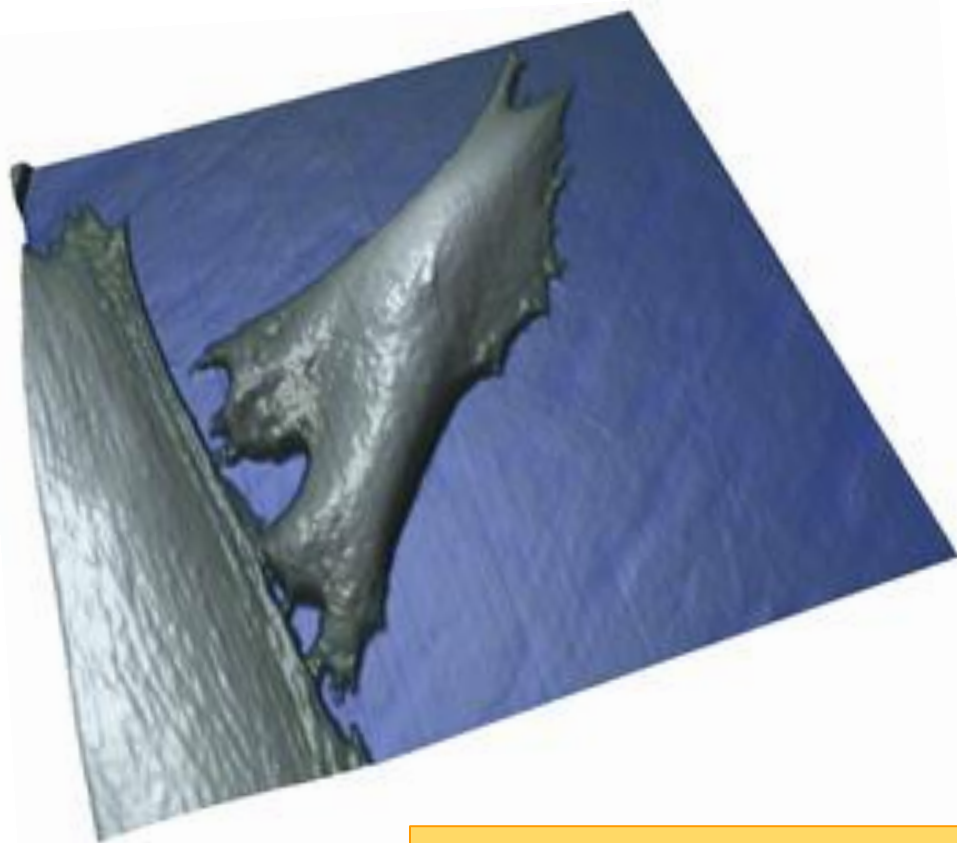
k	0.03 N/m
r	30 nm
f	37 kHz
Q	25

为了得到好的力分辨率，选择较小、较软、弯曲漂移较小的探针



k	0.02 N/m
r	32 nm
f	10 kHz
Q	19

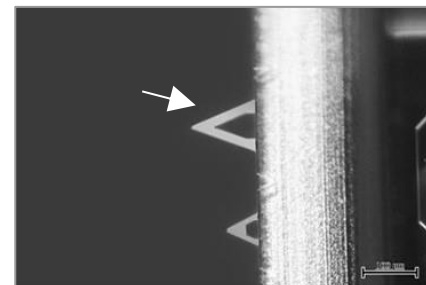
应用：生物学 – 液相中细胞的接触模式成像 成纤维细胞



对于液相中的**接触模式**成像，选择弹性系数很低、较稳定的探针

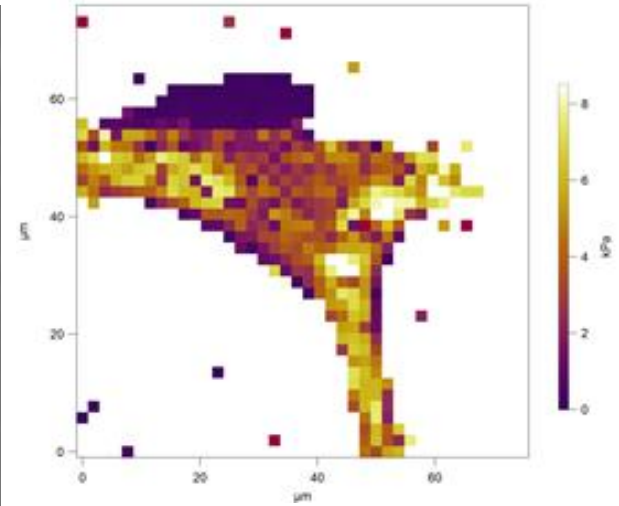
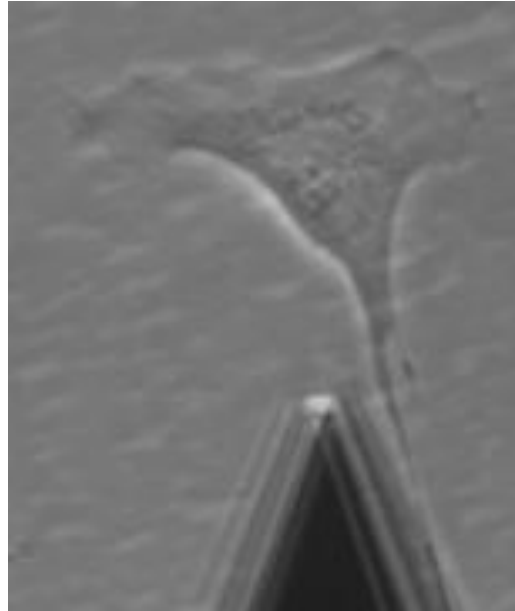
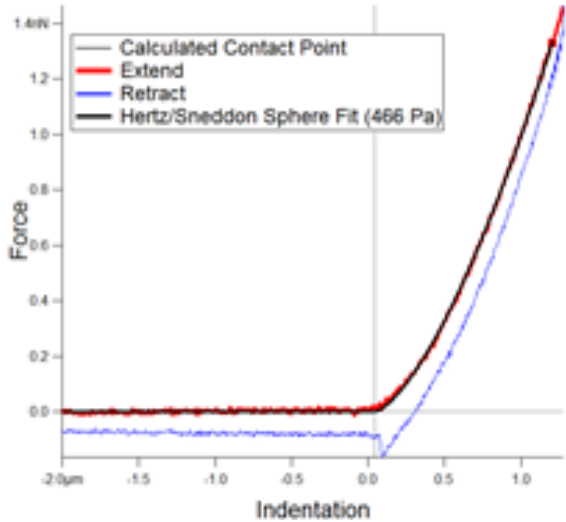
注：对于较高的（未附着的）细胞，或许需要用较高的针尖来扫描

TR400PB (Long)

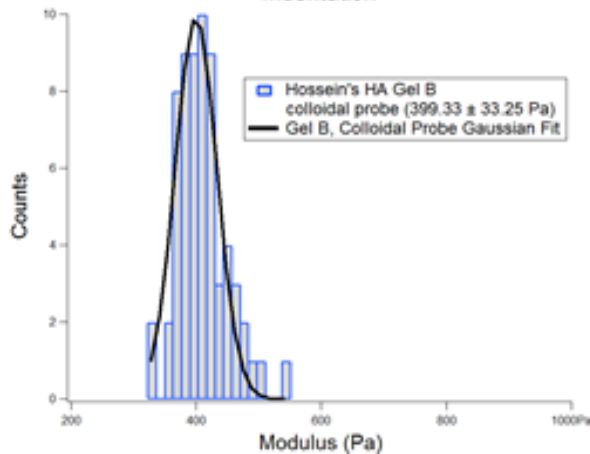


k	0.02 N/m
r	32 nm
f	10 kHz
Q	19

透明质酸凝胶
Novascan探针
(0.07 N/; $\varnothing=4.5 \mu\text{m}$)



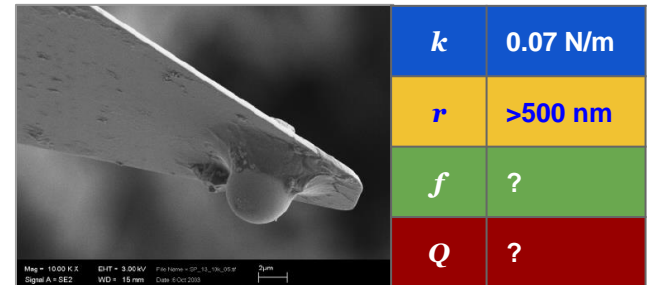
活体成纤维细胞
Novascan探针
(0.07 N/; $\varnothing=1.5 \mu\text{m}$)



选择非常柔软的胶粒探针，
这样可以减小接触压强

注：已知、明确的针尖形状
有助于对Hertz模型的拟合

Novascan胶粒探针



应用： 纳米力学测量

MODE MASTER

Favorites Standard PFM Electrical Bio **NanoMechPro** Cypher

不同的材料和成像模式需要使用不同的探针。

NanomechPro
ASYLUM RESEARCH

- AM-FM Viscoelastic Mapping
- Loss Tangent / Phase
- Contact Resonance Viscoelastic Mapping
- Vertical Nanoindenting
- Functional Measurements (PFM, ESM...)
- Advanced Modeling (DMT, JKR, Oliver-Pharr...)
- Force Curves/Volumes, Force Modulation...
- Ztherm™ Local Thermal Analysis
- NanoRack™ Stretch Stage

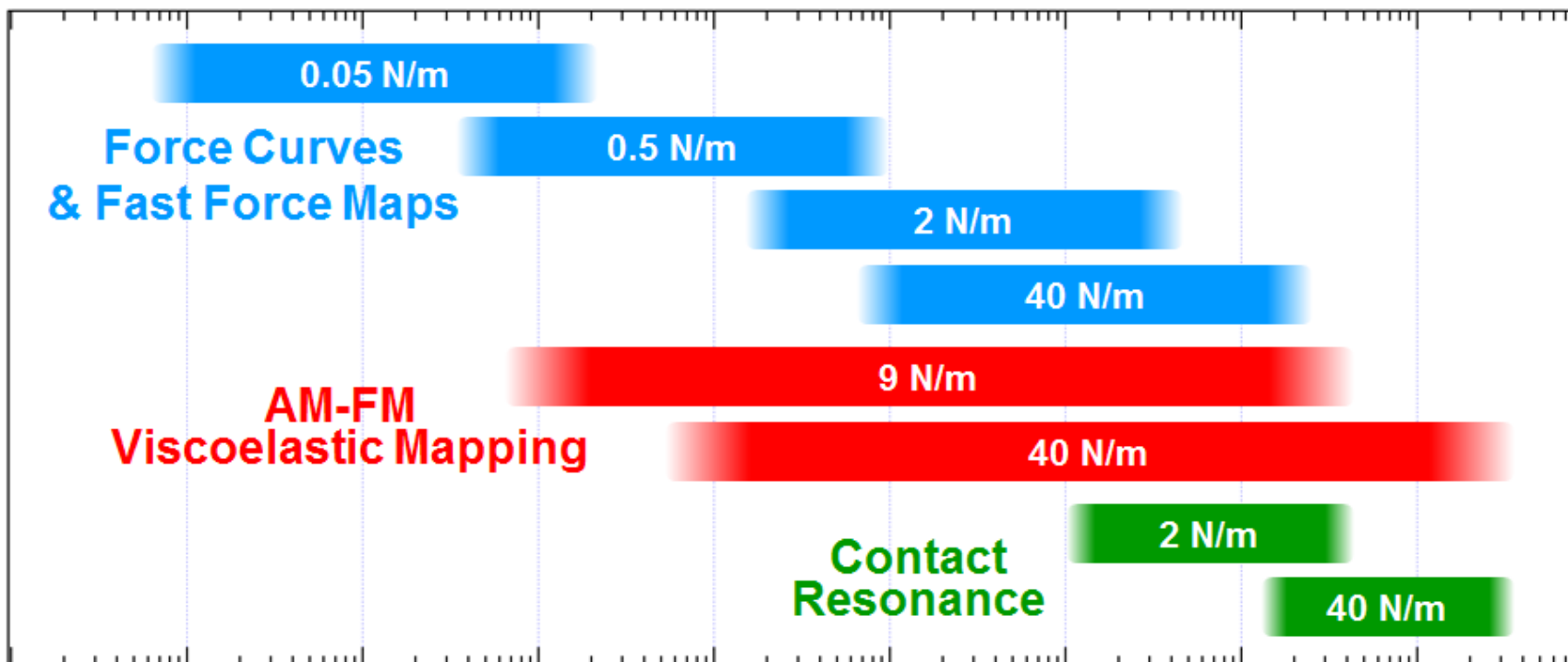
应用:

纳米力学测量

OXFORD
INSTRUMENTS

The Business of Science®

1 kPa 10 kPa 100 kPa 1 MPa 10 MPa 100 MPa 1 GPa 10 GPa 100 GPa

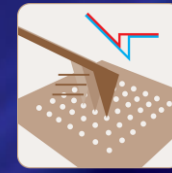


1 kPa 10 kPa 100 kPa 1 MPa 10 MPa 100 MPa 1 GPa 10 GPa 100 GPa

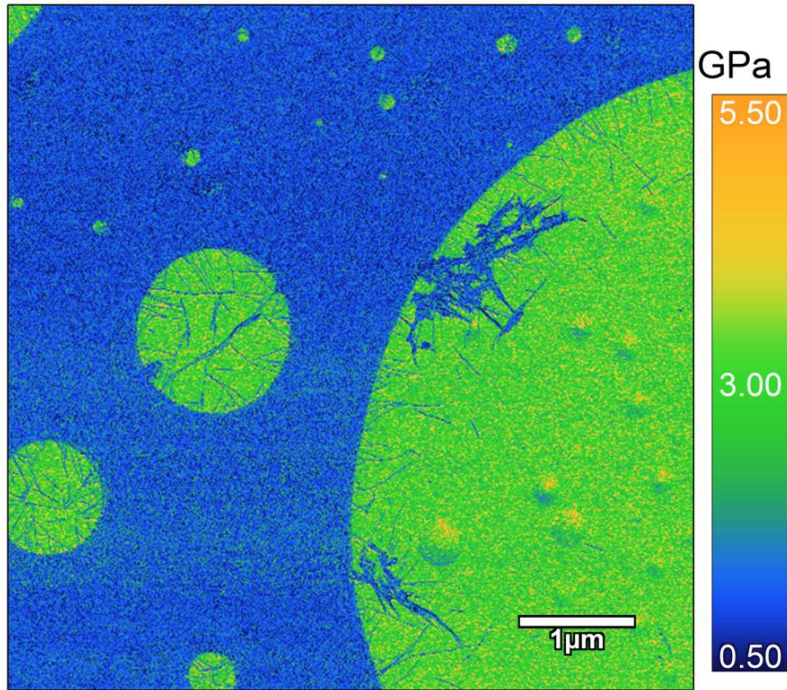


纳米力学测量:

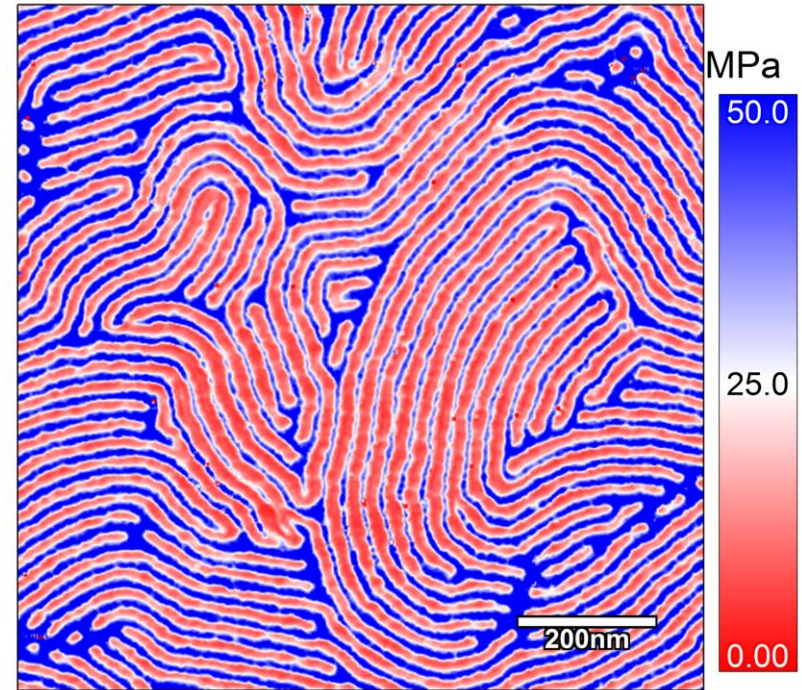
Fast Force Maps



弹性模量 (PS/PP)



弹性模量 (SEBS)

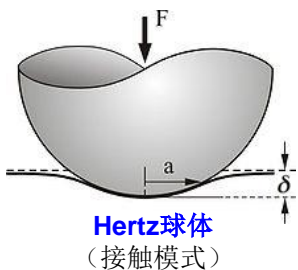
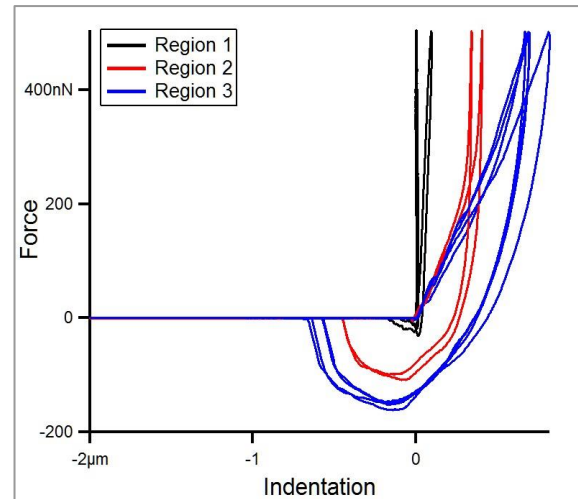
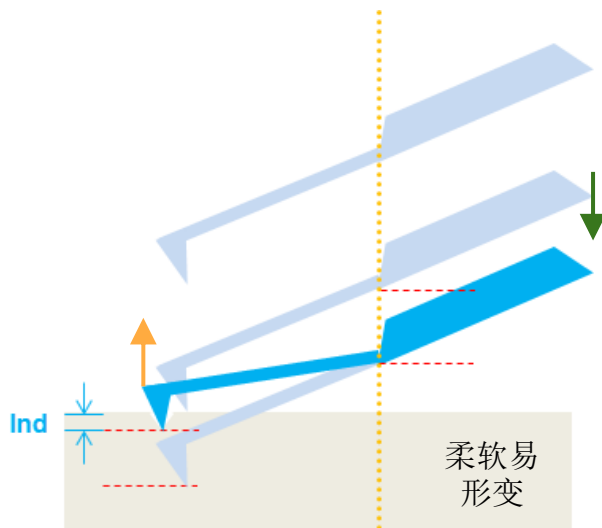
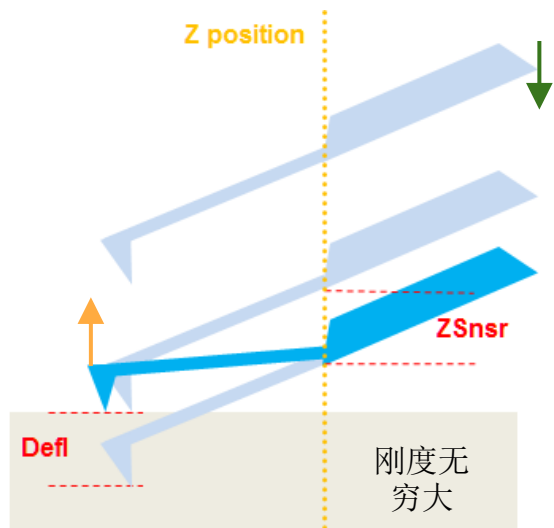
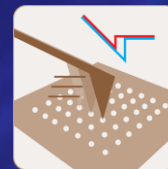


选择适合做力谱的探针，探针的刚度要适中，例如~1-2 N/m.

AC240TS-R3

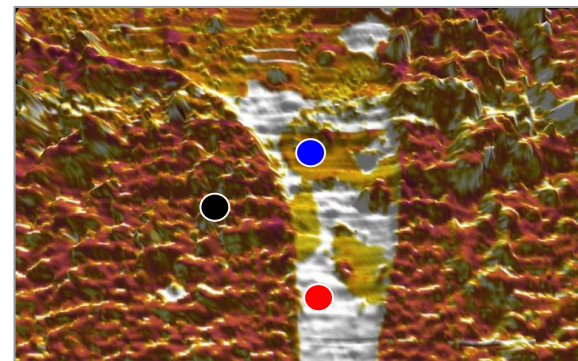
k	2 N/m
r	7 nm
f	70 kHz
Q	123

Fast Force Maps



$$F = \frac{4}{3} r^{1/2} E_r \delta^{3/2}$$

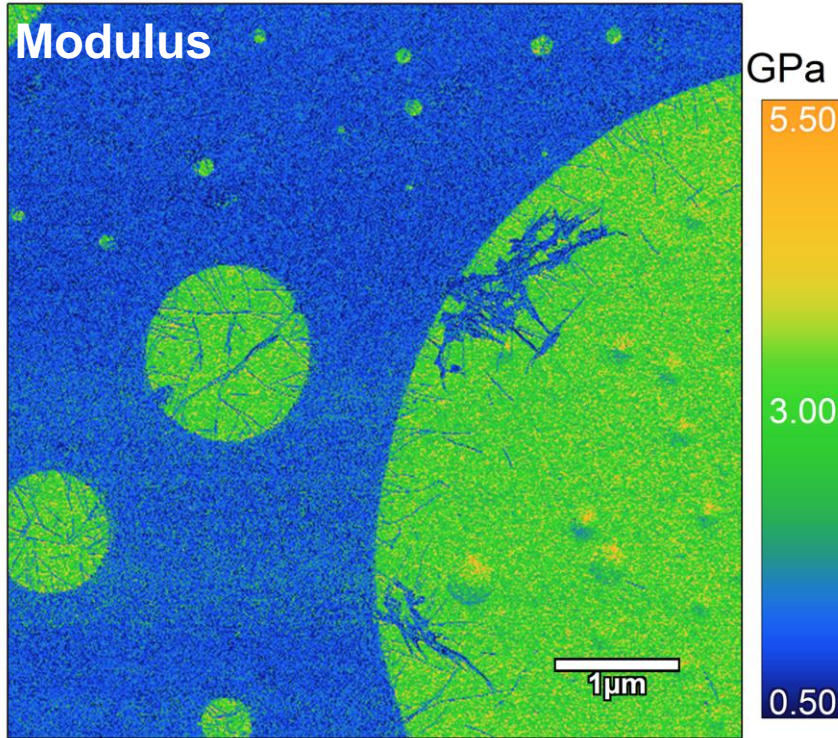
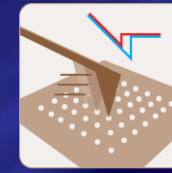
弹性模量



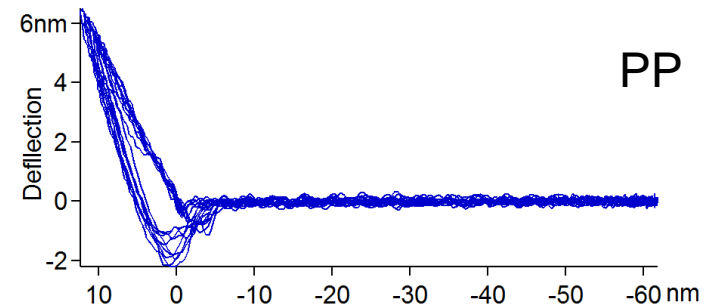
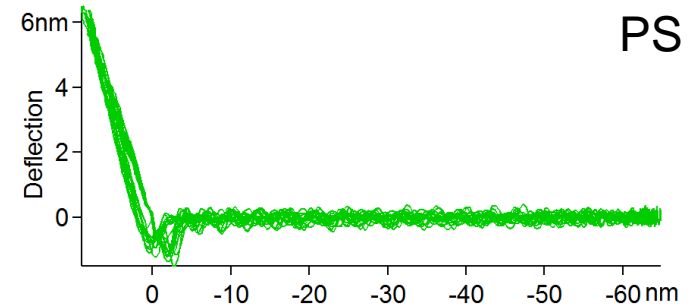
三元高分子共混物

纳米力学测量:

Fast Force Maps



聚苯乙烯/聚丙烯 (PS/PP) 旋涂薄膜



选择适合做力谱的探针，探针的刚度要适中，例如~1-2 N/m.

AC240TS-R3

k	2 N/m
r	7 nm
f	70 kHz
Q	123

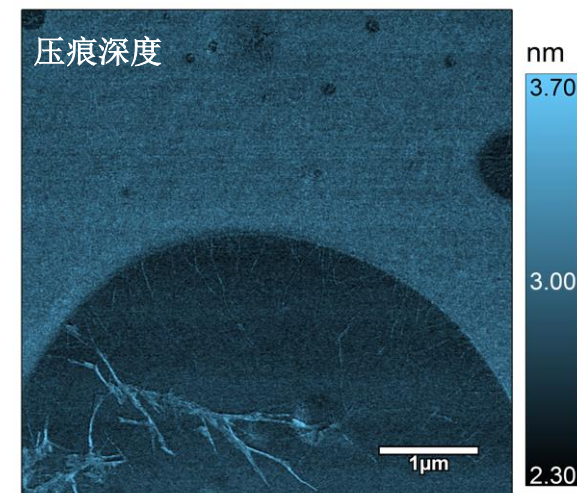
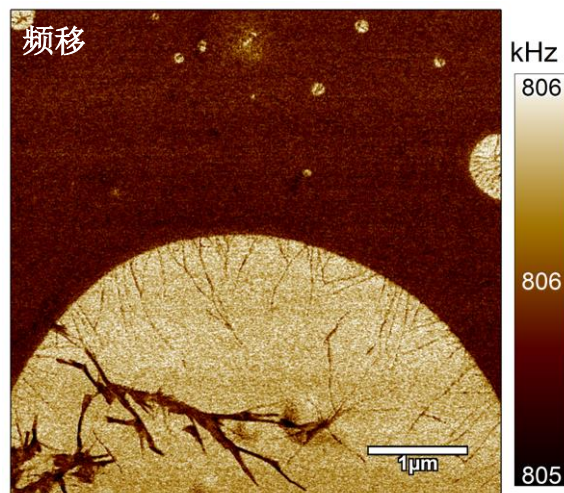
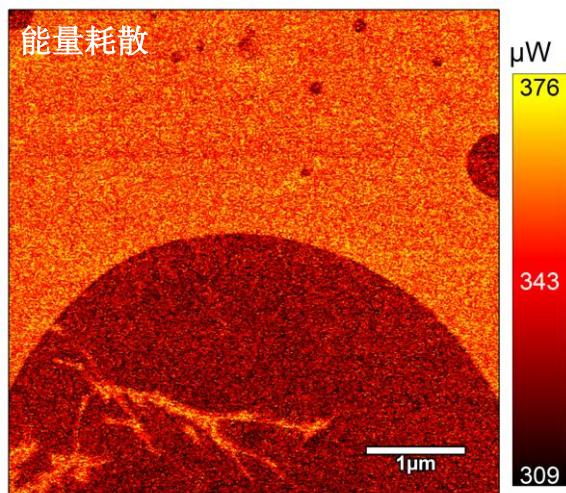
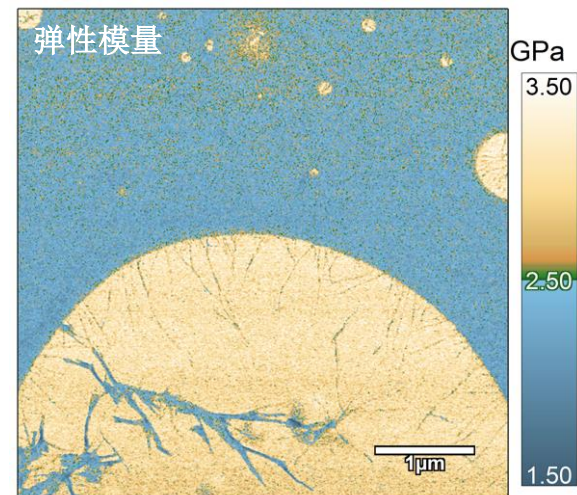
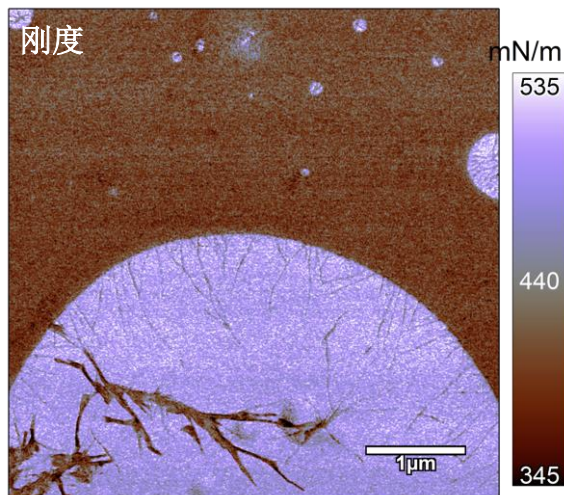
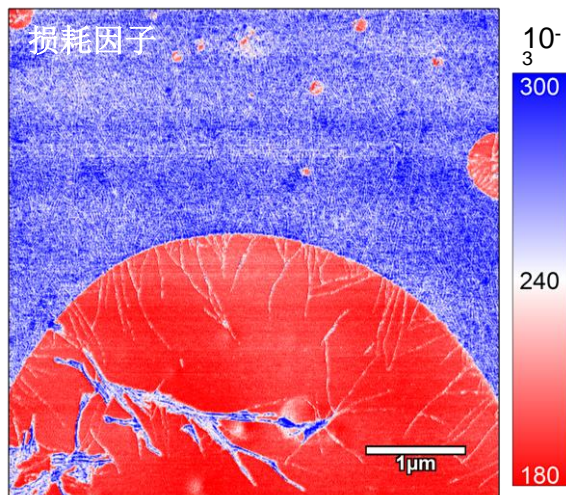
纳米力学测量:

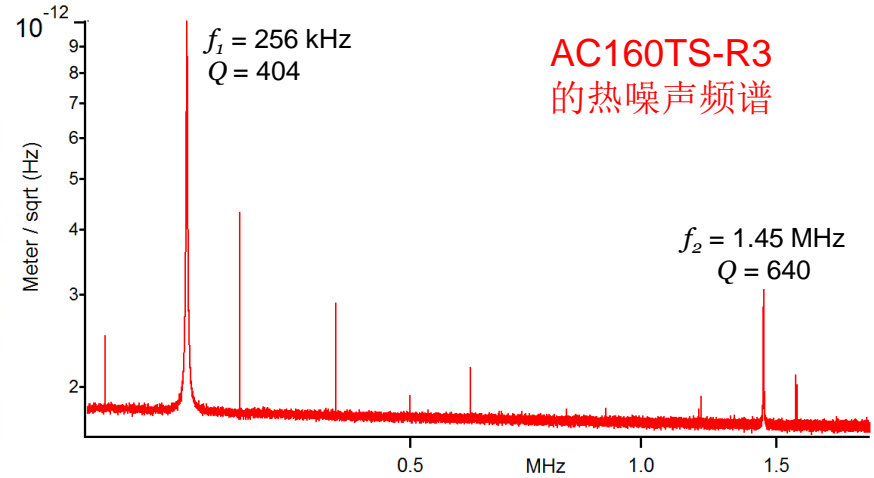
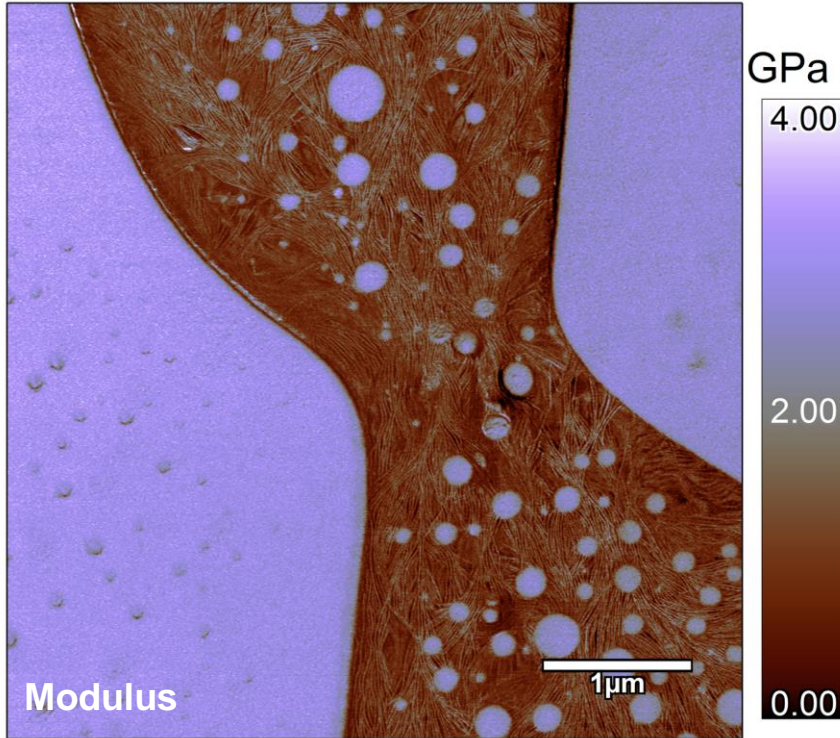
AM-FM (粘弹性图像)



OXFORD
INSTRUMENTS

The Business of Science[®]



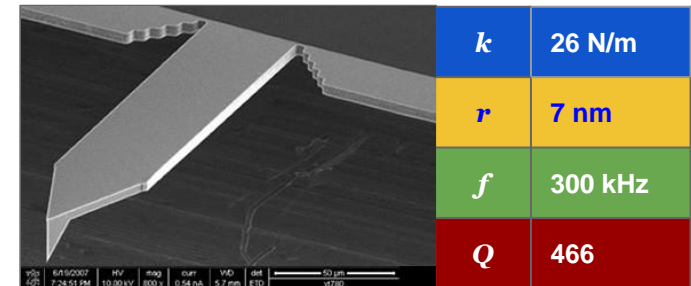


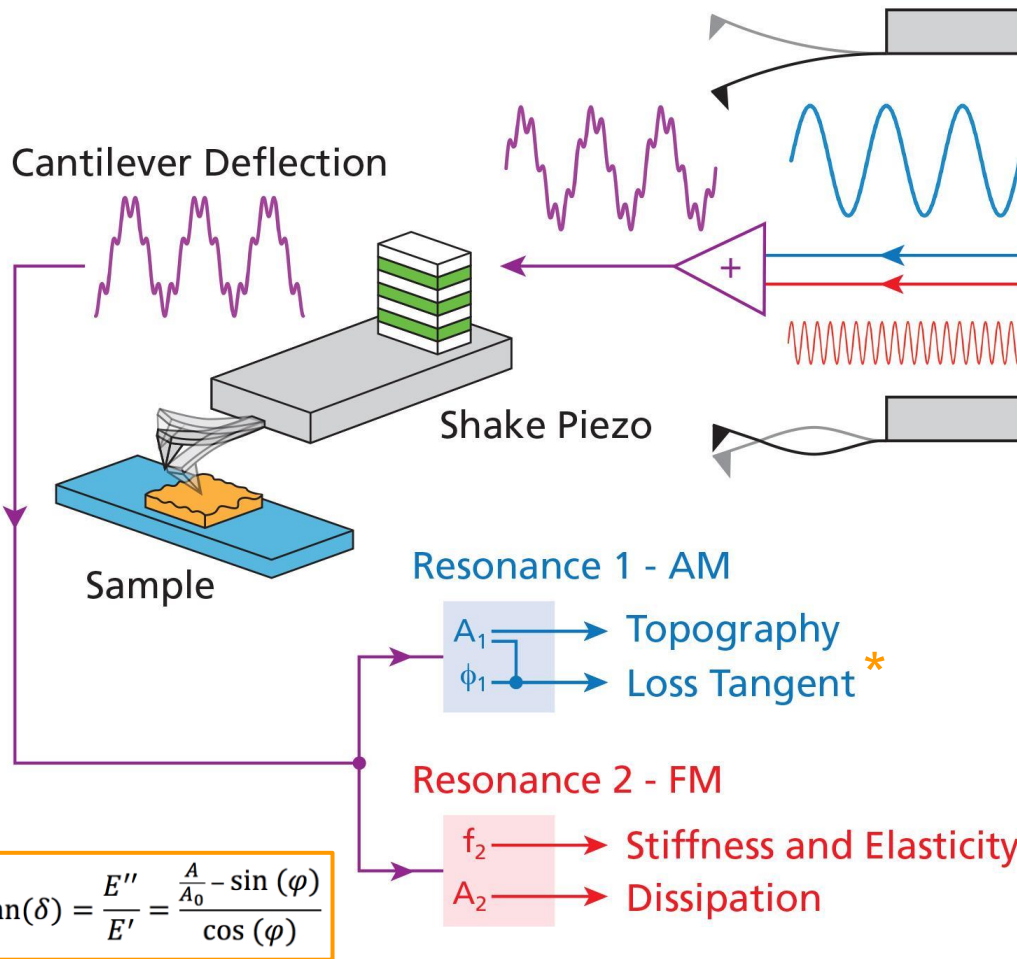
选取**轻敲模式**的探针，基础共振频率 f_1 在~150-350 kHz之间, 而二阶共振频率 f_2 (~6.25 $\times f_1$) 仍在AFM可测范围内

含有两种聚合物的旋涂薄膜:

- 聚苯乙烯: $E \sim 3 \text{ GPa}$
- 聚己酸内酯: $E \sim 0.5 \text{ GPa}$

AC160TS-R3





基础振动模态

- 调幅 (AM)
- 可观测的信号:
 - 振幅, A_1
 - 相位, $\phi_1 \rightarrow$ 频移, Δf_1

二阶振动模态

- 调频 (FM)
- 可观测的信号:
 - 频移, Δf_2
 - 驱动幅度, A_v

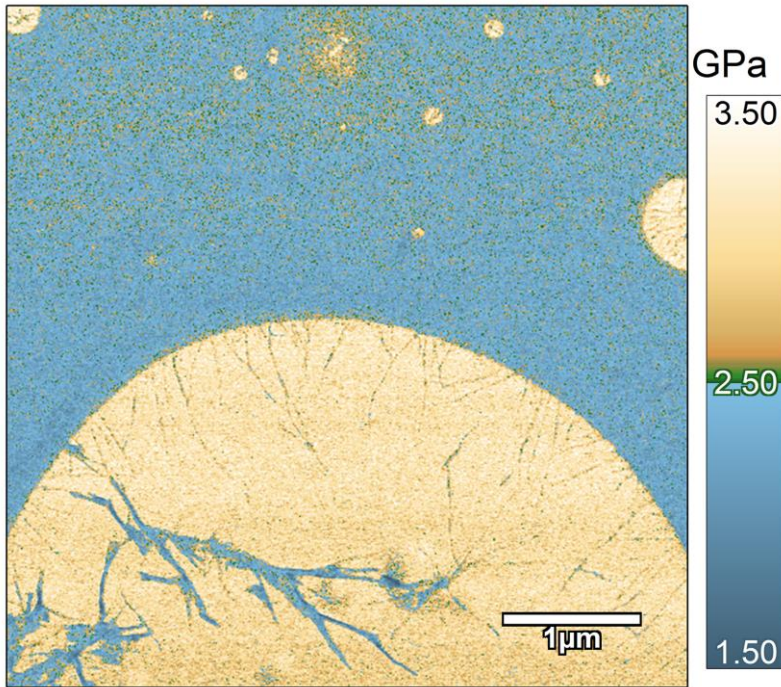
纳米力学测量:

AM-FM (粘弹性图像)

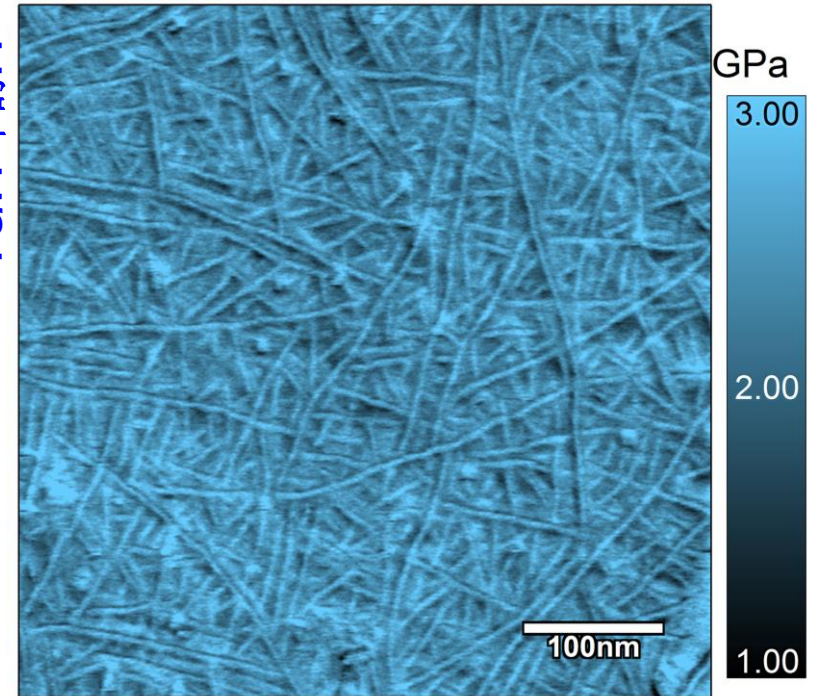


The Business of Science®

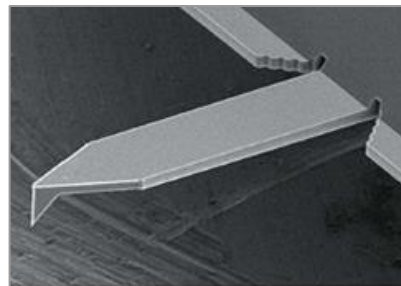
PS/PP



PS/PP中的PP

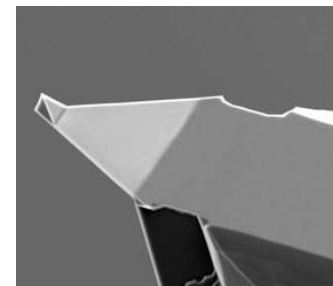


AC200TS



k	9 N/m
r	7 nm
f	150 kHz
Q	?

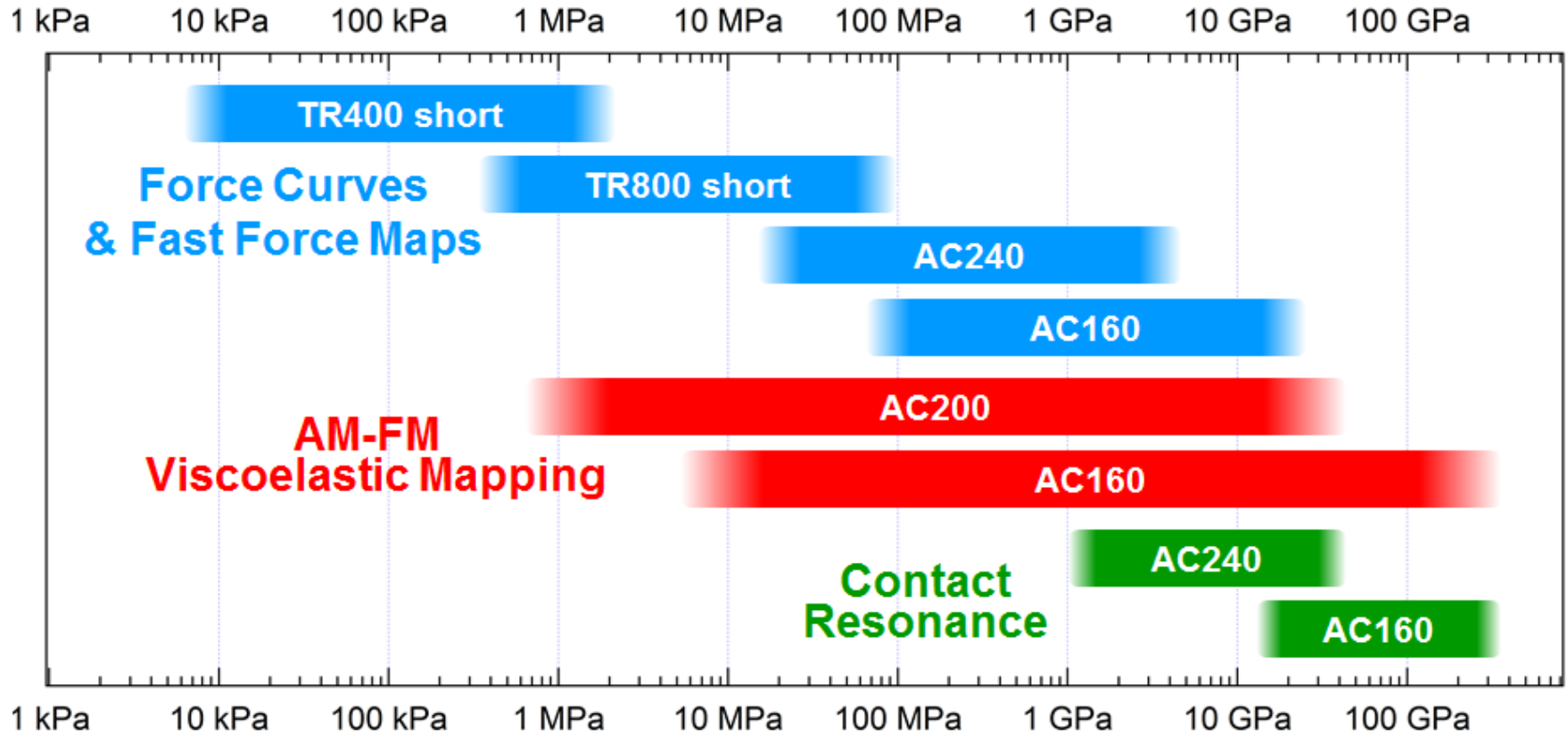
Arrow UHF



k	6 N/m
r	10 nm
f	2 MHz
Q	183

应用:

纳米力学测量



应用:

电学测量技术

OXFORD
INSTRUMENTS

The Business of Science®

MODE MASTER

Favorites Standard PFM **Electrical** Bio NanoMechPro Cypher



EFM SKPM Orca STM sMIM AC sMIM Single Pass SKPM MFM

电学测量技术需要探针具有导电性。

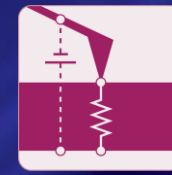


Orca

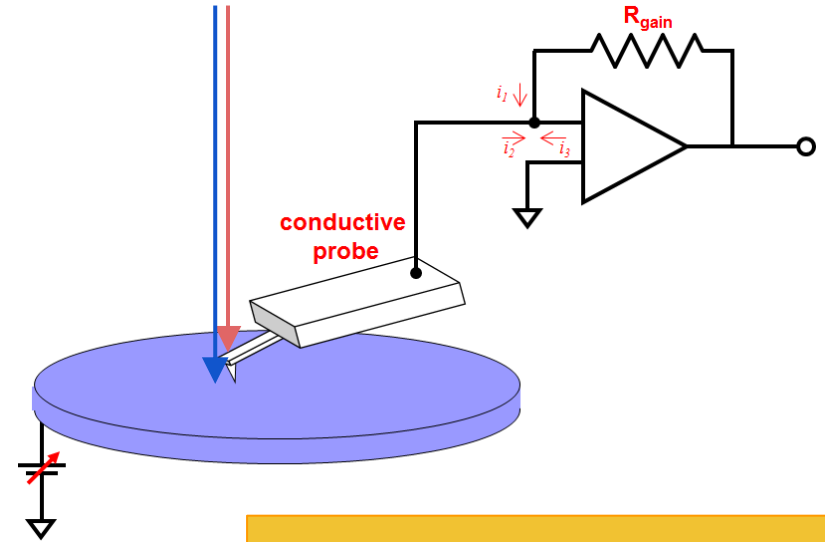
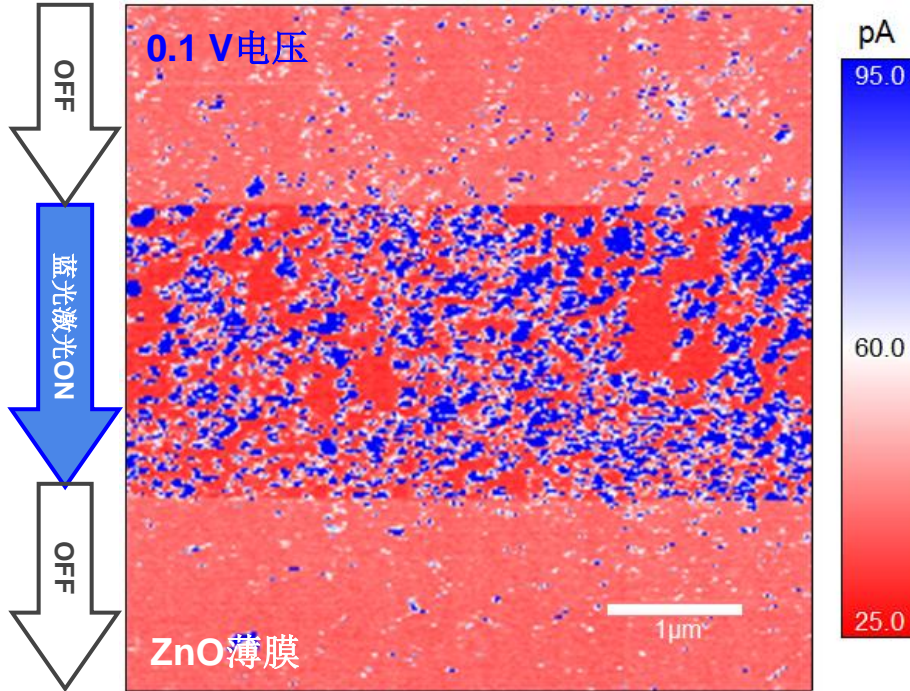
Conductive AFM (ORCA™) scans in contact mode while measuring any current flowing through the sample into the conductive tip. Additionally, this mode allows for localized I-V measurements which can be made at specific user-defined points.

电学测量技术:

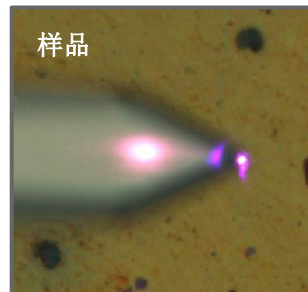
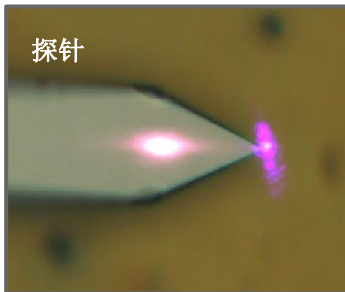
CAFM (ORCA™)



The Business of Science®



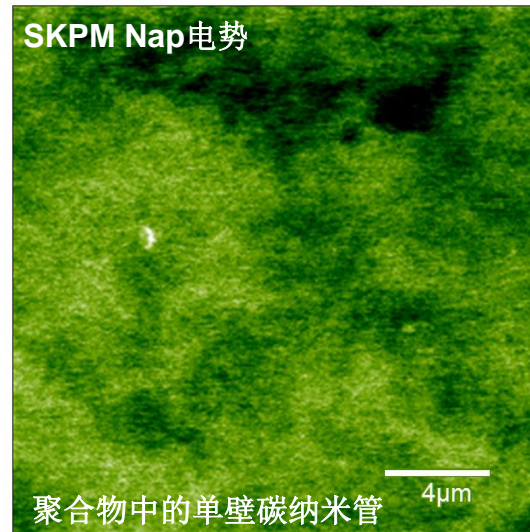
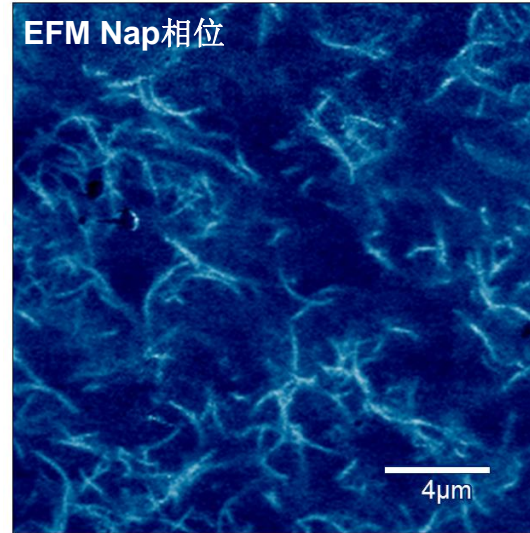
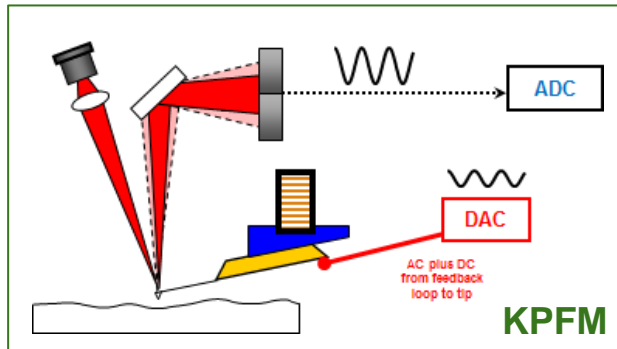
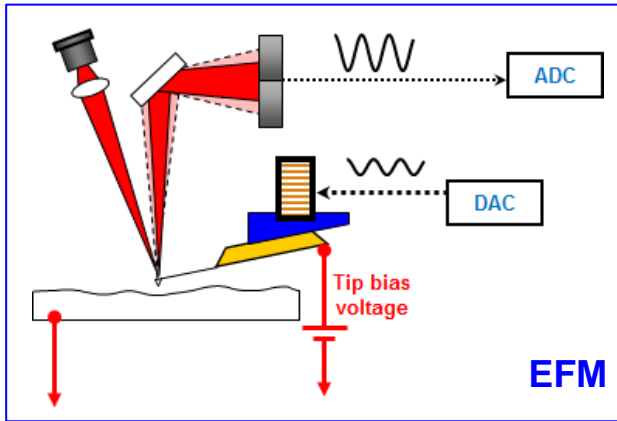
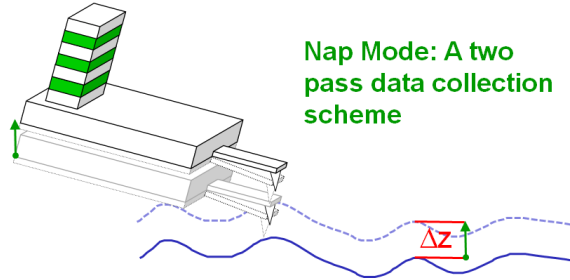
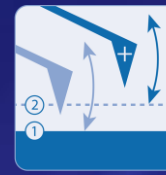
选取**接触模式**的探针，适中的弹性系数，例如~1-2 N/m



AC240TM-R3 (Ti/Pt镀层)

k	2 N/m
r	28 nm
f	70 kHz
Q	123

EFM和SKPM



选取轻敲模式的探针 (~70 kHz), 适中的弹性系数 (~1-2 N/m), 从而可以测量到微弱的长程力

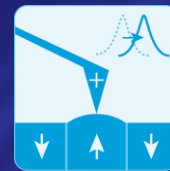
Asyelec-01 (Ti/Ir镀层)

k	2 N/m
r	28 nm
f	70 kHz
Q	123

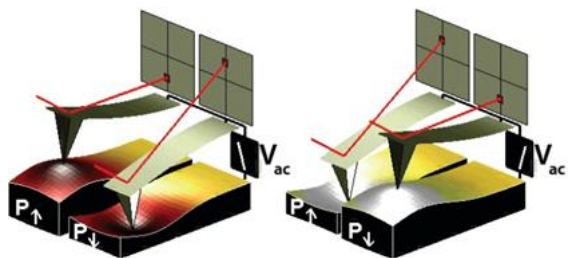
Arrow EFM (Pt/Ir镀层)

k	2.8 N/m
r	25 nm
f	75 kHz
Q	?

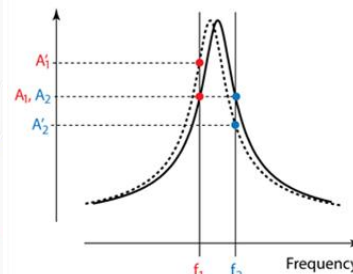
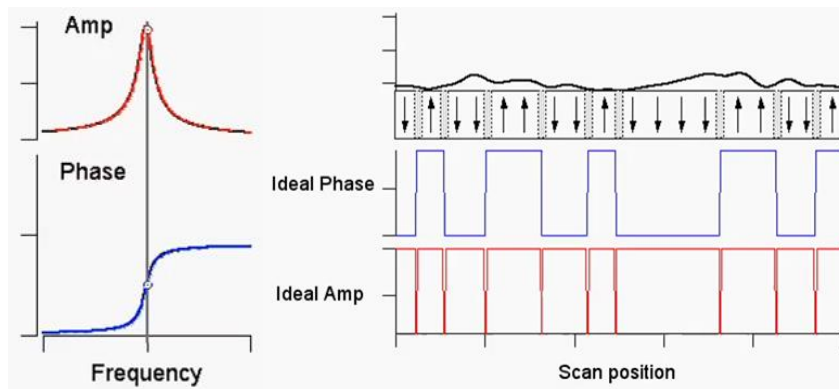
DART™ PFM



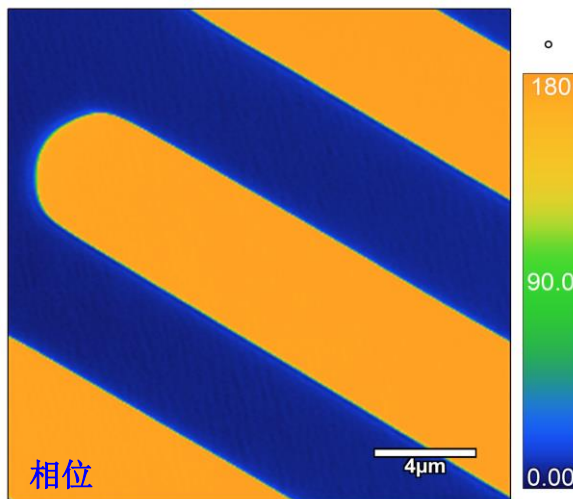
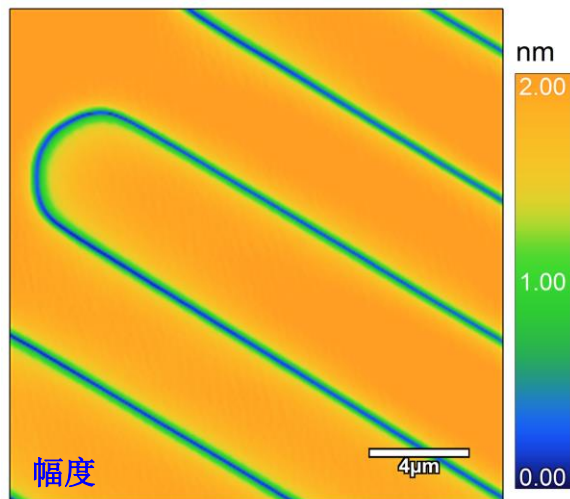
The Business of Science®



PFM: 接触模式+针尖上施加AC电压
记录由样品压电性质引起的接触共振信号



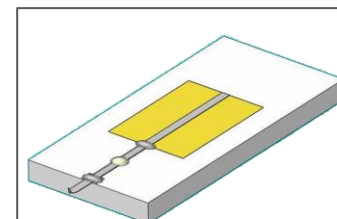
DART: 有助于在粗糙的样品表面保持对接触共振频率的追踪



周期极化铌酸锂 (PPLN) 样品

- ✓ 针尖较长
- ✓ 针尖完全由金属构成
- ✓ 弹性系数较大

Rocky Mountain探针



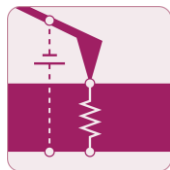
25Pt300B

k	18 N/m
r	20 nm
f	20 kHz
Q	?

应用:

电学测量技术

CAFM (ORCA™)



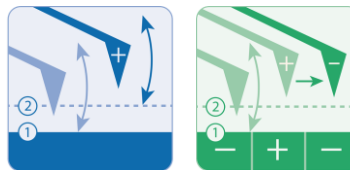
对于较硬的样品:

1. CDT-FMR
2. PtSi-FM
3. RMN 25Pt300B
4. Asyelec-02
5. Asyelec-01

对于较软的样品:

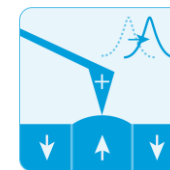
1. AC240TM-R3
(Electrilever)
2. ATEC-EFM
3. PPP-EFM

EFM和SKPM



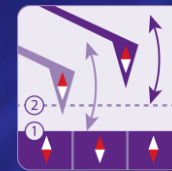
1. AC240TM-R3
(Electrilever)
2. ATEC-EFM
3. PPP-EFM

PFM

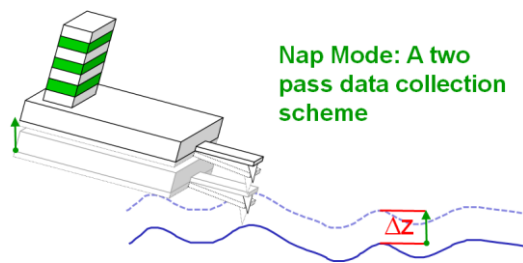


1. AC240TM-R3
(Electrilever)
2. CDT-FMR
3. PtSi-FM
4. RMN探针 (最好是较短的探针)

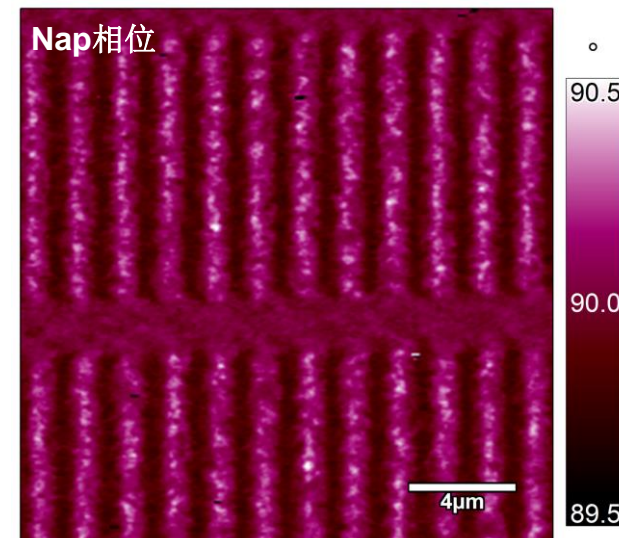
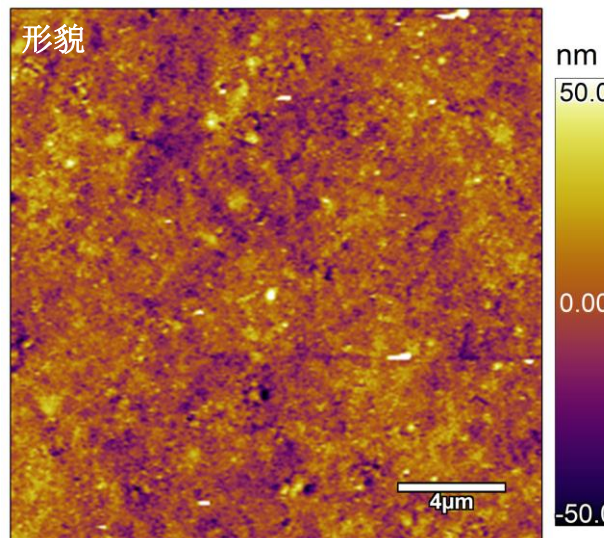
应用： MFM



The Business of Science®



- 同样基于Nap模式
- 针尖由磁性镀层
- Nap相位显示样品的磁性性质



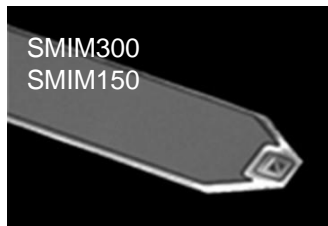
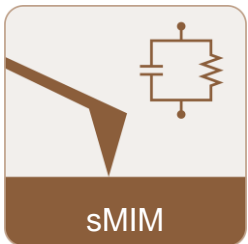
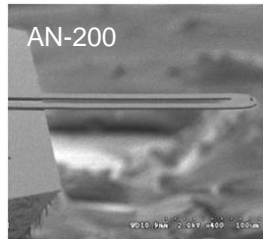
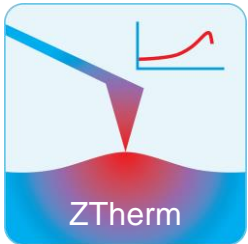
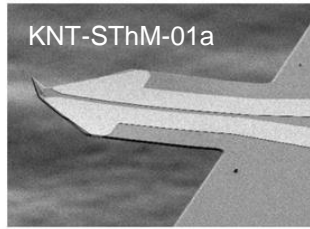
磁盘

型号	类型	针尖镀层	曲率半径
ASYMFMLC	低矫顽力	permalloy	32 nm
ASYFMHC	高矫顽力	CoPt/FePt	32 nm
ASYMFMLM	低磁矩	CoCr	20 nm
ASYFMHM	高磁矩	CoCr	84 nm

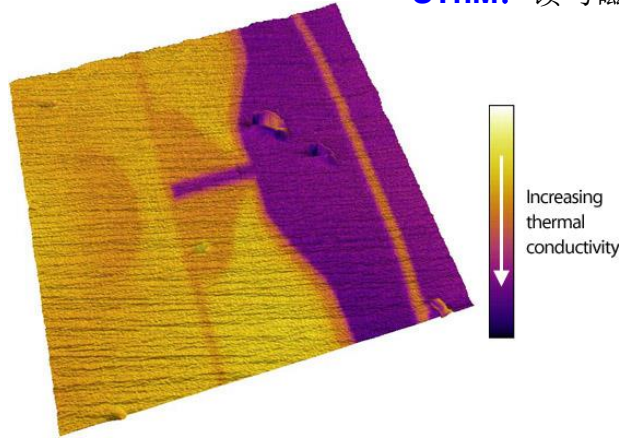
ASYMFM系列探针

	k	2 N/m
	r	various
	f	70 kHz
	Q	123

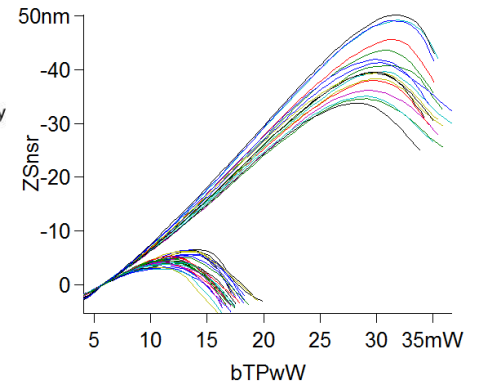
特殊探针



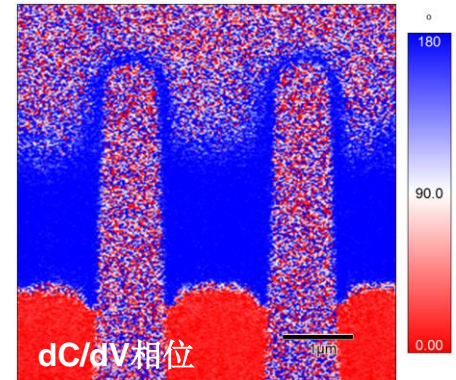
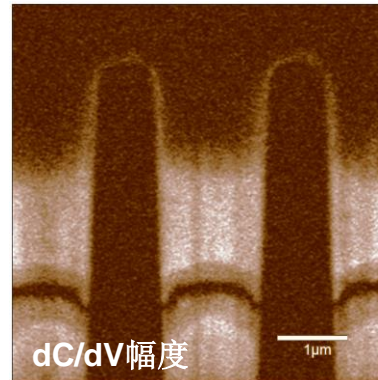
SThM: 读写磁头



Ztherm:
PS/PCL共混物



sMIM: 晶体管 (IGBT) 掺杂浓度和掺杂类型



您当前的位置：首页 > AFM

- 所有商品
- 设备&工具 ^
- SEM ^
- TEM ^
- FIB ^
- AFM ^
- 不导电探针
- 导电探针
- 磁性探针
- 生物探针
- 快扫描探针
- 特殊探针
- 经济型探针
- 不导电探针 导电探针
- AFM实验工具用品
- 耗材&试剂 ^
- 特价促销 ^
- 培训&应用 ^

热榜推荐 MORE+

商品筛选(共39件商品) 重置筛选项 >

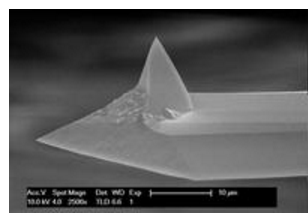
您已选择：

分类： 不导电探针 导电探针 磁性探针 生物探针 快扫描探针 特殊探针 经济型探针 AFM实验工具用品

品牌： **不限** Olympus Asylum Research Nanoworld/Nanosensor PrimeNano

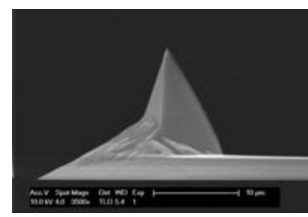
排序： 仅显示有货 1/2

筛选：



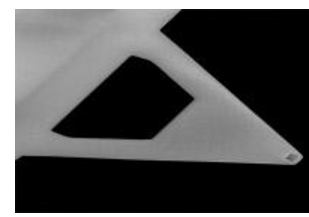
AFM导电探针Econo-SCM-PIT 10根/盒

¥1800.00



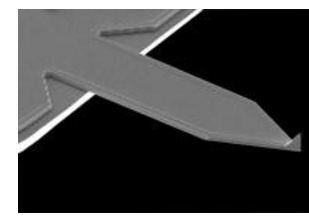
AFM接触式探针Econo-TESP 10根/盒

¥1500.00



AFM探针Olympus生物探针TR400PSA 10根/盒

¥2400.00



AFM探针Olympus不导电探针A 10根/盒

¥2950.00

展开商品对比

所有商品

设备&工具 ^

SEM ^

TEM ^

FIB ^

AFM ^

不导电探针

导电探针

磁性探针

生物探针

快扫描探针

特殊探针

经济型探针

不导电探针 导电探针

AFM实验工具用品

商品筛选(共5件商品)

您已选择：

品牌：**不限** Olympus Asylum Research Nanoworld/Nanosensor

探针数量：**不限** 10根 30根 70根 100根

默认

价格↓

销量↓

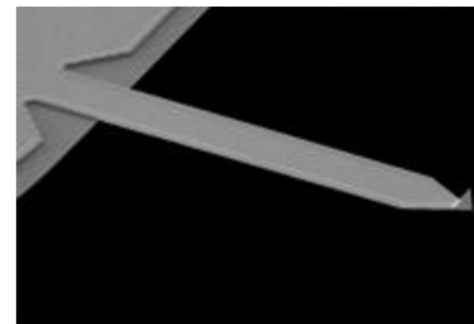
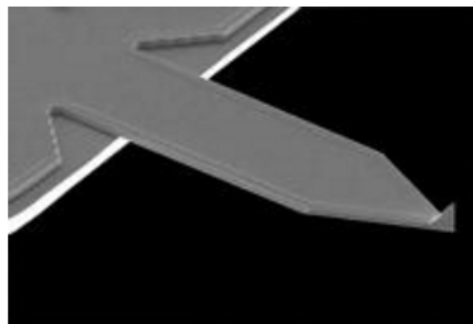
排序：默认

大图

列表

仅显示有货

筛选：



Asylum推出

全新的SurfRider™探针产品线

OXFORD
INSTRUMENTS

The Business of Science®

Econo Board™探针

- Asylum SurfRider™产品线中的第一款探针
- 价格实惠，可用于日常使用
- 一流的性能和一致性
- 多种型号，支持大多数的成像模式
- 兼容blueDrive™，GetReal™，和GetStarted™



了解更多信息：www.oxford-instruments.com/EconoBoardProbes

Fast Board™探针

- 高速，超尖锐，可用于气相和液相的扫描
- 最好的制作质量，最严的加工公差，帮助您取得一致的结果
- 共振频率通常在1.5MHz，针尖曲率半径小于10 nm

订购您的探针

美洲和澳洲

全新的探针商店: afmprobes.asylumresearch.com

中国

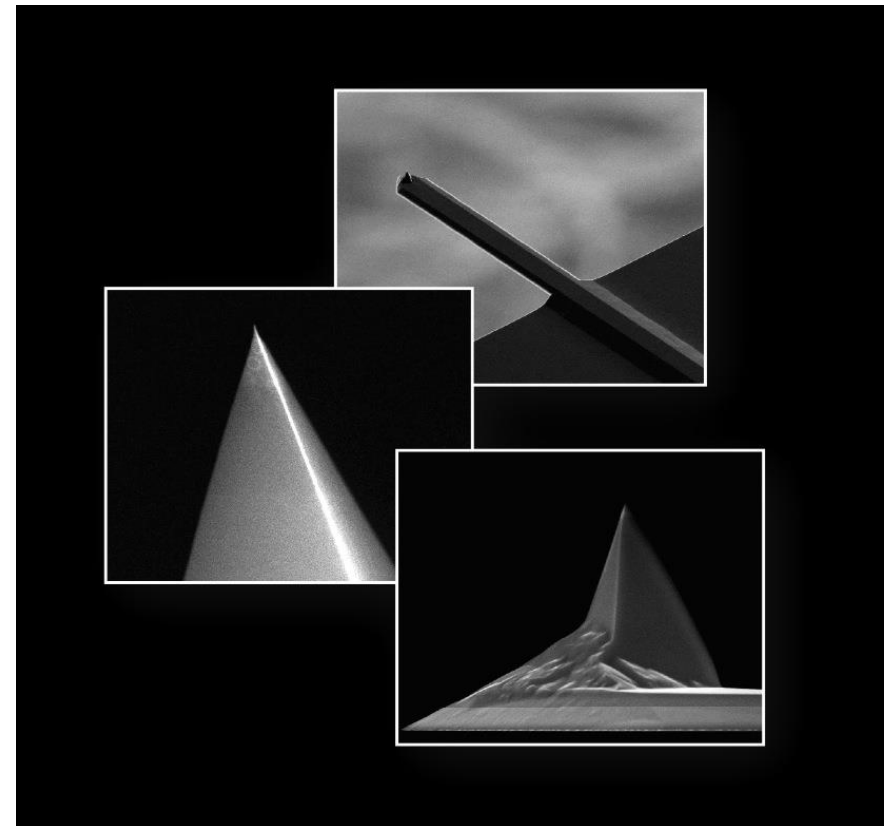
全新的探针商店: www.51haocai.cn

欧洲

发送邮件至: afm.info.eu@oxinst.com

日本

发送邮件至: support.asylum.jp@oxinst.com



谢谢观看

