扫描探针显微技术

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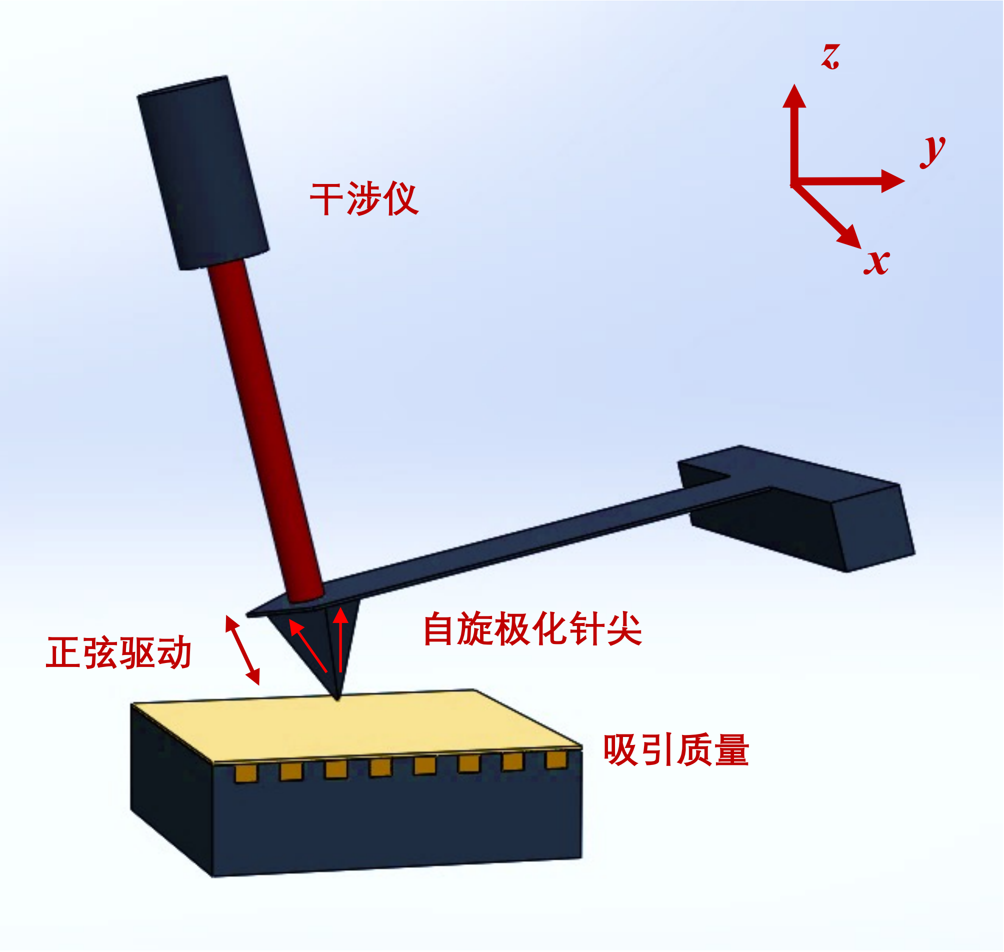
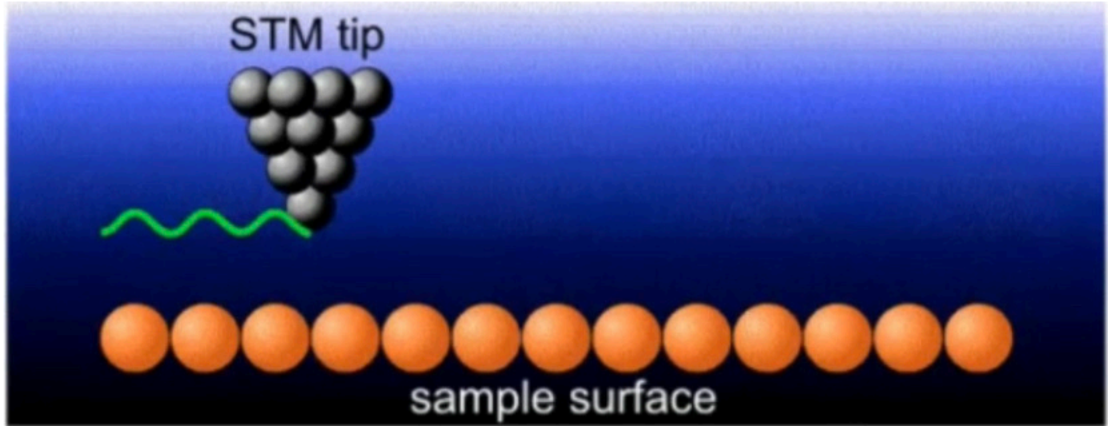


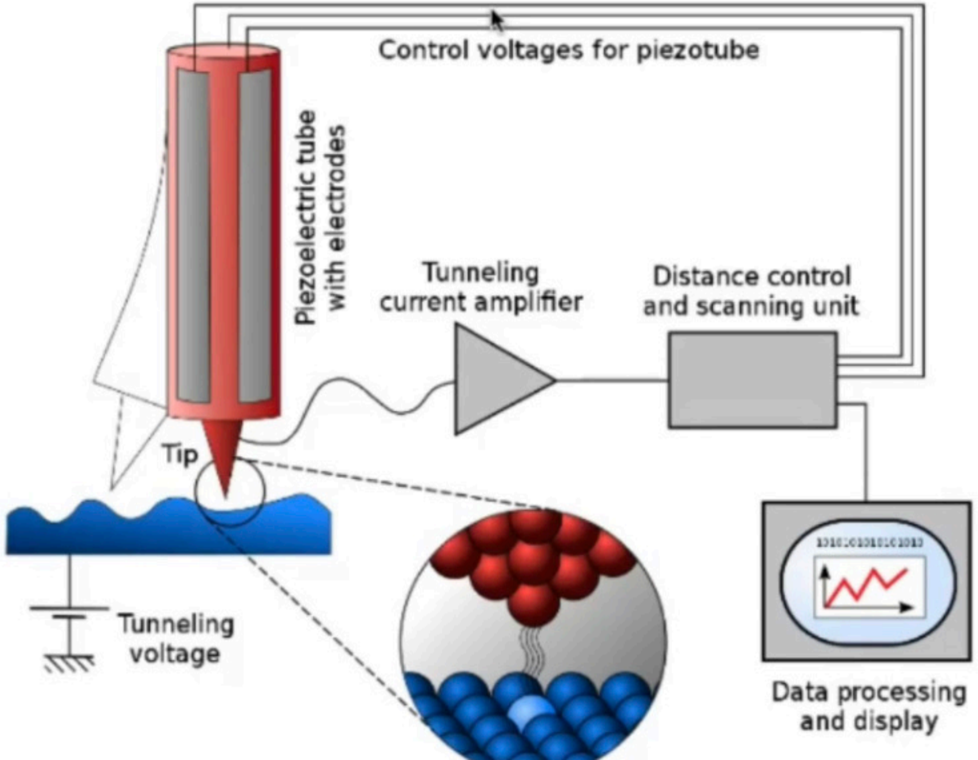
STM（Scanning Tunnel Microscope，扫描隧道显微镜）

The invention of the scanning tunneling microscope(STM) by G. Binnig and H. Rohrer in 1981.(Nobel Prize in physics in 1986)

IBM's Zurich Research Laboratory

STM（Scanning Tunnel Microscope，扫描隧道显微镜）





- 隧道电流：nA, pA
- 工作间距：nm
- 原子分辨：

  Z: 0.01 nm

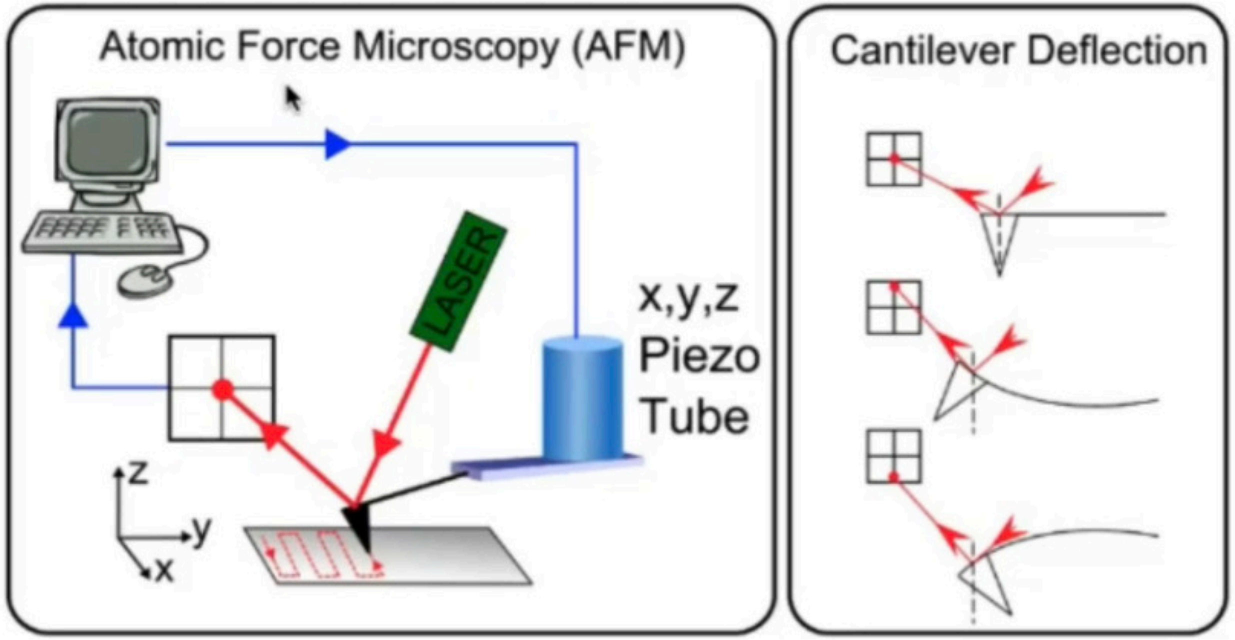
  XY: 0.1 nm

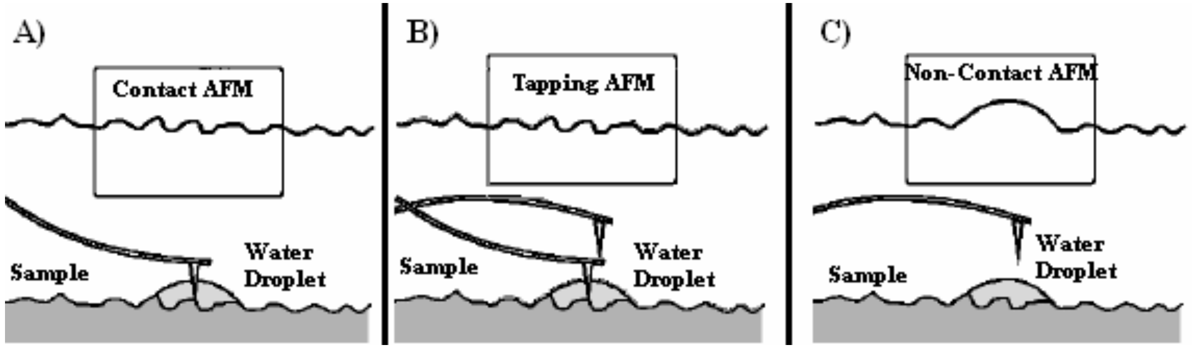
需要：

- 精密位移控制
- 微弱信号测量
- 环境（低温、低振动、真空）
- 系统控制

AFM（Atomic Force Microscope, 原子力显微镜）

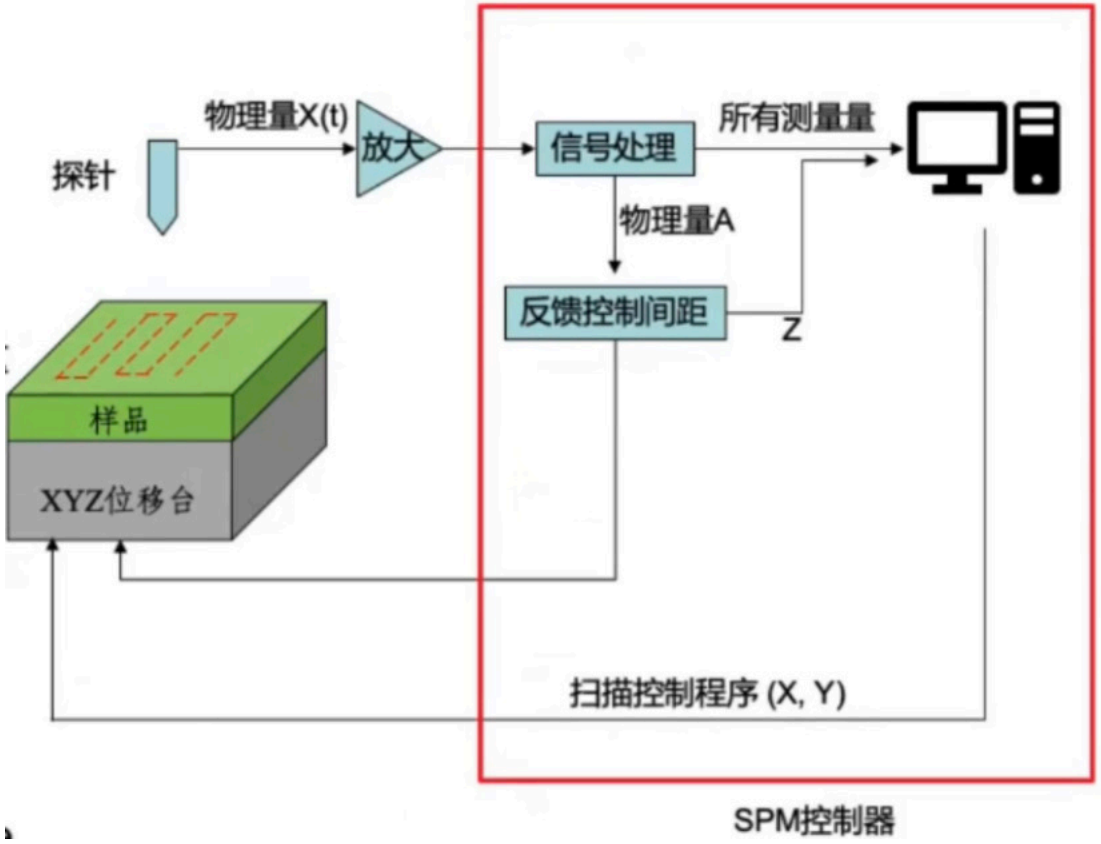
The first and most important extension of the STM was the scanning force microscope(SFM) or atomic force microscope(AFM), invented in 1986 by Binnig, Quate and Gerber.





Scanning Probe Microscope Family(SPM)

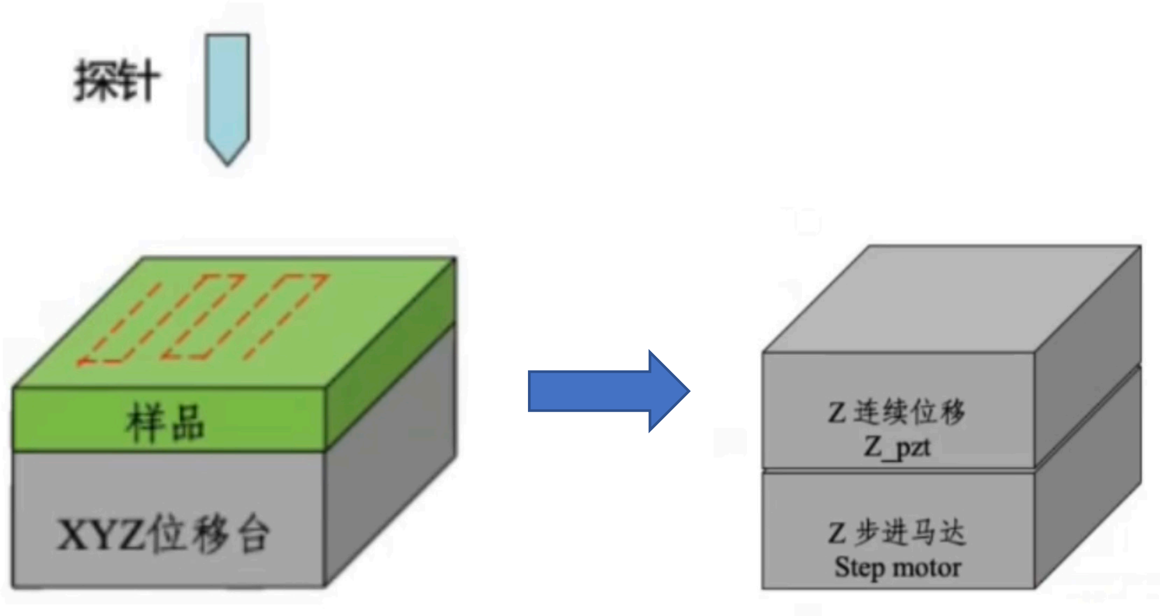
- STM: 金属针尖，隧道电流
- AFM：悬臂梁针尖，悬臂梁位移
- MFM（磁力显微镜）：AFM扫出表面形貌；
  设置间距重扫
- SNOM(扫描近场光学显微镜)：光纤，光信号



scanning squid microscope

scanning capacitance microscope

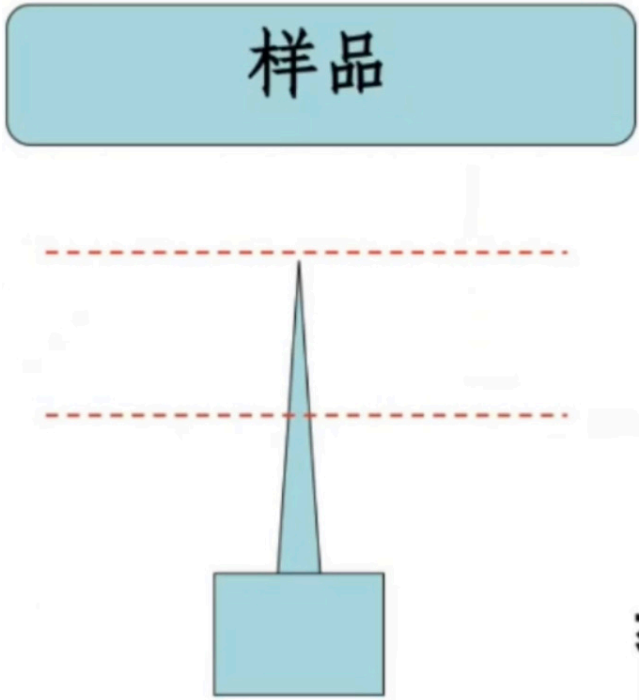
精密位移控制

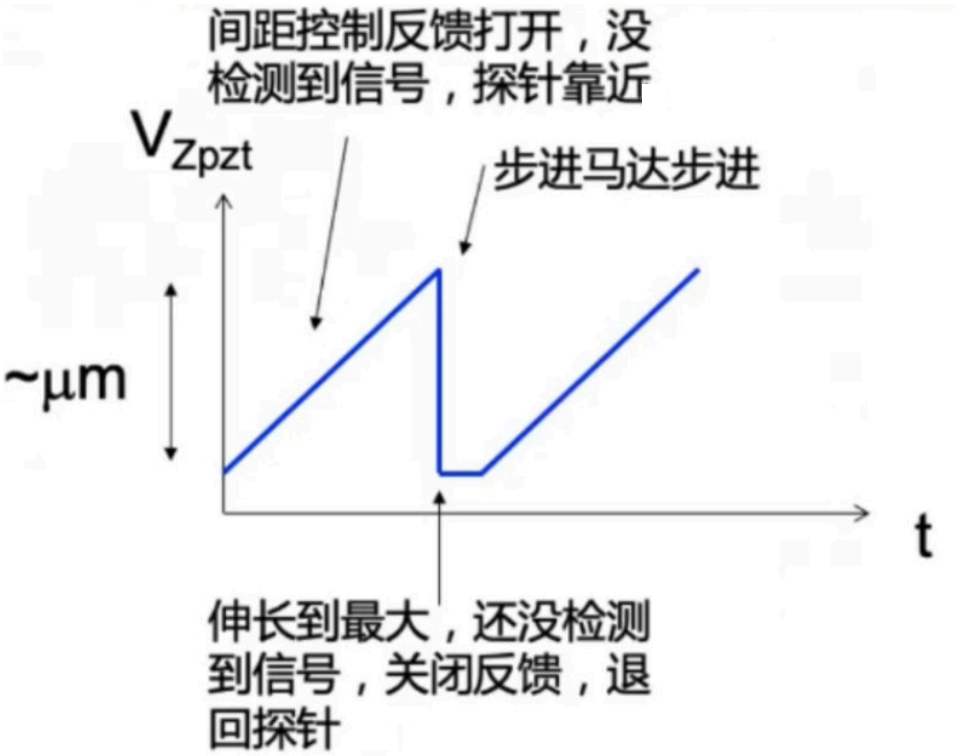


精密位移的实现依赖于：

- 压电陶瓷的压电特性——连续位移
- 进针程序、步进马达——离散位移
- 反馈控制（PID反馈）

精密位移控制（进针程序）


样品


间距控制反馈打开，没
检测到信号，探针靠近
V_{Zpzt}
步进马达步进
~μm
t
伸长到最大，还没检测
到信号，关闭反馈，退
回探针

精密位移控制（PID反馈）

比例-积分-微分反馈, Proportion-Integral-Derivative(PID)

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d\frac{de(t)}{dt}\right]$$

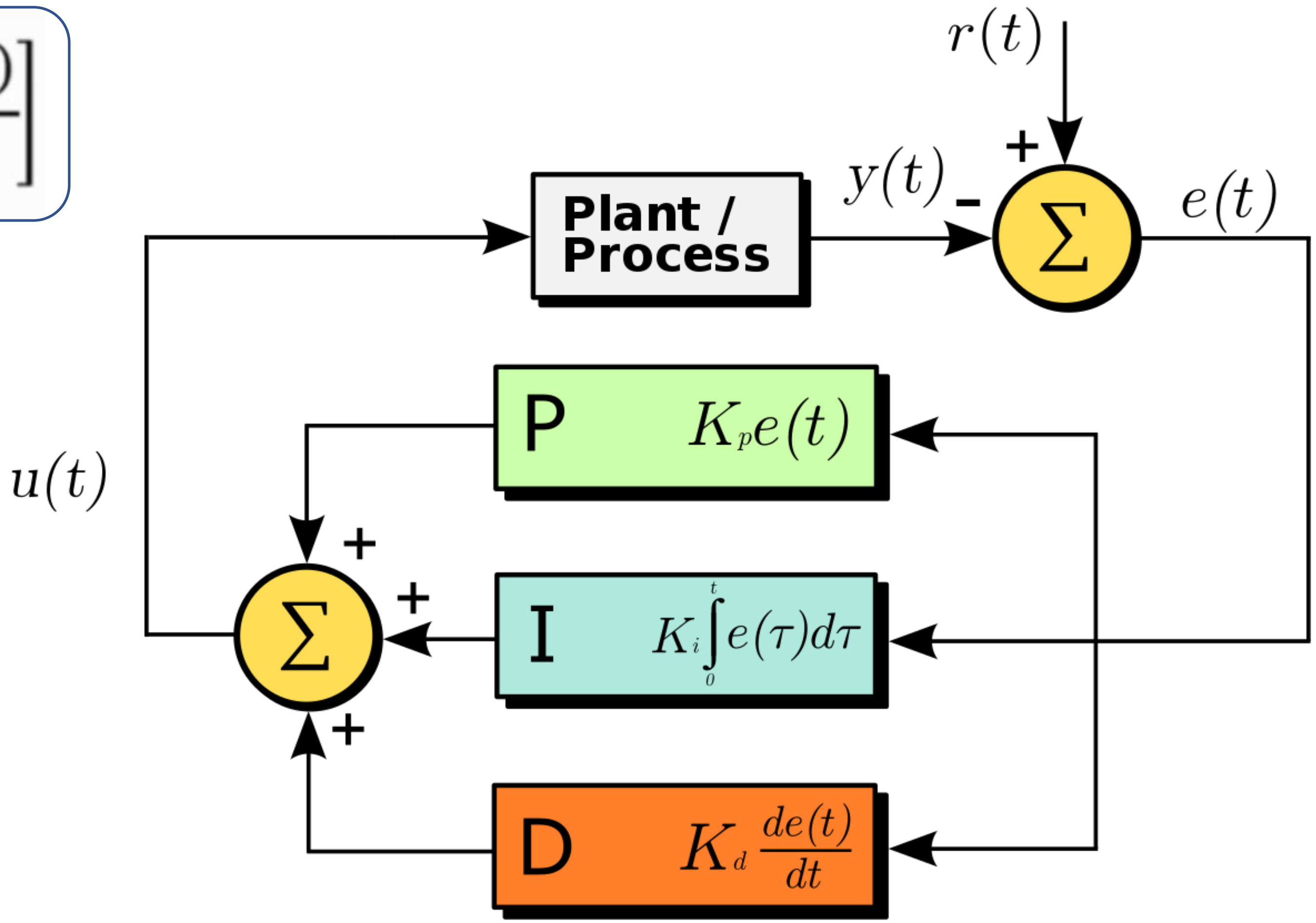
Laplace transform

$s = i\omega$

传递函数：

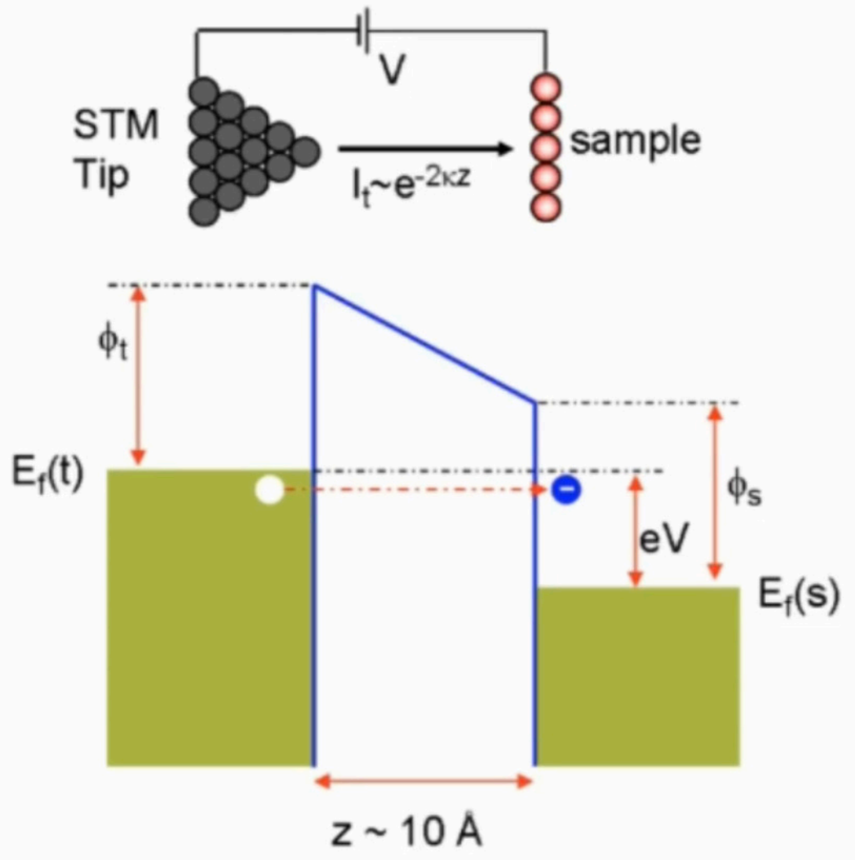
$$G(s) = \frac{U(s)}{E(s)} = K_p\left[1 + \frac{1}{T_i s} + T_d s\right]$$

$$= K_p + K_i\frac{1}{s} + K_d s$$



微弱信号测量

$$I=\int_0^{eV}\rho_t(E)\rho_s(E-eV)[f(E)-f(E-eV)]T(E,eV)dE$$



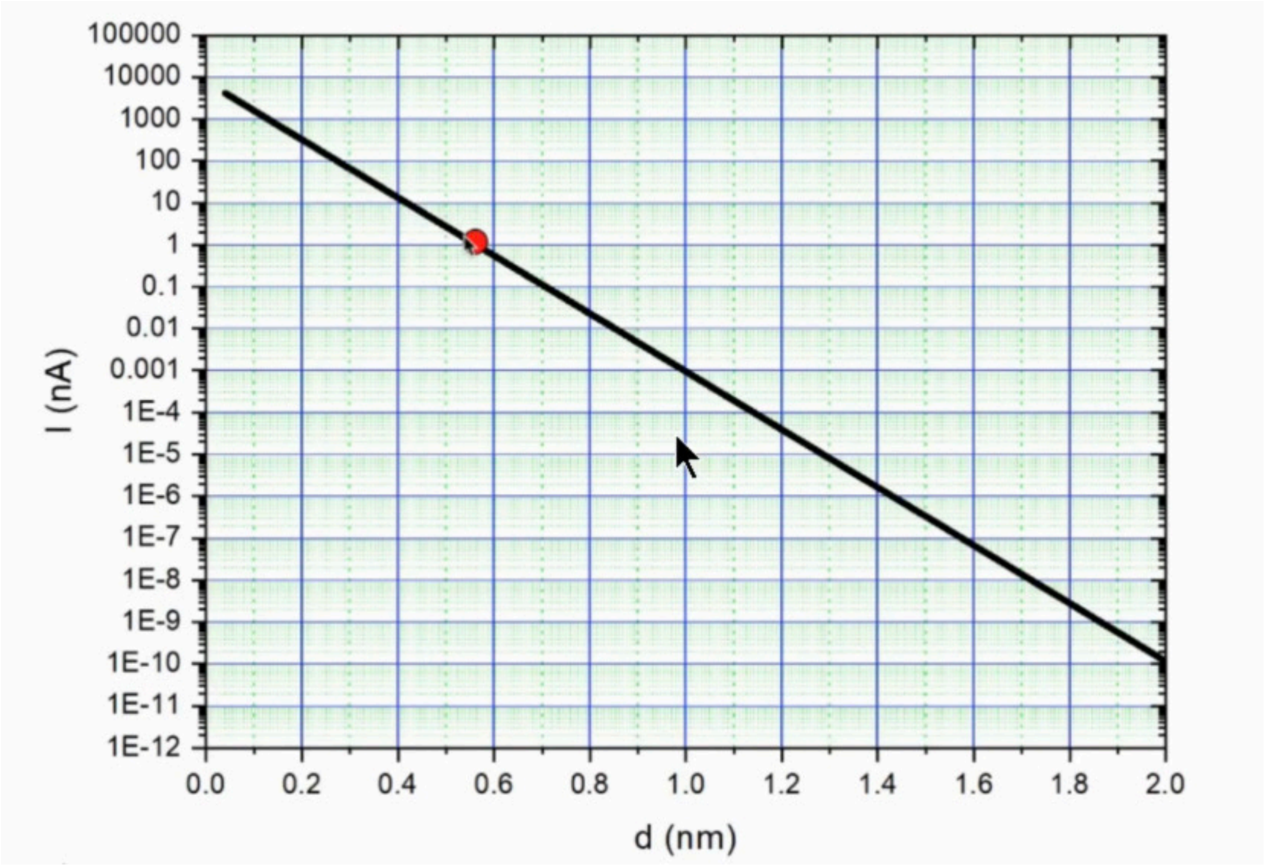
$$I \propto e^{-2\kappa z}$$

$$\boxed{\frac{\mathrm{d}I}{\mathrm{d}V}\propto \rho_s(\vec{r},eV)}$$

局域态密度测量

$$k\approx\frac{\sqrt{2m_e\phi_0}}{\hbar}\qquad \text{Au:}\quad \phi_0=4.83\ eV$$

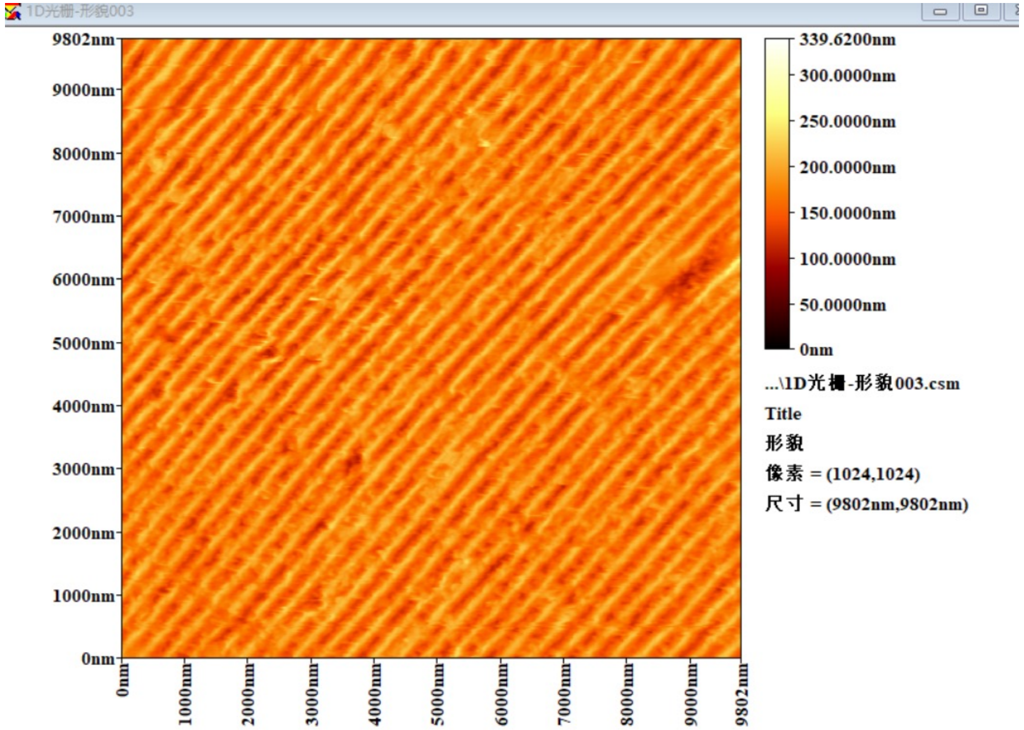
微弱信号测量



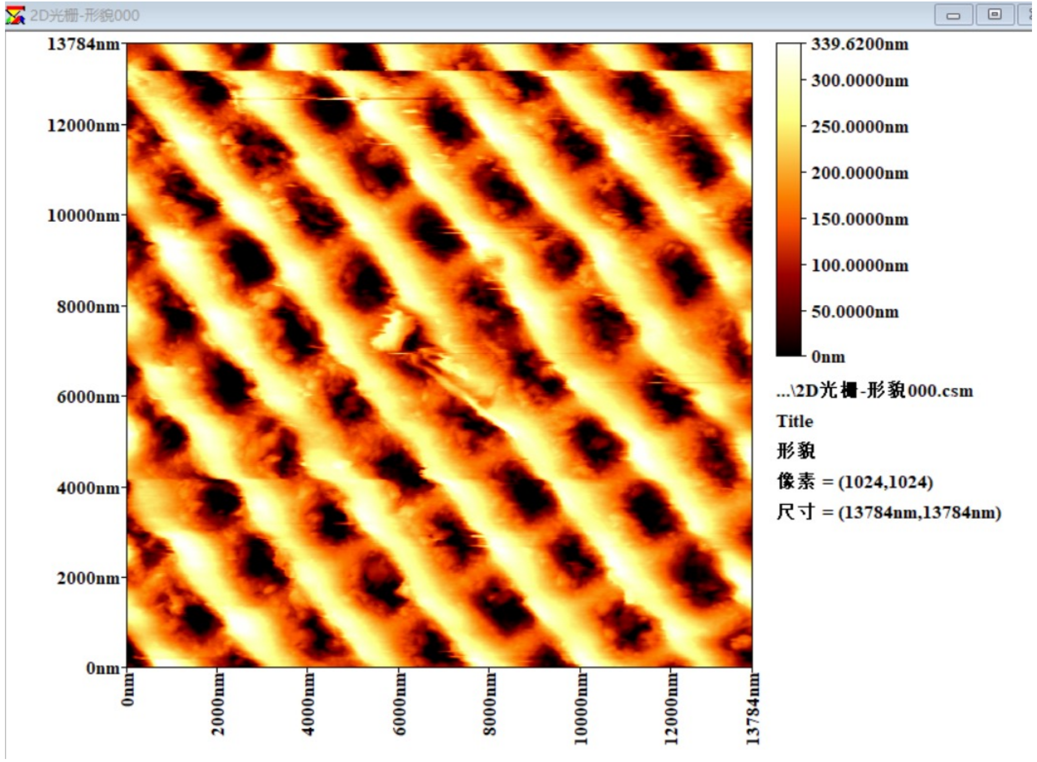
- 电流放大器：

- 双绞线、同轴线（回路中的感应电流）

扫描探针显微镜的应用：表面形貌

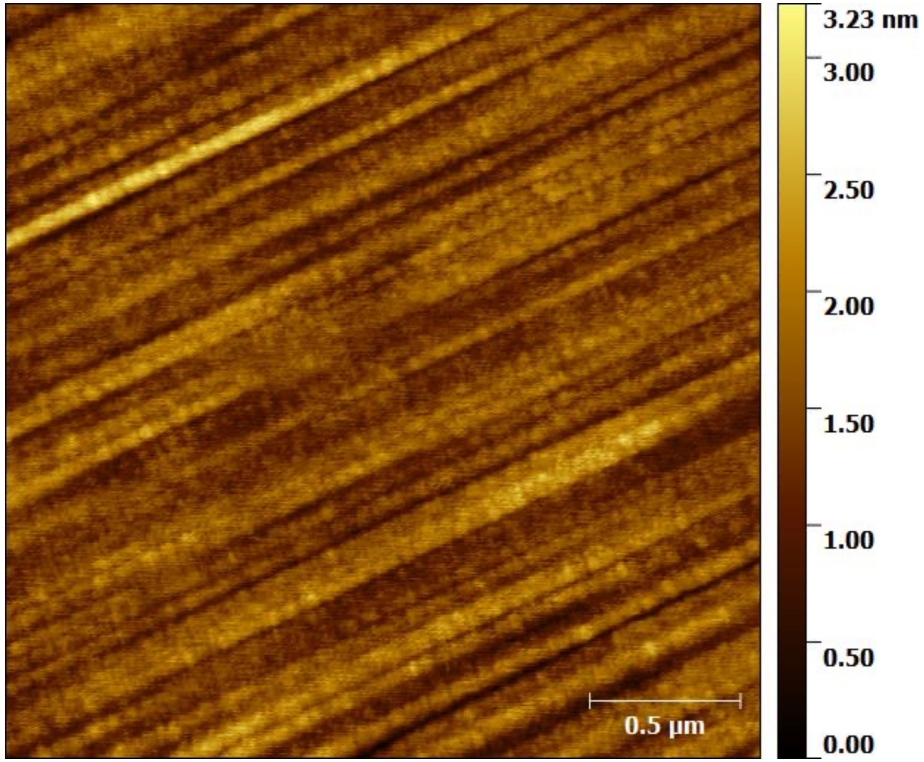


一维光栅，周期尺寸为190nm

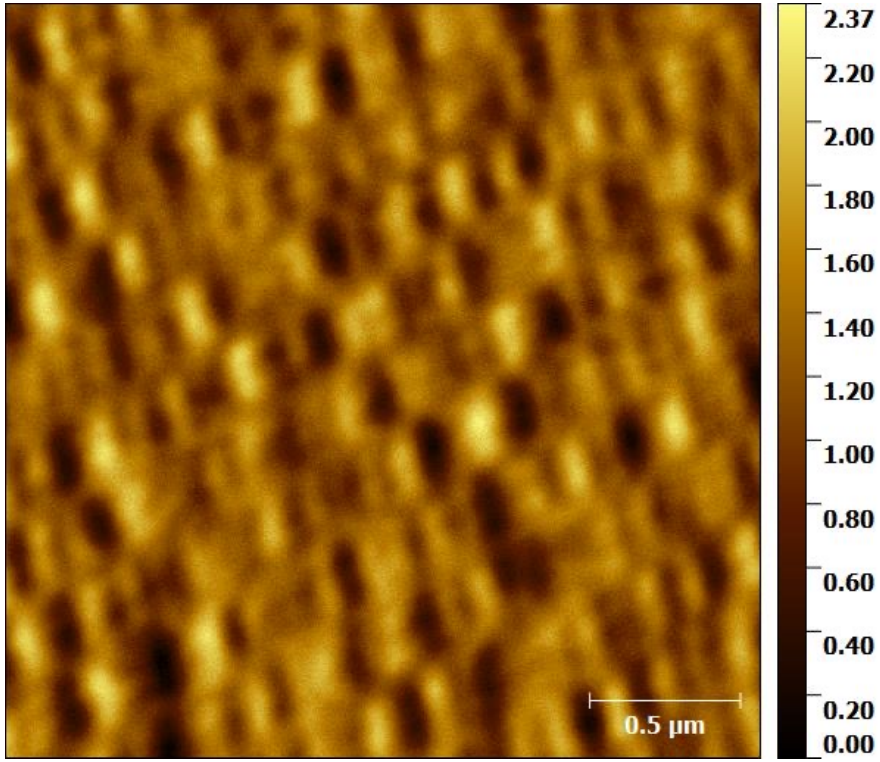


二维光栅，周期尺寸1.8um

扫描探针显微镜的应用：表面形貌



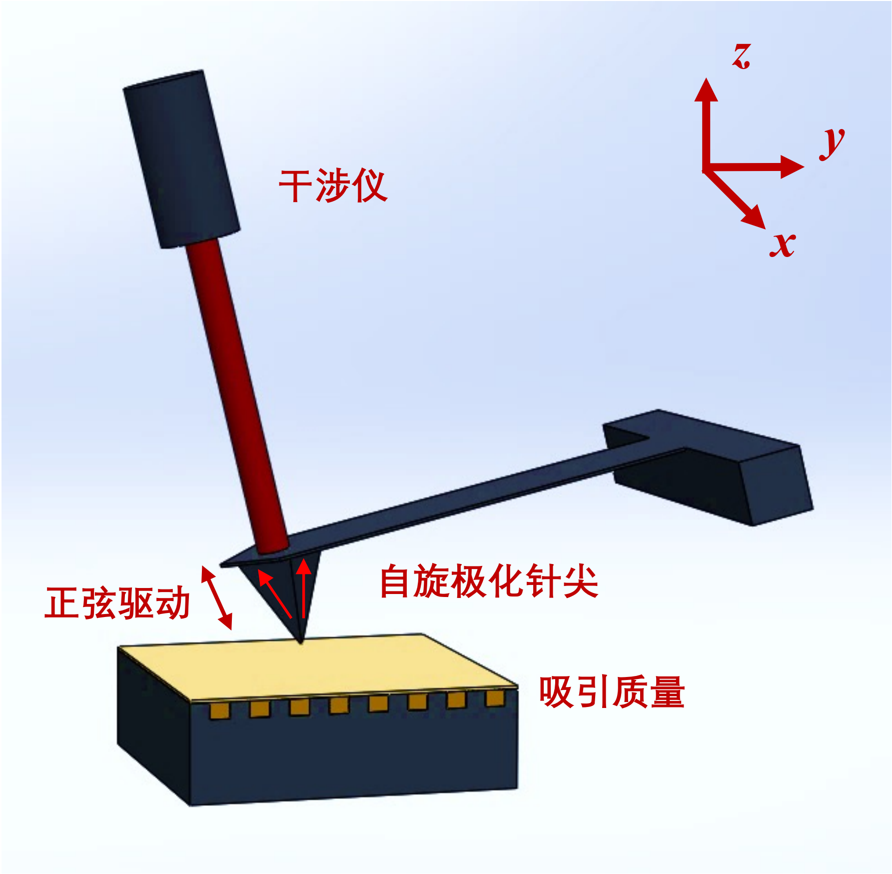
磁盘形貌图

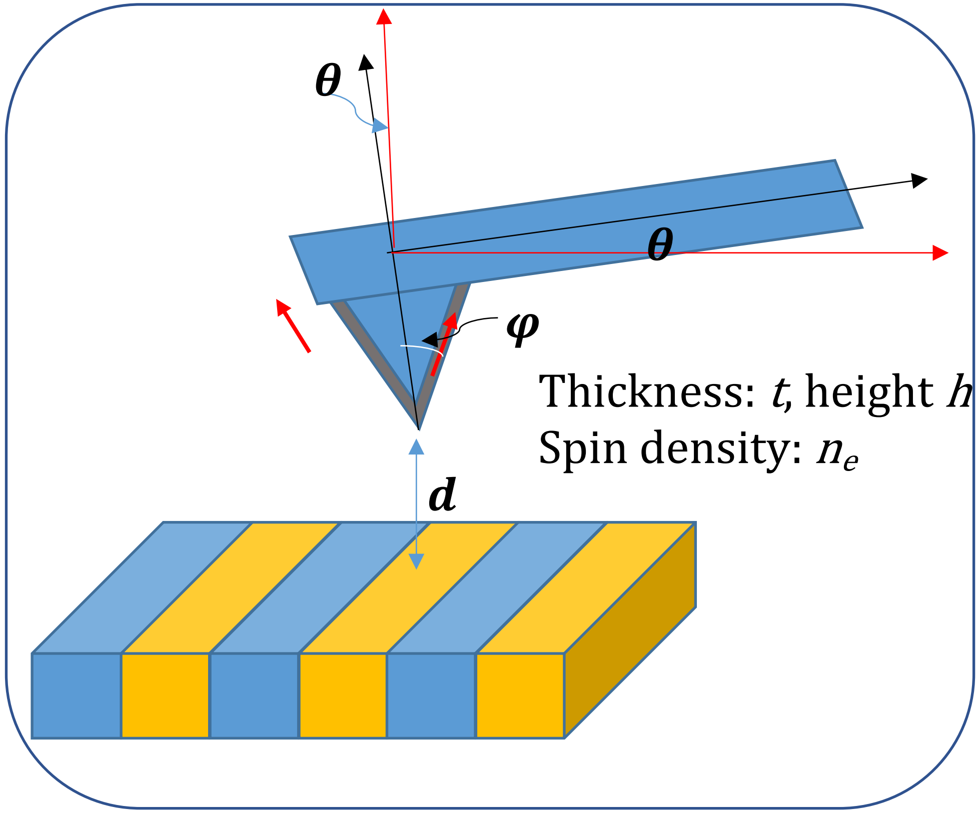


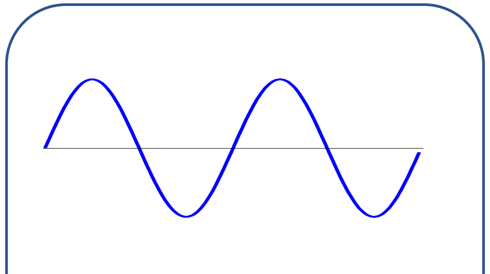
磁盘磁畴图

扫描探针显微镜的应用：新物理效应的检验

$$V_{12+13} = Af_v \frac{\hbar}{8\pi} \int n_a dV_a \int n_e dV_e v \cos\varphi \left(\frac{1}{r}\right) e^{-\frac{r}{\lambda}}$$







谢谢！

Much of the content credited to Pengshun Luo, sincere thanks.