

# LATERAL PFM

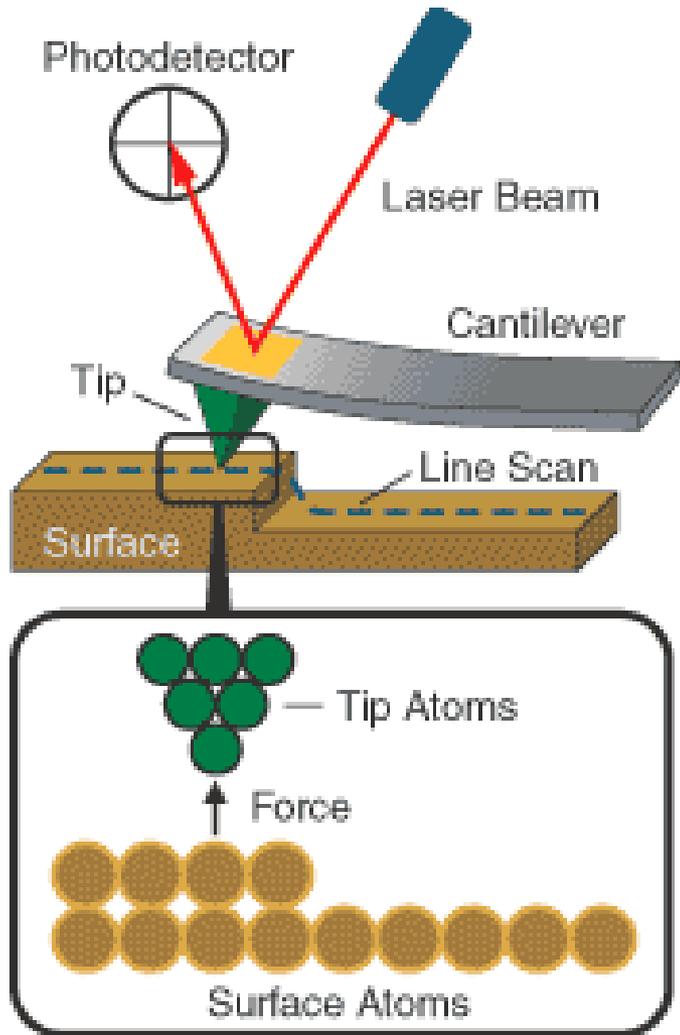
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Yuewei Yin

2016-09-02

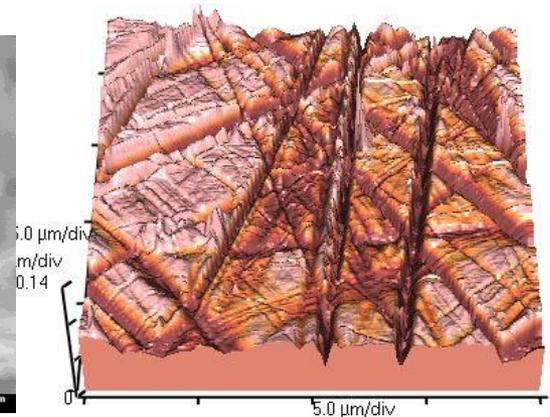
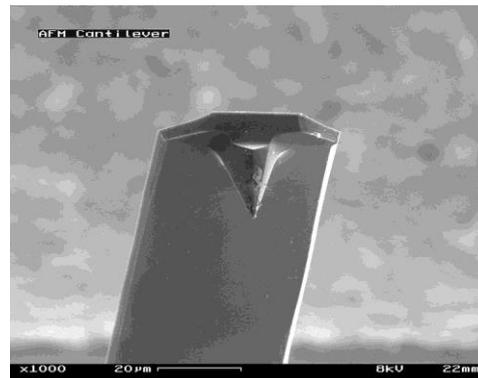
Prof. Xu's Group meeting

# Atomic force microscopy

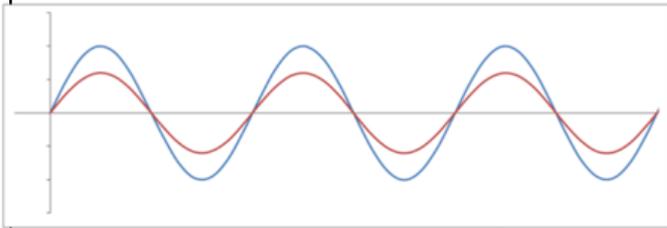


- 1986, invented by Binnig, Quate, and Gerber.
- 1989, commercialized.

The deflection of the tip is measured using a laser spot reflected from the top surface of the cantilever into an array of photodiodes.

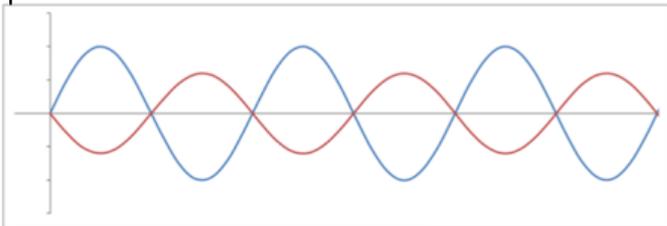


# Piezoresponse Force Microscopy

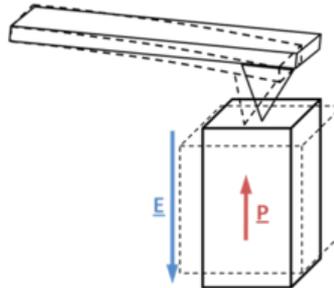
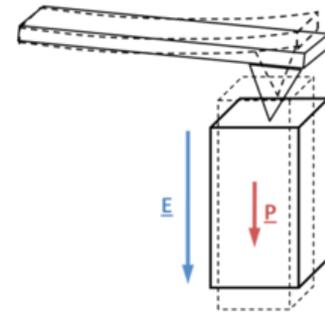


0° in-phase

Driving Voltage  
Piezoresponse



180° out-of-phase



Piezoresponse Force Microscopy

Sample

Vertical Piezoresponse

Lateral Piezoresponse

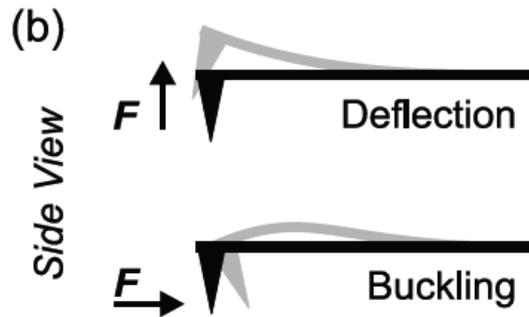
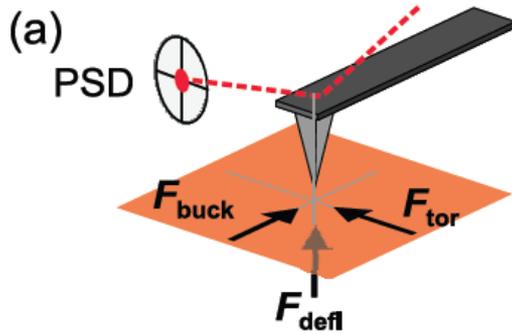
Vert. Oscill. Phase Lag

Lateral Oscill. Phase Lag

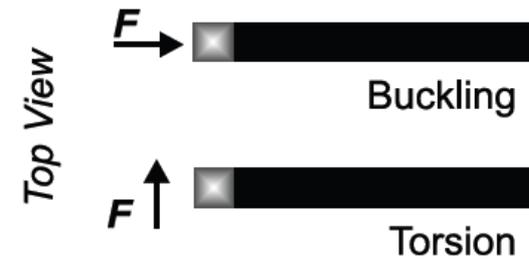
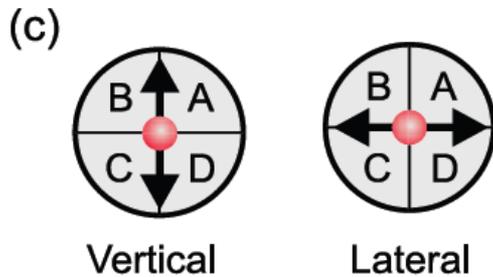
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The vertical PFM related to the tip deflection is quite straight forward and easy to understand.

What is the origin of lateral PFM component?

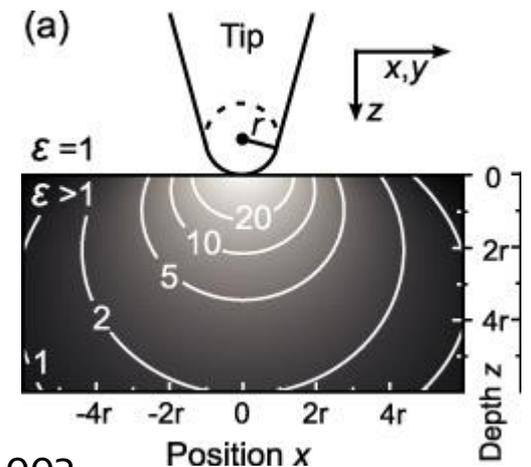
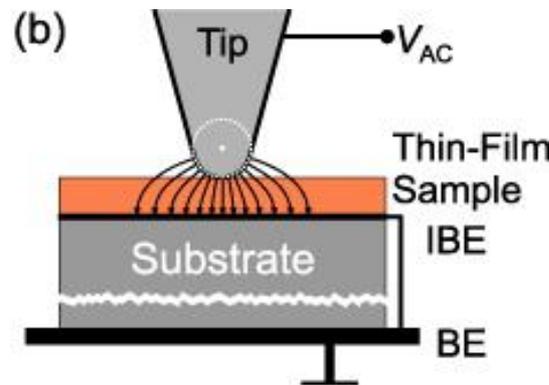
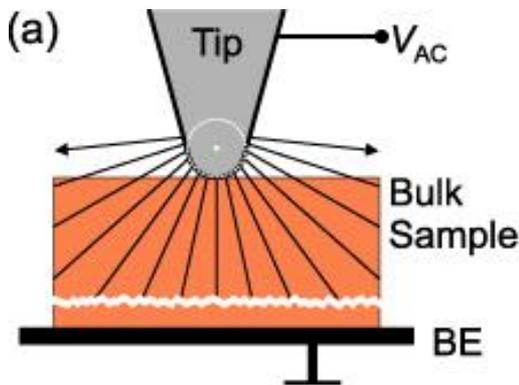


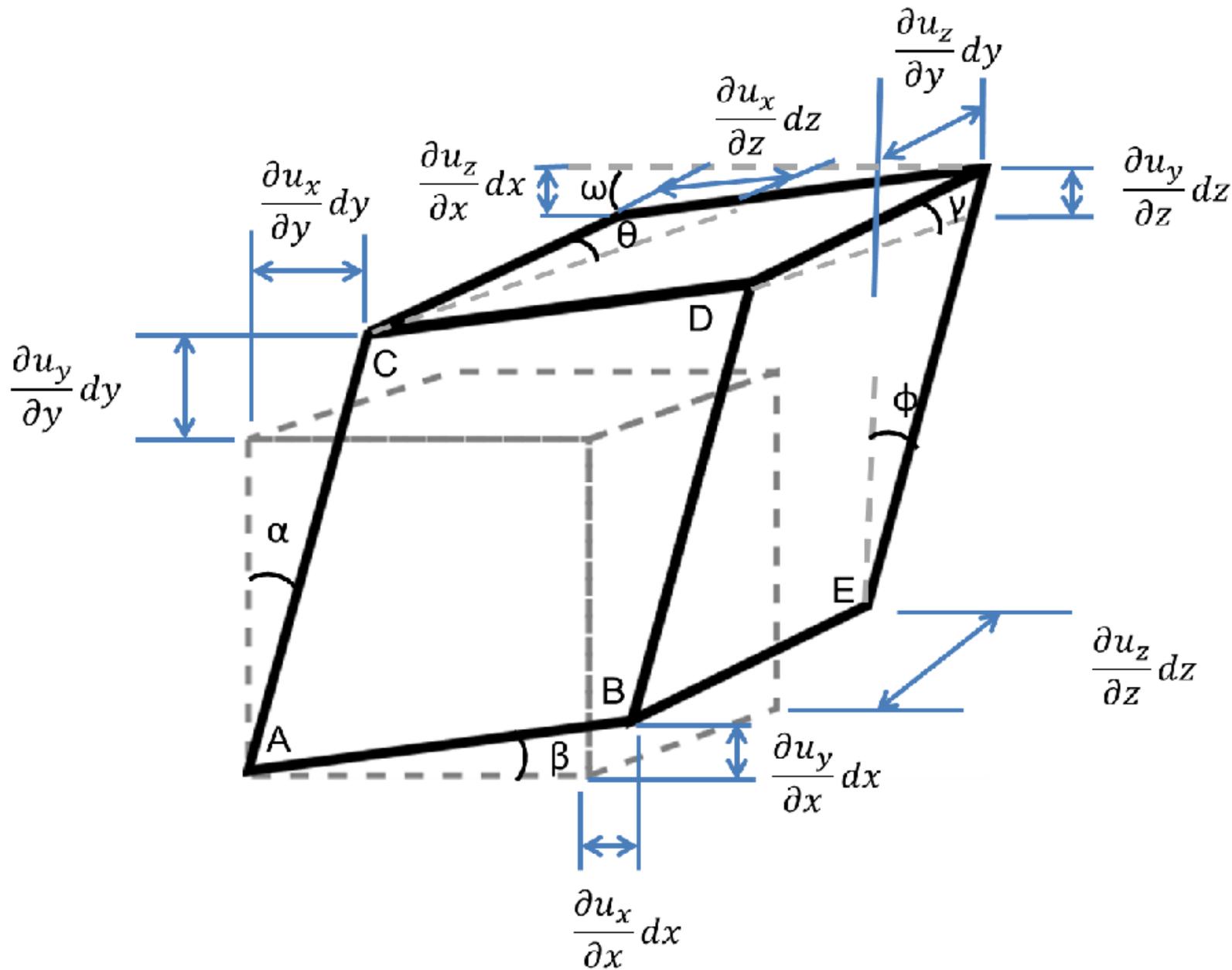
Tip motion:  
**Deflection**  
**Buckling**  
**Torsion**



Vertical PFM comes from Deflection **AND** Buckling.

Electric field contains both In-plane and Out-of-plane components.



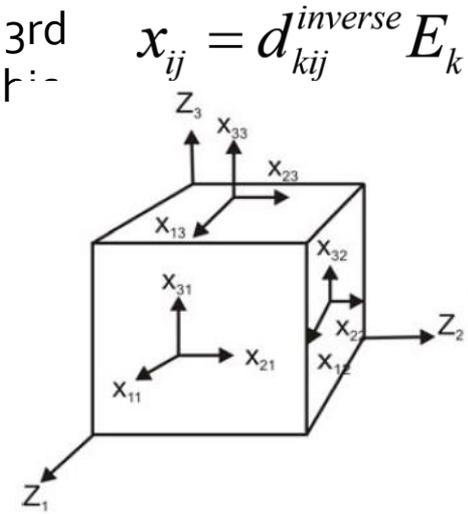


A realistic description uses a piezoelectric coefficient that is a 3rd rank piezoelectric tensor, based on the principal crystallographic axes. In case of the indirect piezoelectric effect it is:

The 27 tensor-coefficients  $d_{kij}$  couple the input and output parameters. Input parameter is the electric field in direction  $k=1,2$  or  $3$ . The strain refers to a fractional change of shape  $u_i$  in direction  $Z_i$ , in directions  $i=1,2$  or  $3$ , and  $j=1,2$  or  $3$ .

To simplify the framework, index abbreviations can turn the tensor expression into a matrix expression. Since the stress or strain are symmetric indices, as was described above, they are rewritten, using  $11 \rightarrow 1$ ,  $22 \rightarrow 2$ ,  $33 \rightarrow 3$ . The mixed pairs of indices represent the shear deformation planes  $23$  or  $32 \rightarrow 4$ ,  $13$  or  $31 \rightarrow 5$ ,  $12$  or  $21 \rightarrow 6$ , resulting in the matrix:

Often experiments using the inverse piezoelectric effect, will use an electric field that is applied in the  $z$ -direction and the piezoresponse that will be either parallel or perpendicular to the applied field. Effectively only the longitudinal coefficient  $d_{33}$ , the transverse coefficient  $d_{31}$ , and the shear coefficient  $d_{15}$  can describe the total generated strain.

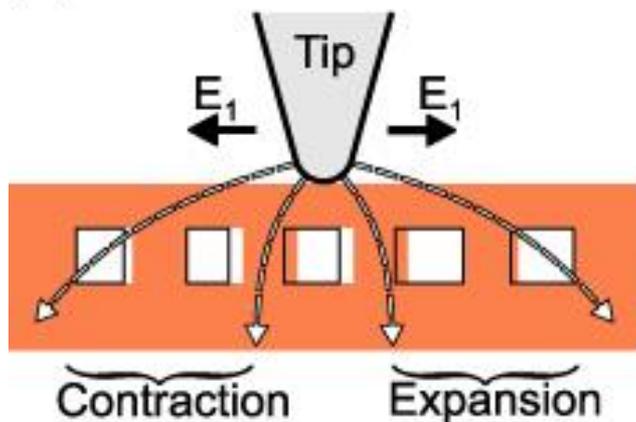


$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix} = \begin{pmatrix} d_{11} & d_{21} & d_{31} \\ d_{12} & d_{22} & d_{32} \\ d_{13} & d_{23} & d_{33} \\ d_{14} & d_{24} & d_{34} \\ d_{15} & d_{25} & d_{35} \\ d_{16} & d_{26} & d_{36} \end{pmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

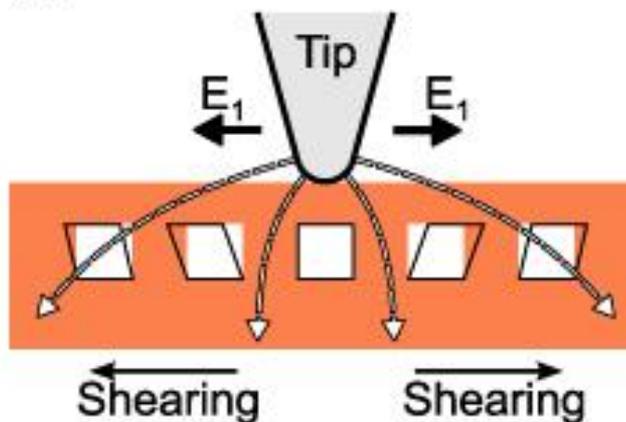
$$d_{ki}^0 = \begin{pmatrix} 0 & 0 & d_{31}^0 \\ 0 & 0 & d_{31}^0 \\ 0 & 0 & d_{33}^0 \\ 0 & d_{15}^0 & 0 \\ d_{15}^0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

# Lateral PFM from in-plane FE domain

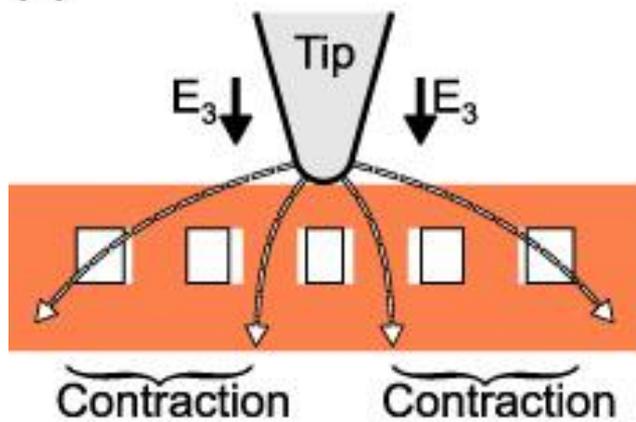
(a)



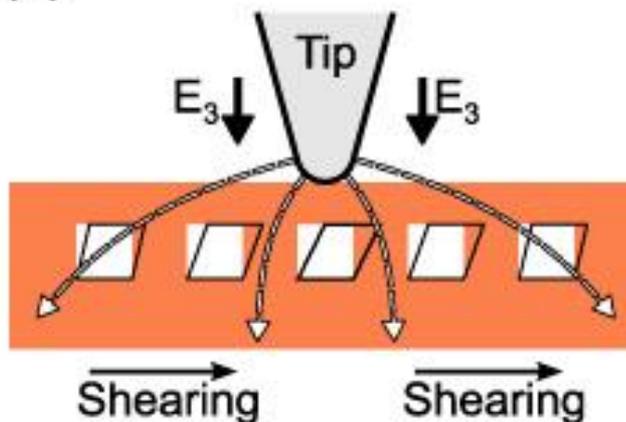
(b)



(c)



(d)



# Lateral PFM from domain boundary

