Addition 1

Shear Stack Piezoelectric Elements and Shear Effect Basics

Introduction

The STM scanner built up in this work is a Besocke type scanner (see room temperature STM instrumental chapter). The movements are obtained with piezoelectric materials. Due to the lack of an inversion center in the crystal structure such materials respond to an applied electric field by expanding (or contracting) continuously on a sub-Angström scale. Typical voltages needed for this are of the order of 100 V. In our STM special designed shear piezoelectric elements are used, which are now commercially available. These actuators consist of a variable number of the single shear plates and metal shims (electrodes), stacked and glued together. The basic design of such a piezoelectric element is shown in *Fig.1*.

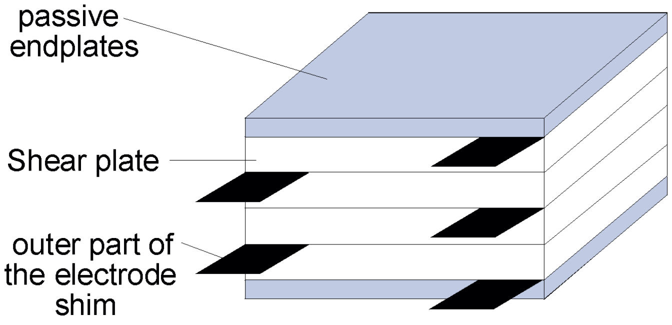

Fig.1
Basic design of the shear piezoelectric element stack.

The stacked shear actuators are available in two basic options: single directional and multi-directional displacement. Also a combination with a shear displacement component and a translation displacement component in one stack is possible. The available combinations of displacement directions are shown in *Fig.2*.

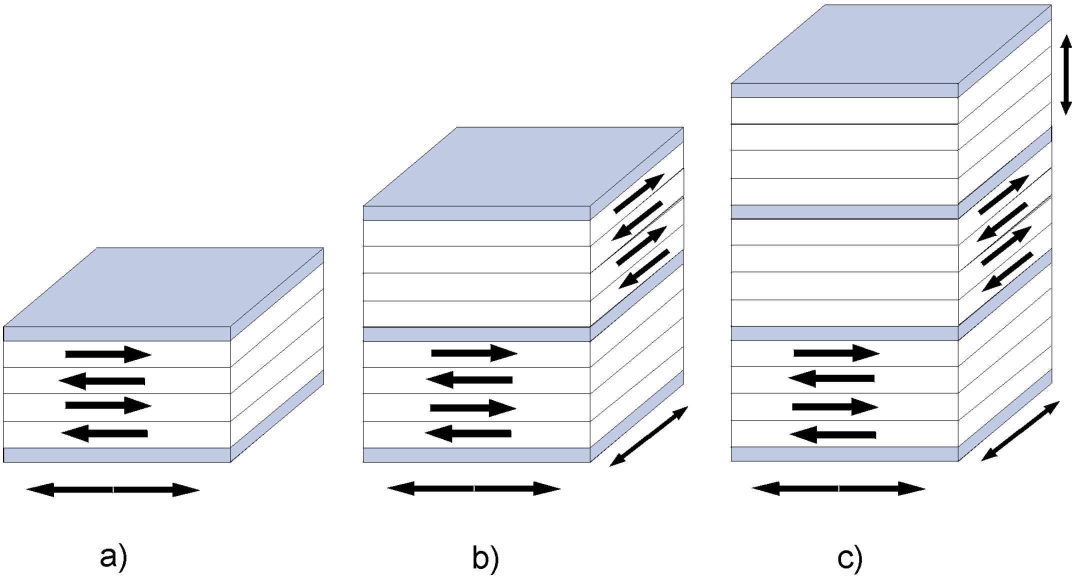

Fig.2

Available combinations of the displacement directions:

a) X actuator consists of one shear displacement component.

b) X-Y actuator consists of two shear displacement components or X-Z actuator consists of one shear displacement component and one translation displacement component.

c) X-Y-Z actuator consists of two shear displacement components and one translation displacement component.

The basic design of the shear piezoelectric element which is used in the scanner of this work is shown in *Fig.3*. The dimensions were chosen to fulfill the requirements of moving the ramp (see RT STM chapter) and optimizing the stability.

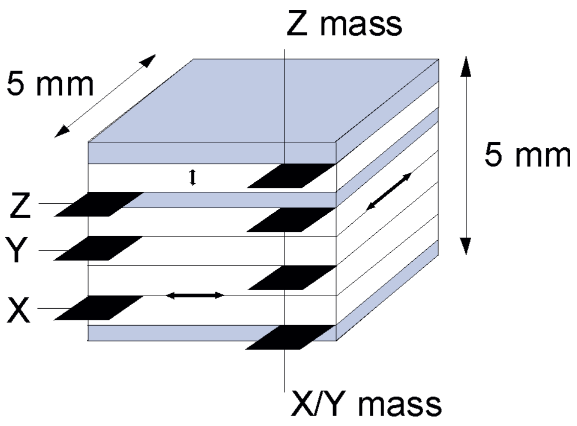

Fig.3

Design of the piezoelectric element used in the scanner of this work.

Piezoelectricity

Piezoelectricity is the general term to describe the property exhibited by certain crystals to become electrically polarized when stress is applied to them. If the stress is applied to such a crystal, it will develop an electric moment proportional to the applied field. This is called the direct piezoelectric effect. On the other hand if a crystal is placed in an electric field it changes its shape slightly, which is called the inverse piezoelectric effect.

If a voltage U is applied to the opposite electrodes of a piezoelectric shear element of thickness h and length L (*Fig.4*), the resulting length change ΔL is given by

$$\Delta L = d_{31} \frac{L}{h} U \tag{1}$$

where d_{31} is the relevant piezoelectric tensor coefficient.

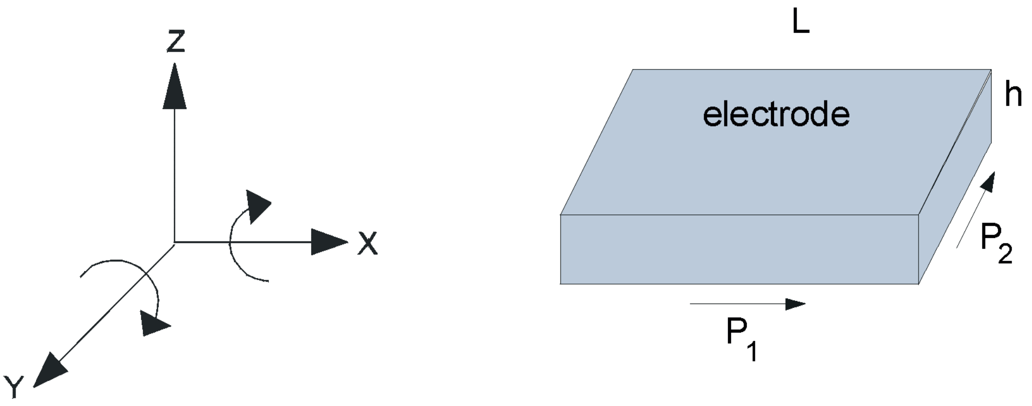

Fig.4

Piezoelectric shear element.

A piezoelectric shear element usually consists of a plate like the one shown in the illustration with the polarization parallel to the outer electrodes and therefore perpendicular to the applied electric field. The shear effects about the x-axis and y-axis are of equal amplitude. P_1 and P_2 are the possible poling directions of the shear plate.

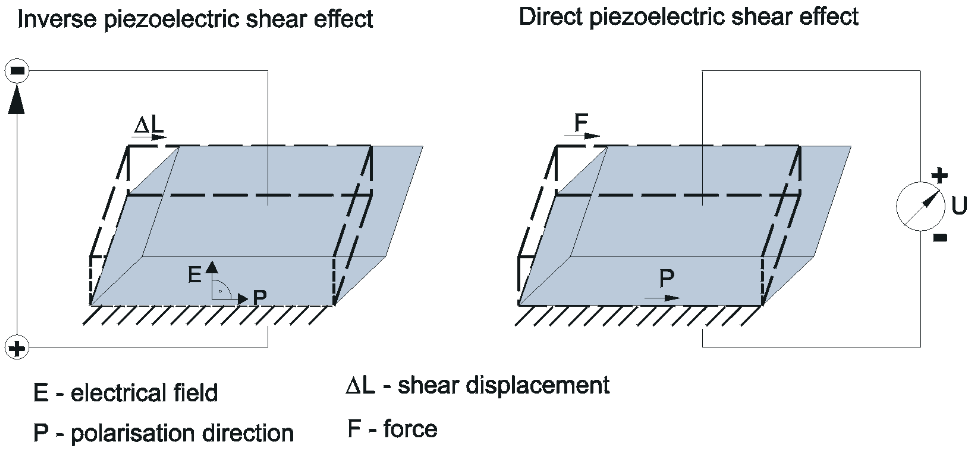

Fig.5

Direct and inverse piezoelectric effect.

The inverse piezoelectric effect is used for moving the tip during scanning. Thus, when an electric field is applied in direction Z, a shear displacement will be induced about an axis Y. This effect is described by the shear charge coefficient d_{15}:

$$\Delta L = d_{15}U \text{ , where } d_{15} \approx d_{33} + |d_{13}| \qquad (2)$$

The direct piezoelectric effect is used for measuring the resonance frequencies. If a force is applied in direction X, mechanical stress will be induced about axis Y and an electric field in direction Z. This effect is described by the shear voltage coefficient g_{15}:

$$U = \frac{g_{15}F_{15}}{W} \qquad (3)$$

Piezoelectric and ferroelectric crystals

Piezoelectricity is also exhibited by ferroelectric crystals, e.g. tourmaline and Rochelle salt. These crystals already have a spontaneous polarization, and the piezoelectric effect shows up in them as a change in this polarization.

An important group of piezoelectric materials are piezoelectric ceramics. These are polycrystalline ferroelectric materials with perovskite crystal structure. They have the general formula ABO_3, in which A denotes a large divalent metal ion such as Pb; B denotes a small tetravalent metal ion such as Zr or Ti; and O is oxygen.

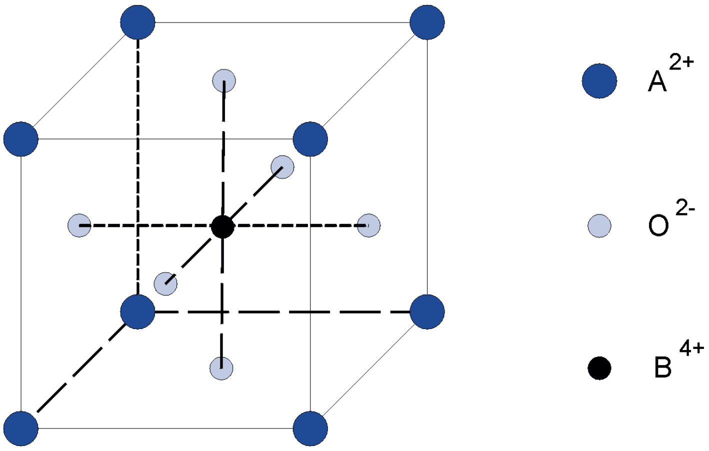

Fig.6

The Perovskite crystal structure of piezoelectric ceramics.

Additionally to being strongly piezoelectric, piezoceramics are hard, strong, chemically inert and completely unaffected by humid environment.

In a ferroelectric crystal each cell of the crystal lattice spontaneously polarizes along one of a series of allowed directions. This spontaneous polarization disappears at a critical temperature (the Curie point), above which the crystal becomes paraelectric.

If a crystal is cooled through the Curie point in the presence of an external electric field, the dipoles tend to align in the allowed direction most nearly aligned with the field.

The piezoelectric ceramics may be considered as a mass of crystallites, which are randomly oriented (*Fig.7*). Such material will be isotropic and will exhibit no macroscopic piezoelectric effect because of the random orientation. The ceramics are to become piezoelectric in any chosen direction by applying a strong electric field to it. It should be noted that not all the domains become exactly aligned. Some of the domains align only partially and some do not align at all. The number of domains that align depends upon the poling voltage, temperature and the time the voltage is held on the material. During poling the material permanently increases in dimension between the poling electrodes and decreases in dimensions parallel to the electrodes. When the field is removed, the dipoles remain locked in alignment, giving the ceramic material a remnant polarization and a permanent deformation (making it anisotropic), as well as making it permanently piezoelectric.

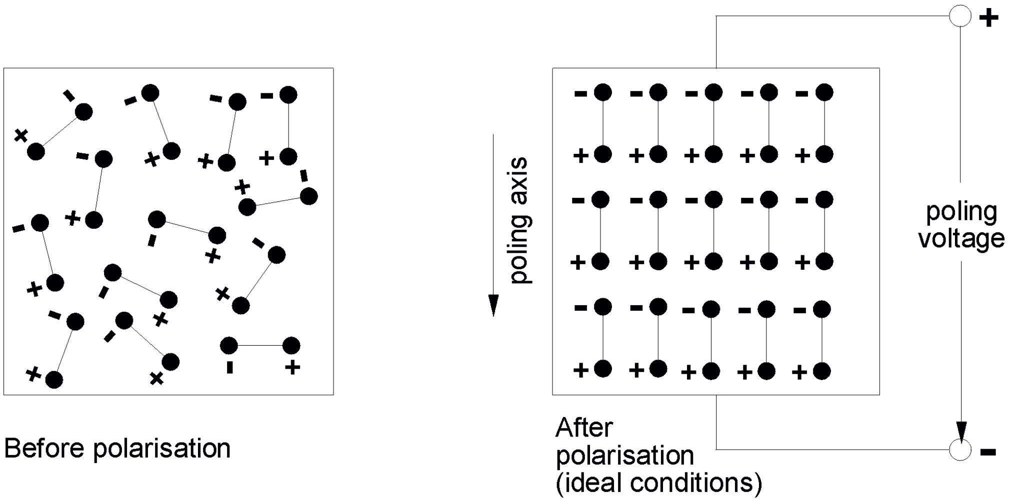

Fig.7

Electric dipoles in piezoelectric materials.

The polarization (poling) of piezoelectric materials is permanent. However, when working with these materials the following points should be kept in mind:

- The temperature should be kept well below the Curie point (important for the soldering)
- The material should not be exposed to very strong alternating electric fields or direct fields, opposing the direction of poling
- Mechanical stress, experienced by the material, should not exceed the specified limits.

Failure to comply with these conditions may result in the fact that piezoelectric properties become less pronounced or disappear completely.

The material of the piezos used in this work is a modified Lead Zirconate Titanate (PZT) PIC 255. PIC 255 is a modification of the PIC 155 type. The increased charge constant makes it useful for actuators and high sensitive receivers. PIC 155 is a material with a high piezoelectric coupling factor, low mechanical quality factor and small temperature dependence of dielectric constant. It is especially suited for low-frequency ultrasonic transducers, buzzers, ultrasonic speakers and micropositioning components.

The coefficients of this material are: Density is 7.80 gcm; Curie temperature is 350 °C; Charge constants: d_{31}=-180, d_{33}=400, d_{15}=500 ($x10^{-12}mV^{-1}$); Voltage constants: g31=-11.3, g33=25.1 ($x10^{-3}VmN^{-1}$).