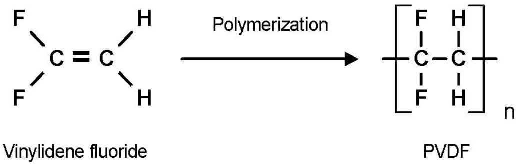
Polyvinylidene Fluoride (PVDF)

POLYMERIZE

Vinylidene Fluoride ($C_2H_2F_2$) is unsaturated (with double bond) making it a monomer meaning it can go through a reaction to bind it with other identical molecules - this is called **polymerization**. The process breaks one of the bonds in the double carbon bond to bind it to another identical molecule. This forms the polymer Polyvinylidene Fluoride (PVDF) - $(C_2H_2F_2)_n$-.



FLEXIBLE, POWERFUL AND STABLE

- Young's modulus 2.4GPa
- Density 1.78g/cm^3
- Glass transition temperature -40℃
- Curie temperature 80℃
- Melting point 170℃
- Negative piezoelectric coefficient
- Electric field strength 6-7pC/N

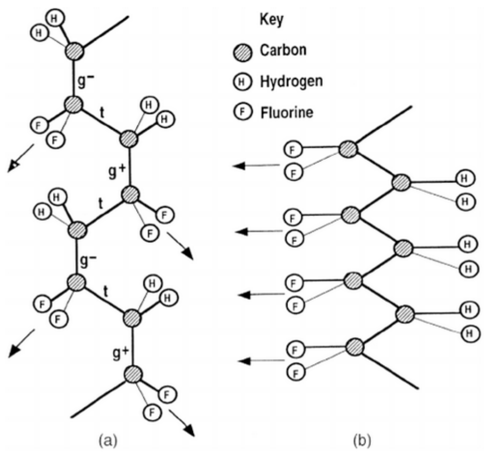
FORCE THE PIEZOELECTRIC EFFECT

When atoms bond to form a molecule the electron(s) are not necessarily distributed equally resulting in an electric dipole moment, i.e. the molecule has a natural polarity. When forming a material, the molecules will naturally try to align themselves to attract each other.

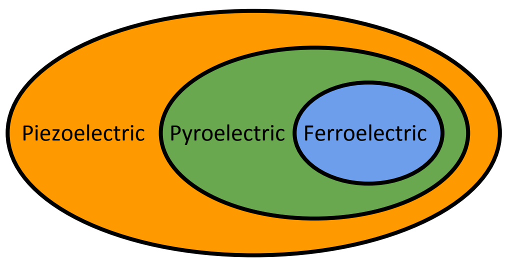
After polymerization, the dipoles have aligned themselves with their polar axis (direction of polarization) in a seeming random fashion - this is called **amorphous**. For the material to exhibit piezoelectric properties, the dipoles must be rearranged so all the polar axes are near parallel - this is called **monocrystal** or **semicrystal**. A pure crystal material has all its dipoles parallel to each other but is very difficult to practically achieve.

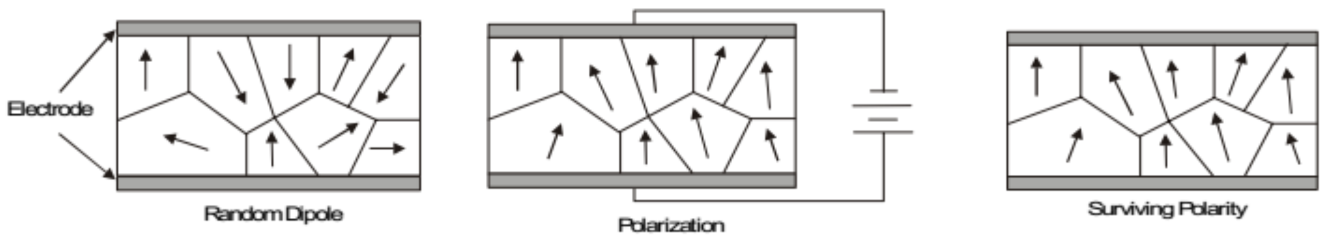
To transition an amorphous polymer into a monocrystal polymer it is placed in an electric field while being heated to its **curie temperature** (85℃-130℃) at which point it becomes ductile and the dipoles are free to move (known as **poling**). The dipoles can be arranged in different **crystalline phases** such as **alpha** (the most common form of VDF) and beta. The **beta** phase exhibits the best piezoelectric behaviour showing a dipole moment of 7x10^{-30}Cm per unit compared to the alpha phase producing 6.4x10^{-30}Cm per unit. There are many different process to transition between the crystalline phases and is still an very active research area.

The rotational position of one carbon atom in a molecule with respect to another carbon atom in the next molecule could theoretically take any angle, however the interaction between the two dipoles will cause a potential energy between the two which limits the positions it may take. There are three minima positions the bond could settle called **Trans**, **Gauche-** and **Gauche**+. The polymer chain can arrange itself with different rotational bonds throughout. The most common and natural formation after polymerization is the **alpha** phase which has a (TG+TG-) chain. After poling the **beta** phase has an all trans chain (TTTT). Other phases exist but provide no great structural changes over the first two phases.



PVDF is a **ferroelectric** material with **pyroelectric** and **piezoelectric** properties. Piezoelectric materials react to mechanical stress by producing a potential difference. Pyroelectric materials also exhibit piezoelectric characters but also react to thermal changes by producing a potential difference. Ferroelectric materials, while also having piezoelectric and pyroelectric behaviours, can have their polarization direction altered under the influence of an electric field.





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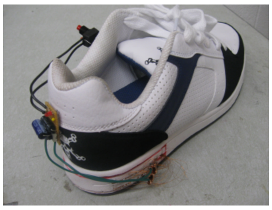
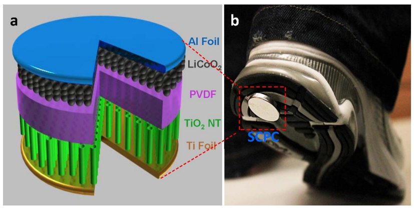
SELF-CHARGING BATTERIES

Replacing the insulative separator between the anode and cathode of a battery with PVDF in the beta phase allows the recharging of the battery. When the battery is under mechanical pressure (e.g. under a shoe) the PVDF piezoelectric effect causes ions to migrate from the cathode to the anode. A desirable feature of this the exclusion of the intermediate energy translation electrical. Traditionally a battery would be recharged from mechanical energy, to electrical energy and finally to chemical energy.

Researchers have investigated this application and found promising results averaging a power output of 0.06mW and V_{rms} of 5.4V which is sufficient to charge small portable devices.

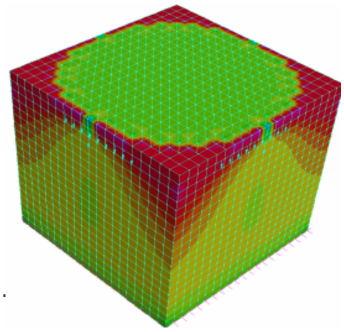




HARVESTING ENERGY FROM ROADS

Being a fluoropolymer, PVDF has a high resistance to chemical attack and moisture making it suitable for outdoor applications include road surfaces. The mechanical properties of PVDF allow a thin layer could practically be embedded inside a concrete road surface. Researchers have produced a model from experimentation advising the ideal location of the piezoelectric transducer inside the concrete. Their results suggest the application is feasible producing a power output of 393.08nW for a 1000N load.

A student project predicts the use of ceramic piezoelectric material (PZT) in californian roads would not recover the cost of enabling a road to harvest energy until 12 years later. The costs of PVDF are lower than the ceramic alternative so may be more financially viable.

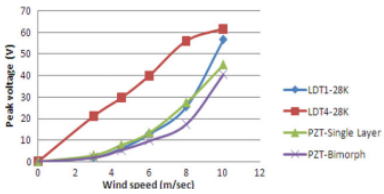


HARVESTING CLOTHING AND WEATHER

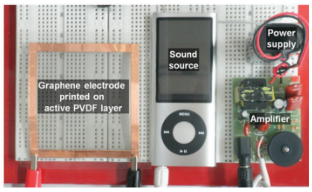
PVDF can be formed to be flexible, light and thin which makes it suitable to be discreetly incorporated into fabrics. A person wearing the clothing would manipulate the PVDF's structure and produce a voltage from the piezoelectric effect. This energy could then feed a portable device such as a mobile phone.

Research has found limitations in the processes stage of the manufacturing of beta phase PVDF. Hadimani suggests beta phase PVDF is limited by the production processes used to pole the material on a mass-scale.

Harvesting the kinetic energy of wind and rain using a PVDF material is powerful enough to operate low-power devices producing 93.6µW in wind speeds of $10ms^{-1}$. This is significantly more than its ceramic counterpart giving just 6.5µW.

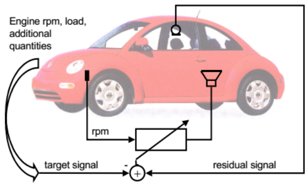


ACOUSTICS



PVDF's flexible nature makes it a suitable material to form a diaphragm. Exploiting its piezoelectric effect, the material can contract and expand in response to a varying voltage (audio signal). When in thin-film transparent form it could be placed over glass thus eliminating the need for an external speaker. This could impact the portable device industry and also aid the implementation of active noise cancellation in noisy environments (e.g. vehicle noise in a car's cabin and environmental noise inside buildings)

Motorola have filed a patent protecting their design of a new screen. Researchers are investigating the use of PVDF as the transducer in ANC systems and predict it will have a 'bright future'.



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