



Thermally Stable Piezoelectric and Pyroelectric Polymers

Neither mechanical nor solvent treatment is necessary for orientation of polymer molecules.

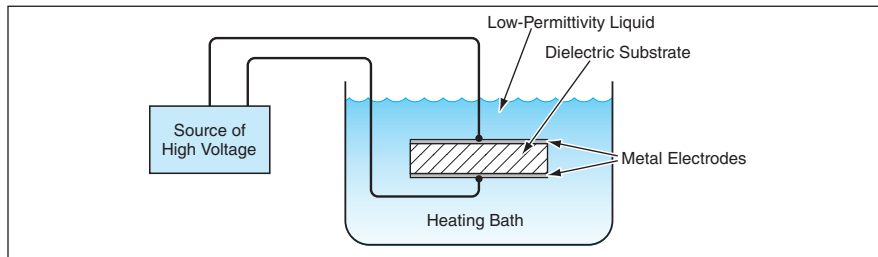
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A class of thermally stable piezoelectric and pyroelectric polymers, and an improved method of making them, have been invented. These polymers can be used as substrates for a wide variety of electromechanical transducers, sensors, and actuators.

In order to enable a material to produce an electrostatic potential in response to mechanical excitation (piezoelectricity) or in response to thermal excitation (pyroelectricity), the material must be electrically polarized; that is, its molecules must be at least partially aligned in a preferred electric-dipole orientation. The preferred orientation or polarization occurs naturally in quartz and some crystalline materials, and can be induced in some ceramics and polymers by application of strong electric or mechanical fields.

Prior to this invention, poly(vinylidene fluoride) [PVF₂] was the only commercially available piezoelectric polymer. In order to be able to exploit the piezoelectricity of PVF₂, it was necessary to orient its molecules by mechanical drawing of sheets or by dissolving the PVF₂ in a solvent and then subjecting it to an electric field while causing the solvent to evaporate. In contrast, the polymers of the present invention are rendered piezoelectric and/or pyroelectric by means of an orientation process that does not involve either a solvent or a mechanical treatment.

The polymers suitable for this invention include polyarylates, polyquinoxalines, polyphenylene ethers, polycarbonates, polyphenylene sulfides, polysulfones, polyaryletherketones, polyimides, polyarylene ethers, polybenzimidazoles,



A Polymer Substrate Is Heated to its softening temperature in a low-permittivity dielectric liquid while a high voltage is applied to metal electrodes on opposite faces to induce electric polarization. When the electrode/substrate/electrode sandwich is cooled, the polarization remains frozen into the substrate.

polyazomethines and possibly other thermally stable polymers. These polymers have softening temperatures greater than about 100 °C, and, once polarized, they retain their polarizations (and, hence, their piezoelectric and pyroelectric properties) at temperatures up to their softening temperatures.

A polymeric substrate to be rendered piezoelectric and/or pyroelectric according to the invention is prepared by depositing metal electrodes on opposite faces. The electrode metal can be gold, silver, or any other suitable low-electrical-resistivity metal that is not readily oxidized at the temperature to be used in the treatment described next. The metal electrodes are connected to a source of high voltage, and the electrode/substrate/electrode sandwich is immersed in a heating bath containing silicone oil or other suitable low-permittivity dielectric liquid (see figure). In the bath, the electrode/substrate/electrode sandwich is heated to the softening temperature of the polymer to increase the mobility of the polymer molecules. A voltage is

applied to the electrodes to generate an electric field (typically between 50 and 200 MV/m) large enough to orient the polymer molecules but not so large as to cause dielectric breakdown of the polymer substrate. The voltage can be low-frequency AC or DC. The voltage is maintained for an interval of time sufficient to obtain the desired degree of polarization. The electrode/substrate/electrode sandwich is then cooled while maintaining the voltage. Once the temperature is well below the softening temperature, the voltage is turned off, and the induced orientation remains frozen into the polymer.

This work was done by Joycelyn O. Simpson and Terry L. St. Clair of Langley Research Center. Further information is contained in a TSP (see page 1).

This invention has been patented by NASA (U.S. Patent Nos. 5,891,581, 5,909,905, and 6,379,809). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center, at (757) 864-3521. Refer to LAR-15279.

Combustion Synthesis of Ca₃(PO₄)₂ Net-Shape Surgical Implants

More-biocompatible materials are produced in fewer processing steps.

John H. Glenn Research Center, Cleveland, Ohio

Self-propagating high-temperature combustion synthesis (SHS) is the basis of a method of making components of porous tricalcium phosphate [Ca₃(PO₄)₂] and related compounds in net sizes and

shapes for use as surgical implants that are compatible with bone. Ca₃(PO₄)₂-based materials are among those preferred for use in orthopedic, restorative, and reconstructive surgery. As explained

below, the SHS method offers advantages over prior methods of manufacturing Ca₃(PO₄)₂-based surgical implants.

Ca₃(PO₄)₂ occurs in at least two crystalline forms: a monoclinic form de-