Nanoengines Open up New Nanotechnology Applications

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A breakthrough in multilayer lead zirconate titanate (PZT) production technology replaces polymer coating with ceramic insulation and doubles the operating temperature range.

Nanomotoren eröffnen neue Nanotechnologie-Anwendungen
Ein Durchbruch in der Mehrschicht-Blei-Zirkon-Titanat (PZT) Produktionstechnologie ersetzt Polymerbeschichtungen durch keramische Isolation und verdoppelt den Betriebstemperaturbereich von Piezoaktoren.

Des nano machines ouvrent la voie à de nouvelles applications en nanotechnologie
Une percée dans la production de multicouches de plomb, zirconium, titane (PZT) remplace les dépôts polymères par insolation céramique et permet de doubler le domaine de température d'utilisation.

I nanomotori pospettano nuove applicazioni nelle nanotecnologie
Una radicale innovazione nella tecnologia usata per produrre il titanozirconato di Piombo (PZT) in strutture multilayer sostituisce il coating polimerico con uno strato isolante ceramico, e raddoppia il campo di temperature operative raggiungibili.

Piezoelectric actuators are solid-state ceramic devices that convert electrical energy directly into motion, or mechanical energy, of unlimited resolution. The piezoelectric effect was discovered a century ago, and after decades of research and development, piezoactuators have found their way out of the laboratory and into industrial mass-production applications and, lately, even into the automotive world. Progress in this vital technology has benefited fields such as semiconductor production, biotechnology, telecommunications, mass storage and automotive engineering.

Features and applications

Repeatable nanometre and subnanometre movements at high frequencies can be achieved with piezo actuators because they derive their motion through solid-state crystal effects. They require no maintenance and can be designed to position heavy loads — weighing several tons — or to move lighter loads at frequencies up to several tens of kilohertz. Response

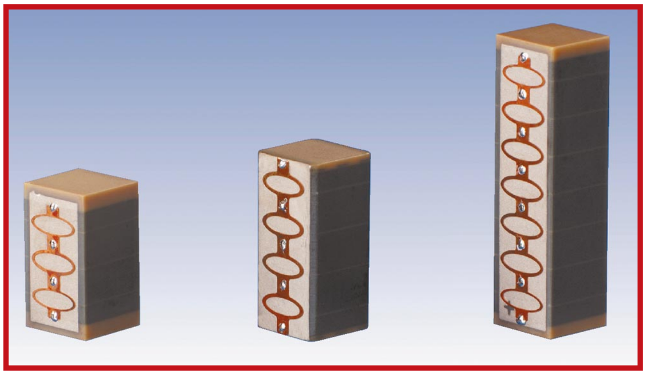

Figure 1. Ceramic-insulated multilayer piezo actuators don't require polymer coatings and are insensitive to humidity.

time to a control signal is as fast as 10 μs. In addition, they require virtually no power in steady-state operation, simplifying power supply needs.

These properties make them ideal nanoengines in applications such as nano-imprinting, nanometrology tools, scanning microscopy systems, cell penetration, microdispensing, wafer and mask alignment, fibre optic aligners and switches, image stabilization systems and adaptive optics, fast tool servos, smart structures and vibration cancellation, and mass storage head and media testing.

Although not affected by mechanical wear, the lifetime of conventional piezoactuators has been limited by environmental conditions. Until now, both the classical stacked piezo models (operating from 0 to 1000 V) and the modern multilayer versions (0 to 100 V) had to be protected with poly-

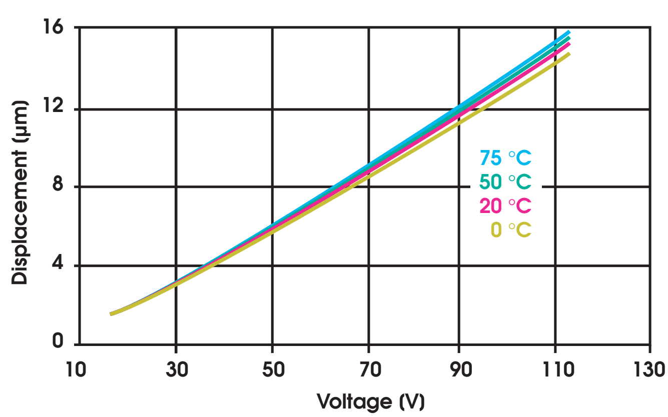

Figure 2. The displacement of these actuators exhibits very low temperature dependence. This, in combination with their low heat generation and maximum operating temperature of 150 °C, makes them optimal for dynamic operation.

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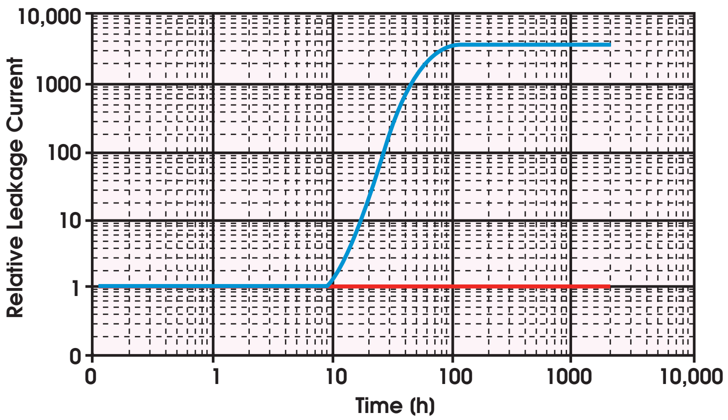

Figure 3. PI Ceramic's multilayer actuators (red curve) are not affected by the high humidity test conditions as are conventional multilayer types with polymer insulation (blue curve). The latter exhibit increased leakage current after only a few hours. Leakage current is an indication of insulation quality and expected lifetime. Test conditions reflected here are: U = 100 VDC, T = 25 °C, relative humidity = 70%.

mer insulation to prevent dielectric breakdown. Because water molecules can permeate polymers, safe operation was possible only in environments with less than 50 per cent relative humidity, or at reduced electrical fields (reduced displacement) or by means of expensive protective measures such as nitrogen/dry air flush systems or hermetically sealed encapsulation.

The lower operating voltage of the compact multilayer actuators used to come at a price: a significantly reduced operating temperature range — less than 80 °C rather than 180 °C — limiting their dynamic properties and potential applications.

A production process developed by engineers at PI Ceramic GmbH of Lederhose, Germany, a subsidiary of Physik Instrumente GmbH, overcomes these limitations. Ceramic insulation makes polymer-film coating unnecessary and gives the PI Ceramic multilayer actuators a usable temperature range extending up to 150 °C. This means that they can be driven harder in dynamic operation and operated in hotter environments.

Real-world applications

In telecommunications components, for example, piezo actuators have been used for wavelength tuning (Fabry-Perot filters, fibre stretching). Laboratories and cleanrooms offer ideal operating conditions. However, if the fibre optic component containing the piezo is to be employed in the field, excellent stability over a wide temperature range and insensitivity to humidity are essential, making expensive encapsulation and thermal stabilization measures necessary. The qualities of the new actuators (Figures 2, 3) give designers a clear advantage: In field applications, they no longer have to trade performance and lifetime for size.

Many applications of piezo actuators are in optics; for example, in lithography for semiconductor manufacturing. Because of the ongoing need for shorter wavelengths, the requirements for precision and stability of the optics become more stringent. Piezo-driven active vibration cancellation and beam correction systems are used to further improve the feature quality and to reduce linewidths into the double-digit nanometre range. Many processes require the optics to operate in high vacuum, and outgassing of materials such as polymers is not tolerable. Piezo ceramics without polymer insulation will prove advantageous for these and other vacuum applications.

One requirement in vacuum preparation is baking all components in the vacuum chamber at high temperatures. The higher the temperature, the better the vacuum. Traditional piezo multilayer actuators have Curie temperatures (the point where the piezo effect disappears) of less than 150 °C and quit working at 80 °C. The ceramic-insulated models have Curie temperatures of 320 °C and operate at up to 150 °C.

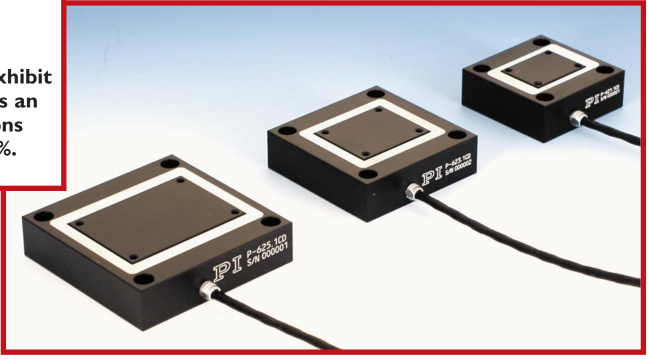

Figure 4. The new actuators drive the PIHera® closed-loop nanopositioning stages from Physik Instrumente GmbH. System specifications include a travel range to 600 µm, subnanometre resolution and repeatability, and capacitive feedback.

Higher dynamic performance

The amount of electrical energy required to drive a piezo actuator is proportional to the operating frequency and amplitude. A percentage of this electrical energy converts into thermal energy to heat the actuator. The low temperature range of conventional multilayer actuators limits their operating frequency and duty cycle and requires the use of costly cooling measures in high-level dynamics applications. Increasing the operating temperature range to 150 °C allows designers to build more tightly packaged systems at lower cost and to run actuators at higher frequencies, opening the door to a variety of new applications.

PI Ceramics' actuators combine the wide operating temperature range of classical piezo actuators with the low operating voltage and compact design of multilayer actuators. In addition, the ceramic insulation overcomes limitations imposed by environmental conditions. In a decade when nanotechnology may become the driver for economic growth, these devices are the engines for processes requiring fast and precise motion with subnanometre resolution. □

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