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Design Principle of Multi-Functional Materials

Kenji Uchino
The Pennsylvania State University, USA

We are the inventors/discoverers of magnetoelectric laminated composites, photostrictive actuators, and converse flexoelectric devices, 'monomorphs'. This paper introduces the general design principle of these multifunctional materials, using so-called 'functionality matrix', which is composed by a 5 x 5 matrix to correlate the input parameters (electric field, magnetic field, stress, heat and light) with the output parameters (charge/current, magnetization, strain, temperature and light).

In order to create the 'magenetoelecric effect', we can combine 'magnetostriction' and 'piezoelectric' effect (i.e., product of individual functionality matrixes) as this sequence: first, magnetostriction matrix multiplied by piezoelectric matrix. A PZT disk is sandwiched by two Terfenol-D (magnetostrictor) disks. When a magnetic field H is applied on this composite, Terfenol-D expands, which is mechanically transferred to PZT, leading to the high detection performance ($\partial E/\partial H$).

Similarly, photostrictive effect can be obtained by coupling photovoltaic effect and piezoelectric effect. A bimorph unit has been made from PLZT 3/52/48 ceramic doped with slight addition of W. The remnant polarization of one PLZT layer is parallel to the plate and in the direction opposite to that of the other plate. When a violet light is irradiated to one side of the PLZT bimorph, enormous photovoltage of 1 KV/mm is generated, causing a bending motion. The tip displacement of a 20mm long bimorph with 0.4mm in thickness was ±150μm.

Stress-gradient in terms of space in a dielectric material exhibits piezoelectric-equivalent sensing capability (i.e., 'flexoelectricity'), while electric-field gradient in terms of space in a semiconductive piezoelectric can exhibit bimorph-equivalent flextensional deformation, as converse flexoelectricity ('monomorph'). When the piezoelectric or electrostrictor is slightly semiconductive, contraction along the surface occurs through the piezoelectric effect only on the side where the electric field is concentrated via the Schottky barrier effect.

Biography:

Dr. Kenji Uchino, the pioneer in 'piezoelectric actuators', is Director of International Center for Actuators and Transducers, Professor of EE and MatSE, and Distinguished Faculty of Schreyer Honors College at The Pennsylvania State University. He was Founder and Senior Vice President of Micromechatronics Inc., PA from 2004 till 2010, and Associate Director at Office of Naval Research – Global from 2010 till 2014. After his Ph. D. degree from Tokyo Institute of Technology, Japan, he became Research Associate (1976) at this university. Then, he joined Sophia University, Japan as Associate Professor in 1985. He was recruited from The Penn State in 1991. Fellow of American Ceramic Society and IEEE.