Enhancement of photocurrent in curved materials

In 2030, the flexoelectricity is considered as a core knowledge for designing nanoscale devices and it is applied to various applications including information storage and solar energy conversion to electric power. Overcoming the scaling limitation that silicon–based industry has been facing, three–dimensional device architectures with the control of nanoscale strain gradients realize peta(1000 tera) byte high–density memories enabling continual progress of our information technology. In the same period, the strain–gradient engineering accomplishes a new innovation for highly efficient solar cells

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- The polymorphic phase interface of bismuth ferrites subject to a giant strain gradient exhibits a large enhancement of the anisotropic interfacial photocurrent by two orders of magnitude as a consequence of the flexoelectric effect.

- The flexoelectric effect, which is a dielectric property whereby electric polarization is induced by a strain gradient, is a critical ingredient in understanding mechanoelectric phenomena. The flexoelectric effect is ubiquitous in materials subject to inhomogeneous mechanical deformation. Recent advances in nanoscale characterizations have led researchers to the discovery that large strain gradients are often present in the various self–assembled inorganic nanostructures involved in the strain relaxation of epitaxial films, dislocations, ferroelectric domain walls, and morphotropic phase boundaries. Moreover, such inhomogeneous deformations at a nanoscale level have a strain gradient that is million times larger than that in macroscopic flexural bending, which is most likely to induce large modulations in electronic behavior and new functionalities. However, electronic conduction in the presence of a giant strain gradient at a nanoscale level has received little research attention despite its importance for nanoscale device applications.

- Recently, Prof. Chan–Ho Yang of the Department of Physics, Korea Advanced Institute of Science and Technology (KAIST), and his colleagues have found that photocurrents can be enhanced in some particular interfacial regions of epitaxial bismuth ferrite thin films. The competition between the metastable phases of bismuth ferrite leads to a spatial phase separation and forms a phase boundary where a large strain gradient as much as $\sim 10^7\ m^{-1}$ exists. Remarkably, a light–induced short–circuit current was enhanced in proportion to the area of the interface located inside an incident light beam. It could be found through careful analysis of a spatially resolved photocurrent map and a surface morphological image in an integrated manner. In addition, the photocurrent exhibited two–fold azimuthal dependence of light polarization, indicating the anisotropic nature of light–induced electron–hole pair formation, possibly due to the fact that inhomogeneous structural deformation affects the electron orbital structure and consequently, the optical transition probability. These interfaces were carefully investigated by means of nanoscale characterization tools, i.e. piezoresponse force microscopy (PFM) and transmission electron microscopy (TEM). A position–sensitive angle–resolved PFM technique disclosed complicated ferroelectric domain structures in the vicinity of the phase interface, and electron holography was employed to identify the local charge distribution across the interface. In this way, it was clarified that the flexoelectric polarization induced by the strain gradient resulted in a dipole charged domain wall and moreover, a large built–in electric field created at the interfacial area played an important role in the separation of photo–induced electron–hole pairs. This observation, associated with interfacial flexoelectricity, provides a new pathway to improving the efficiency of photovoltaic cells.

- Of great importance in this work is the suggestion that a quadratic polarization response with respect to strain gradients can overwhelm the linear response in a large–strain–gradient regime when the system doesn't have inversion symmetry. This quadratic effect is considered to be a new, fourth, symmetry element that was missing in electromechanical phenomena, following piezoelectricity, electrostriction, and the linear flexoelectric effect.

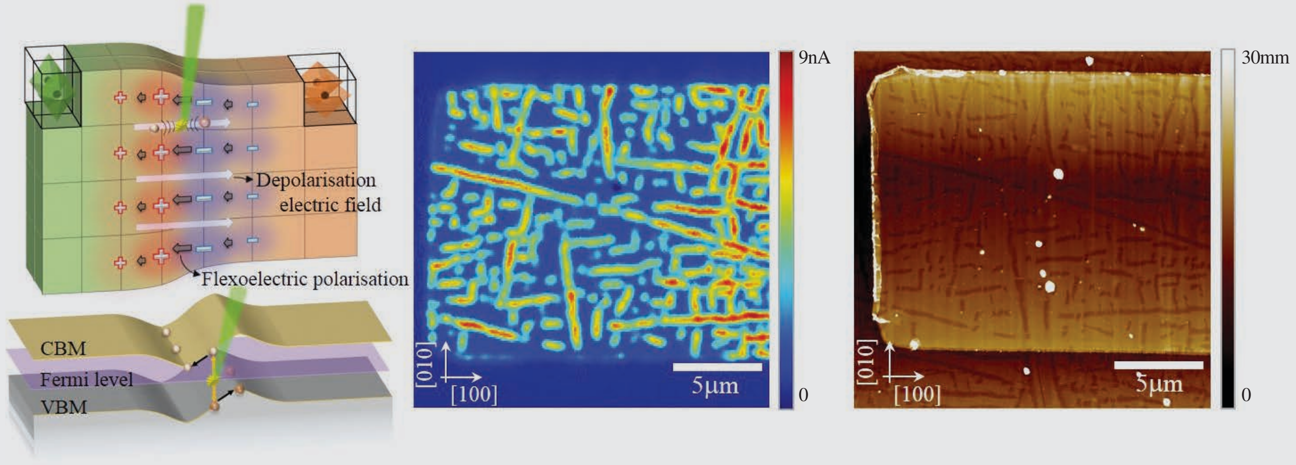

Figure 1.
(Left) Giant strain gradient at the interface of two different structural polymorphs induces a phenomenological flexoelectric polarization across the boundary. As a result, a dipole–charged domain wall is created and the built–in field across the interface can serve to separate the light–induced electron–hole pairs more efficiently.
(Middle) The spatially resolved photocurrent map for a bismuth ferrite thin film.
(Right) The surface topographic image of the same area.

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Research Outcomes
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