Novel monolayer ferroelectric hybrid structures

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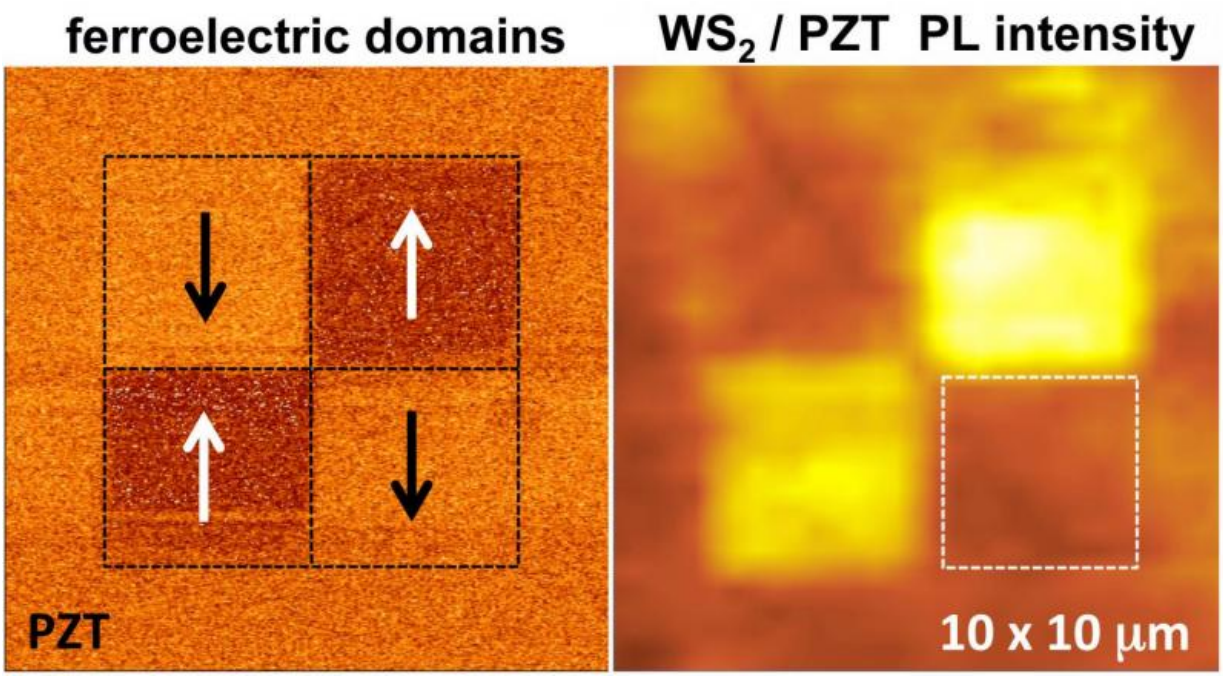

Domains consisting of electric polarization dipoles are written in a checkerboard pattern into a thin film of lead zirconium titanate (PZT) with a conductive atomic force microscope, and imaged with the same instrument (left panel). Both intensity and spectral distribution of the photoluminescence emitted from a monolayer of tungsten disulphide (WS2) transferred onto the PZT surface is strongly modulated by these polarization domains (right panel). Credit: U.S. Naval Research Laboratory

Scientists at the U.S. Naval Research Laboratory (NRL), Materials Science and Technology Division, have demonstrated that the intensity and spectral composition of the photoluminescence emitted from a single monolayer of tungsten disulphide (WS2) can be spatially controlled by the polarization domains in an adjacent film of the ferroelectric material lead zirconium titanate (PZT).

These domains are written in the PZT using a conductive atomic force microscope, and the photoluminescence (PL) is measured in air at room temperature. Because the polarization domain wall width in a ferroelectric can be as low as 1-10 nm, this approach enables spatial modulation of PL intensity and the corresponding carrier populations with potential for nanoscale resolution.

Single monolayer transition metal dichalcogenides (TMDs) such as WS2 exhibit striking optical properties due to their direct band gap. The dielectric screening is very low due to their two dimensional (2D) character, and thus their properties are strongly affected by their immediate environment, and can be modified and controlled by variations in local charge density due to adsorbates or electrostatic gating. This has generated keen interest in a wide variety of electronic and optical device applications.

The NRL scientist used a conducting atomic force microscope to write polarization domains into a PZT film in a checkerboard pattern. In each domain, the polarization dipole points either up out of the surface plane or down into the surface plane, and produces either positive or negative charge on the PZT surface, respectively. The team then transferred monolayer WS2 that they had grown by chemical vapor deposition techniques onto the PZT film.

They found that the PL intensity from the WS2 is high only from the areas over domains in the PZT where the polarization dipole points out

of the surface plane, as shown in the adjacent figure. Further analysis revealed that the spectral composition of the PL was also strongly affected—the spectra from the "up" domains were dominated by neutral exciton contributions (a bound state of an electron and hole arising from Coulomb interaction), while those from the "down" domains were dominated by negatively charged exciton, or trion, contributions (an exciton with an extra electron).

"Fabricating these hybrid 2D/3-D ferroelectric heterostructures enables one to purposefully design and modulate adjacent populations of trions and neutral excitons, creating lateral domains in any geometry of choice" notes Dr. Berend Jonker, senior scientist and principal investigator. Dr. Connie Li, lead author of the study, further points out: "Because the FE domains can be rewritten with an atomic force microscope and are non-volatile, this enables spatial modulation of the TMD properties with nanometer scale resolution."

The payoff includes development of TMD materials and hybrid 2D/3-D heterostructures with new functionality relevant to the DoD mission, including ultra-low power electronics, non-volatile optical memory and quantum computation for future DoD applications in information processing and sensing.

More information: Connie H. Li et al. Spatial Control of Photoluminescence at Room Temperature by Ferroelectric Domains in Monolayer WS/PZT Hybrid Structures, *ACS Omega* (2016). DOI: 10.1021/acsomega.6b00302

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