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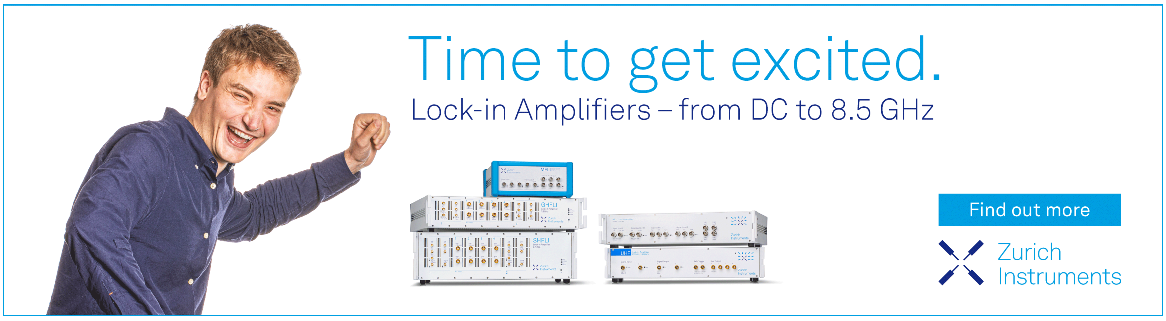

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Note: This paper is part of the Special Topic on 2D Piezoelectrics, Pyroelectrics, and Ferroelectrics.

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Piezoelectric, pyroelectric, and ferroelectric materials have attracted tremendous attention owing to their potential applications in nonvolatile memories, logic devices, photodetectors, sensors, actuators, transducers, and energy harvesting devices. In recent years, a range of two-dimensional (2D) layered materials have been experimentally confirmed or theoretically predicted to be piezoelectric, pyroelectric, or ferroelectric.[1–9] Compared to their bulk counterparts, 2D piezoelectric, pyroelectric, and ferroelectric materials exhibit many intriguing properties, such as excellent size scaling, tunable bandgap, negative piezoelectric coefficient, and high mechanical flexibility.[1–9] Furthermore, the stackable nature of 2D layered materials makes them promising building blocks for designing functional heterostructures, where the 2D layers can be integrated with conventional piezoelectric, pyroelectric, and ferroelectric oxides and polymers. These new materials and heterostructures enable a wide range of emerging applications, including nonvolatile memories, steep slope transistors, programmable junctions, charge and pressure sensors, photodiodes, and smart optical filters.

The Special Topic "2D piezoelectrics, pyroelectrics, and ferroelectrics" in the *Journal of Applied Physics* offers an overview of the most active research areas currently under investigation in the broad field of 2D piezoelectrics, pyroelectrics, and ferroelectrics. In particular, featured topics include van der Waals (vdW) piezoelectric/pyroelectric/ferroelectric materials,[10–13] correlated oxide nanowires,[14] and 2D/ferroelectric hybrid stacks,[15,16] as well as advanced electronic and pyroelectric devices based on these materials.[12,15,16]

A variety of vdW piezoelectric, pyroelectric, and ferroelectric materials have been discovered in recent years, including group III chalcogenides,[17–20] transition-metal thiophosphate,[21,22] group IV monochalcogenides,[23–25] distorted transition-metal dichalcogenides,[26,27] oxy-chalcogenides,[28] and layered perovskite.[29] Many of them can retain piezoelectricity, pyroelectricity, or ferroelectricity even down to 1 unit-cell thickness.[18,23,24] In this Special Topic, O'Hara *et al.* investigated the effect of various metal contacts on the scaling of 2D ferroelectrics. They found that metal contacts can facilitate the stabilization of the ferroelectric phase, enabling aggressive scaling of 2D ferroelectrics.[13] As a recently discovered vdW ferroelectric, α-In_2Se_3 exhibits inter-correlated in-plane and out-of-plane polarization.[17,18] Unlike traditional ferroelectric materials, which are usually insulators, α-In_2Se_3 is a semiconductor with a band gap of 1.36 eV (bulk). This semiconducting nature allows α-In_2Se_3 to serve as the conducting channel, the photo absorber, and the ferroelectric storage layer concurrently.[30] Logic transistors and multifunctional devices based on α-In_2Se_3 have been demonstrated.[30,31] In this collection, Zheng *et al.* demonstrated the synthesis of millimeter-scale In_2Se_3 with a thickness of $\sim$3 nm by physical vapor deposition and developed asymmetric ferroelectric semiconductor junctions based on ultrathin In_2Se_3 films.[12] $CuInP_2S_6$ (CIPS) is a vdW ferroelectric material with a 2.9 eV band gap (bulk) and out-of-plane polarization.[32] CIPS exhibits giant negative piezo-response and possesses unconventional quadruple-well potential.[33,34] Various electronic devices have been demonstrated based on CIPS, including nonvolatile memories,[35,36] reconfigurable logic devices,[37] and ferroelectric tunneling junctions (FTJs).[21] Kong *et al.* reported the photocatalytic activity of ferroelectric CIPS for the chemical deposition of silver nanostructures (AgNSs).[11] In addition, Parker *et al.* discussed the recent developments in van der Waals ferroelectric device technologies.[38] Lai provided an overview of the research in vdW ferroelectric materials, spanning from theoretical calculation, material synthesis, sample characterization, to device implementation.[39]

Furthermore, extensive research has been carried out on the heterostructures of 2D materials integrated with piezoelectric/pyroelectric/ferroelectric materials, leveraging their interfacial synergy to realize a wide range of electrical, optical, thermal, and mechanical applications. The atomic thin nature of 2D material allows for effective tuning of carrier densities through the polarization in ferroelectric materials, as well as substantial crystal deformation through the use of piezoelectric materials. A wide range of ferroelectrics have been integrated with 2D materials, including perovskites such as $Pb(Zr,Ti)O_3$ (PZT), $BaTiO_3$, and $BiFeO_3$,[40–59] doped hafnium oxides,[60–66] and ferroelectric copolymer poly(vinylidene fluoride-co-trifluoroethylene) or P(VDF-TrFE).[67–88] In this Special Topic, Chen *et al.* studied the effect of remote optical phonon scattering on the magneto-transport of graphene field-effect transistor back-gated by ferroelectric $Ba_{0.6}Sr_{0.4}TiO_3$ thin films and demonstrated field effect mobility up to 23 000 $cm^2 V^{-1} s^{-1}$.[16] Utilizing 2D/ferroelectric heterostructures, a variety of electronic devices including nonvolatile memories, steep-slope field-effect transistors, and FTJs have been demonstrated.[47–50,59,61–66,68–72] The heterostructures of 2D/piezoelectrics and 2D/pyroelectrics also enable the development of pressure sensors and infrared bolometers.[75,77,89] Mbisike *et al.* demonstrated an integrated pyroelectric device based on WSe_2 and PZT, which significantly amplifies the output current as compared to the standalone device based on PZT only.[15]

In summary, 2D piezoelectric, pyroelectric, and ferroelectric materials open up a new paradigm for electronic, photonic, and mechanic devices, which bring in strong potentials in a variety of applications. This collection of papers on 2D piezoelectric, pyroelectric, and ferroelectric materials provides a timely forum for investigators to share their new results and provide their assessment of the new technologies based on these materials. We hope the "2D piezoelectrics, pyroelectrics, and ferroelectrics" Special Topic will inspire many scientists and accelerate the expansion of this research field.

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