Electronic properties of electronic materials: interfaces & doping

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Electronic and opto-electronic devices used in information, communication, energy conversion, and energy storage technologies rely on a precise control of the charge density distribution, which is the key parameter for a wide range of electronic and optical processes in devices. The charge density and its energy spectrum in electronic materials determine elemental parameters and functions, such as the Fermi level position, type and mobility of charge carriers, interfacial energy level alignment, carrier injection and extraction at contacts, and the characteristics of excitations. The primary conventional method to control the charge density in electronic materials is doping, as already employed by Shockley, Bardeen, and Brattain in the first transistors in the 1940s. However, established electronic materials and doping concepts, e.g., the statistical incorporation of dopant atoms in a covalent lattice, will soon reach fundamental limits. The anticipated route beyond this deadlock is the use of new electronic materials and combinations thereof, where tuning quantum confinement, dimensionality, and the charge density enable new device concepts. In this contribution, at first the fundamental differences in the electronic properties of selected advanced and emerging electronic materials are contrasted, i.e., organic semiconductors, metal halide perovskites, and two-dimensional (2D) transition metal dichalcogenide (TMDC) monolayers. Next, considerations of how the energy levels differ in practical thin films from those in single crystals will provide the basis for discussing fundamental interfacial phenomena in hybrid heterostructures comprising dissimilar material classes. Modern approaches to tune the interfacial charge density re-arrangement, and concomitantly the energy level alignment, will then be introduced and their impact on interface functionality in devices exemplified. Most of these approaches are based on employing very strong molecular electron donor or acceptor molecules as interlayers, and photochromic molecular switches even facilitate *operando* optical control over electrical device characteristics, i.e., multifunctionality.