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Nanotechnology-enabled Flexible Hybrid Electronics

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Technology has contributed significantly to enhance the well-being of society, and innovation in nanotechnology is at the crux of changing industry throughout the world. To fuel the increasing demand for functionality from mobile devices to the "Internet of Things (IoT)" integrated electronics on flexible hybrid substrates is well recognized as a realistic solution. After a decade of intense searching for alternatives to enable the continuous improvement of speed and power consumption, it was found that a viable option was the integration of a few atomic layers or atomic-layer-thin materials such as carbon nanotubes (CNTs), nanowires, graphene and other atomic-layer-thin materials (MoS_2, BN, etc.), which have been perfected for other niche applications such as sensors and nanoelectronic devices [1,2]. Integrated nanoelectronic devices on flexible hybrid substrates can offer more enhanced functionality than can silicon-based devices for advanced wearable technology. However, the long-term performance of these new materials is still relatively unknown or misunderstood, which delays their implementation in the consumer electronics market. Therefore, it is critical to understand atomic level fundamentals [3,4]. In addition, integration of nanomaterials is vital for developing high-performance sustainable materials for the flexible hybrid electronics industry and to verify the interaction between the optimization and the short and long-term characteristics of nanodevices [5].

Although these nanomaterials have enjoyed considerable achievements with respect to their use in devices such gate-all-around transistors, FinFETs [6] and tunneling FETs [7] in logic application, their incompatibility with the well-established processing technology prevents them from integrated on a large-scale manufacturing platform readily [8]. Nano sized structures such as quantum dots (QDs) [9], nanowires (NWs) [10], nanorods [11] and nanopillars [12] offer new insights and opportunities for flexible hybrid nanoelectronic devices because of their unique optical, mechanical and thermal properties [5,13]. However, most of these nanostructures present great challenges with respect to integration with flexible substrates using CMOS-compatible fabrication processes [14-16] OTFTs have also been demonstrated on flexible substrates [17,18]. The challenges in flexible hybrid nanoelectronics have not been fully resolved, and device fabrication is still immature [19] Achieving high energy efficiency is becoming one of the highest priorities in the field of integrated electronics for next-generation information technology [20] To support such an energy-efficient technology, the research field of electronic devices is currently focusing on the development of low-energy consumption, high performance devices and corresponding integration technology [21]. The main challenge today is not to replace all the electronic systems with flexible electronics, but to determine how to enable these systems so that they can work together in the most energy-efficient manner. New fabrication processes and device structures should be generated, for both materials and devices, to take into consideration unique behaviors and features in nanotechnology-enabled flexible hybrid electronics [18-21].

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