

DNA Origami as Bio-Chemical Signal Generators

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Abstract: Recent advances in DNA nanotechnology have enabled the systematic design of nucleic acid-based nanoscale devices, transforming DNA from a genetic blueprint into a versatile engineering material. By leveraging the molecule's inherent programmability and molecular recognition capabilities, researchers have developed functional nanostructures for a broad range of applications, including pattern formation, molecular computation, and the construction of dynamic machines at the nanoscale. Among these developments, DNA origami has emerged over the past two decades as the leading technique for precise DNA-based nanoengineering. This method involves folding a long single-stranded DNA scaffold—typically of viral origin—into complex 2D and 3D shapes with the assistance of hundreds of short, custom-designed staple strands. Through predictable base-pairing interactions, these staples guide the scaffold's folding into pre-programmed architectures with nanometre-scale resolution. This technique has enabled the fabrication of an extensive variety of static and dynamic nanoscale forms. Recent implementations have highlighted DNA origami's utility not just as a structural material, but as a dynamic platform for functional devices. Researchers have created molecular machines such as walkers, switches, and hinges, and have demonstrated applications in targeted drug delivery and biosensing. Furthermore, DNA origami has been integrated with proteins, nanoparticles, and carbon-based materials to form hybrid systems with applications in plasmonics, nanoelectronics, and diagnostics. In most existing approaches, DNA origami structures are designed as the end products of assembly. In contrast, our work introduces a new paradigm in which DNA origami systems actively interact with their environment by emitting marked DNA strands as biochemical signals. These outputs can be detected via simple methods such as UV fluorescence or used as inputs for further DNA-based processing. As a proof of concept, we present devices that interpret environmental input strands and generate outputs consistent with formal language constructs, paving the way for programmable, communicative, and computationally active nano systems.

Keywords: DNA Origami; Nanoscale Devices; Molecular Computation; Hybrid Nanostructures; Signal-Emitting Systems.

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