# A Robust DNA-Based Nanomechanical Device

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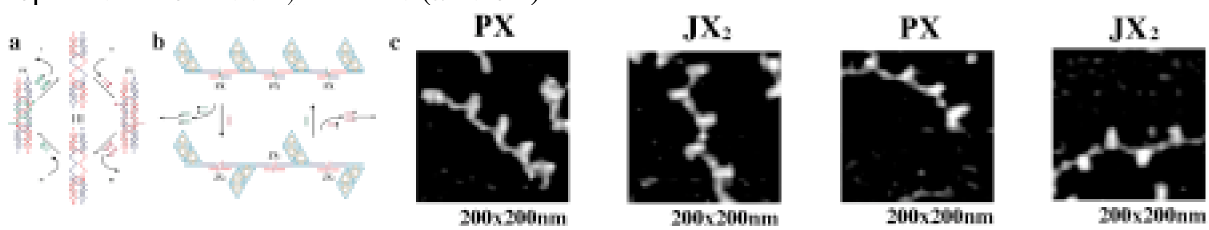
We read frequently about elegant nanostructures that have been fashioned from organic, inorganic or biological components. Carbon nanotubes, molecular linked chains, DNA polyhedra and nano-patterned systems are commonly mentioned in the news of progress in nanotechnology. Despite the value of these systems, an inherent goal of nanotechnology is controlled motion on the nanometer scale, leading to motors, actuators and other nanomechanical devices.

**DNA as a nanoscale building material.** The specificity of DNA interactions has made it a powerful system for exploring engineering at the nanometer scale. DNA itself is a nano-scale molecule, whose diameter is two nanometers and whose helical repeat is about 3.5 nanometers. However, the real virtue of DNA in nanotechnological applications is its specificity of interaction: The same base pairing that results in replication fidelity can be used to join DNA molecules together with high specificity and predictable structures at the point of association. Although the linear nature of biological DNA is not very interesting as a construction material, the Seeman group has worked for over 20 years with synthetic branched DNA molecules. Branched DNA molecules can be thought of as molecular Tinkertoys, and they have been used to make a variety of objects and periodic arrays through self-assembly.

**Current DNA devices.** The Seeman group produced a DNA device several years ago based on a structural transition of DNA, the conversion of right-handed DNA (the usual form) to an unusual left-handed form, known as Z-DNA. This transition is activated by a small molecule or by adding salt to the medium, so it lacks specificity. Sequence-dependent devices are needed if one wishes to activate particular DNA devices within a collection of them at a given time. Several years ago, the Yurke group at Lucent produced a sequence-driven tweezers-like DNA device, but only one of its end-states was well-formed. Recently, Hao Yan, in the Seeman group, produced a robust sequence-driven DNA nanomechanical device. It is based on a change in structure caused by binding different DNA strands to a frame. Depending upon which strands are bound, the system adopts the PX or the $JX_2$ structure (**a** below):




By placing the device between DNA trapezoids, the change of state can be visualized in an atomic force microscope (AFM), which can show nanoscale features. When in the PX state, the trapezoids are all parallel, but in the $JX_2$ state they form a zigzag pattern. This is shown schematically in **b** above. The AFM images shown in **c** above show that the system oscillates between the parallel and zigzag arrangements, as the state of the device is changed.

**Future DNA devices.** The robust sequence dependent device illustrated above is one of a number of possible designs for such a machine. The Goddard-Vaidehi group is working with the Seeman group to model and optimize different devices computationally, without the need to build all of them. The interaction has already yielded an insight, suggesting that one structure variant that had been discarded be re-examined; when re-examined, it was found that it was possible to build that variant. Future DNA devices of this sort will be optimized computationally before being built.

The activation of this DNA device is done deliberately at the instruction of the researcher. However, the Winfree group is making chemical circuits that control the transcription of RNA from DNA. Ultimately, this work will lead to logic gates based on solution conditions and other inputs. The output of those gates will be RNA molecules that can activate the DNA device described above. Work has already shown that the device can form with RNA.