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A Flexible Method for the Fabrication of Gold Nanostructures Using Oligonucleotide Derivatives.

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Running Title: DNA-templated gold nanostructures

Abstract. Several linear and branched DNA structures from 80-200 nm with a biotine molecule in the middle have been prepared. These structures have been decorated by addition of positively charged gold nanoparticles. Streptavidin binds to the central biotine molecule introducing a 20 nm gap in the structure in which a biotinylated nanoparticle can be introduced. The simplest structure (80 nm, linear) is formed by 4

oligonucleotides. By changing some of these components changes on length, shape and recognition system can be easily introduced.

Introduction. Among the biological molecules, oligonucleotides have been used as template to assemble inorganic nanocrystals, especially gold nanoparticles (1, 2). The hybridization properties of the oligonucleotides allow the assembly of gold nanoparticles at distances determined by the length of the oligonucleotides and also the formation of three-dimensional networks (1, 2). Also, oligonucleotides linked to nanoparticles have special optical properties used for monitoring DNA hybridization (3). In addition DNA can be metalized to form conducting wires between electrodes (4). In the present communication we will describe the use of oligonucleotides to obtain functional units with potential interest in nanoelectronics.

Results and Discussion

We are interested in the preparation of synthetic DNA derivatives designed to assemble a molecular wire between two or three gold electrodes, which are needed to address individual nanoparticles from macroscopic electrodes (5-8). Synthetic oligonucleotides were used to prepare the molecular wires, offering the possibility to introduce modifications at any predetermined position.

The simplest target molecule consists of three elements having different roles: anchoring, extension, and recognition (scheme 1). Two anchoring elements are located at each end, both having disulfide groups allowing the wires to be attached to the electrodes. The center of the structure is a chimeric compound with a DNA segment that positions the element in the middle of the structure. It also contains biotin as a recognition group, isolated from the DNA by a spacer molecule made of two

hexaethylenglycol units. This recognition element is used to direct a nanoparticle into the middle of the structure as well as to connect the two branches. The size of the whole structure is determined by the extension elements between the recognition and the anchoring elements.

The extension elements (100 bases long) were prepared using protocols to produce long oligonucleotides while thiolated oligonucleotides were prepared using standard protocols (9). Special protocols were developed for the preparation of the recognition elements since the polarity of the DNA strands is reversed in the middle of the molecule, thereby providing symmetry to the central assembly**.** The two-armed recognition element was prepared by sequentially adding 10 different phosphoramidites. Starting from the 3ô-end, the first half of the sequence was assembled using the four standard phosphoramidites. Subsequently, hexaethyleneglycol and biotin-tetraethyleneglycol phosphoramidites were added. Finally, the second half of the molecule was assembled using the four reversed phosphoramidites (10). Synthesis of the oligonucleotides carrying three branches was conducted in similar fashion although a symmetric branching molecule was added. First, the 20 mer sequence was built in the 3´->5ô direction using standard phosphoramidites and the hexaethyleneglycol phosphoramidite. Then, the biotin-tetraethyleneglycol was added. Afterwards, a symmetric branching phosphoramidite was added to the sequence. Finally, the rest of the desired sequence was assembled in the 5ô->3ô direction using reversed phosphoramidites and the hexaethyleneglycol phosphoramidite (10).

Figure 1 shows the AFM image (tapping mode) of a target assembly connected to two gold nanoparticles of 5 nm. Significantly, both the gold nanoparticles and DNA backbone components can be seen. The center-to-center distance between the

nanoparticles (73 nm) is close to the expected value of the assembly (80 nm). Figure 2 shows the AFM image of a longer assembly connected between two gold nanoparticles. In this case, eight oligonucleotides of 100 bases were used as extension elements instead of two obtaining a linear assembly of 280 nm.

Using these oligonucleotides the DNA-templated assembly of a protein-functionalized 10 nm gap electrode, from suitably modified gold nanoparticles on a silicon wafer substrate, was achieved (6-8). This protein-functionalized electrode was recognized and selectively bound by a suitably modified gold nanoparticle that was localized in the 10 nm gap (6-8). These findings are of interest for the fabrication of next-generation electronic devices.

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FIGURE LEGENDS

Scheme 1. Outline of target nanoscale assembly.

Figure 1. AFM image (tapping mode) of the nanoscale assembly shown in scheme 1 (240 bp, nominal size 80 nm) connected to two gold nanoparticles of 5 nm.

Figuare 2. AFM image (tapping mode) of a long DNA assembly prepared using 8 extension elements of 100 bases (840bp, nominal size 280) connected to two gold nanoparticles of 5 nm.

Scheme 1

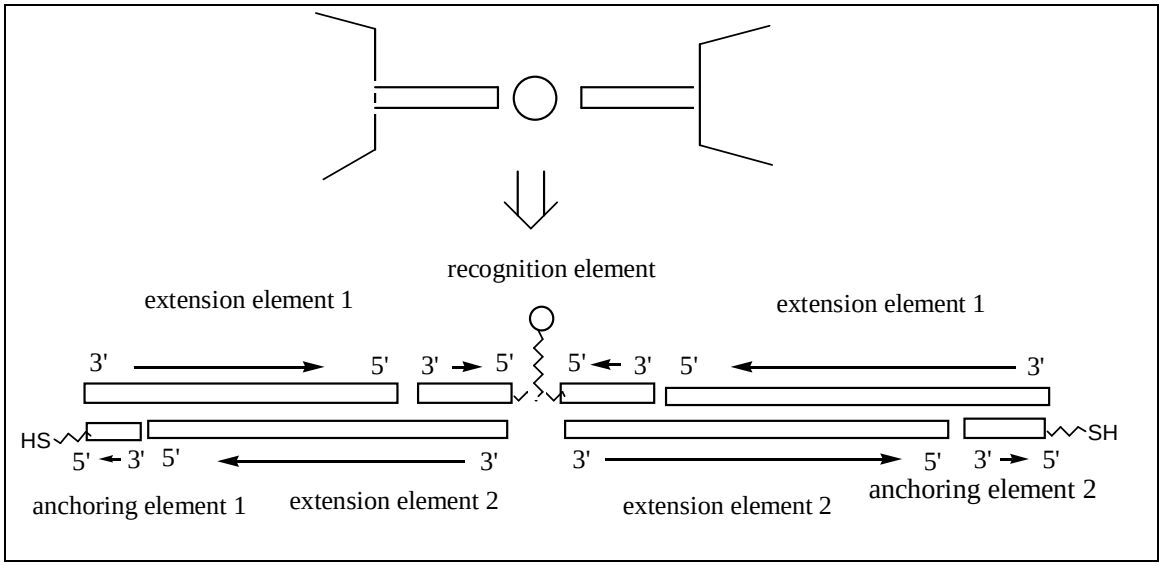
recognition element
extension element 1
extension element 1
3'
5'
3'
5'
5'
3'
5'
3'
HS
SH
5'
3'
5'
3'
3'
5'
3'
5'
anchoring element 1
extension element 2
extension element 2
anchoring element 2

Figure 1

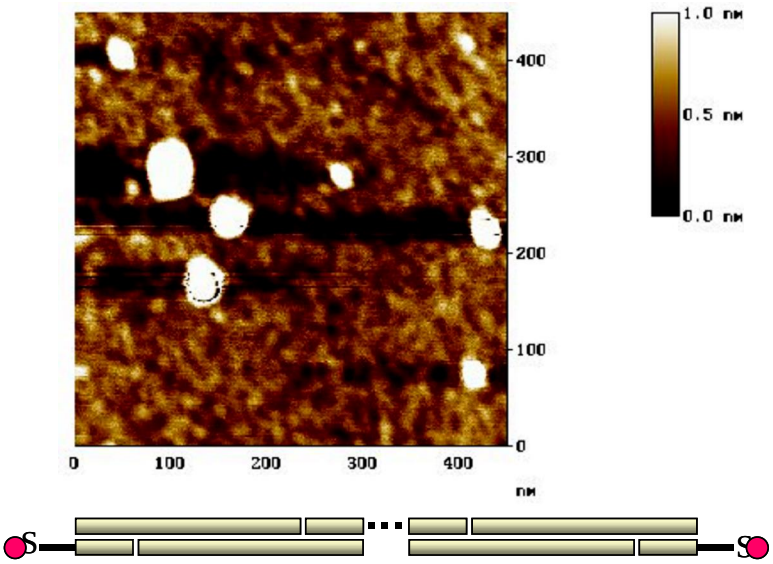

Figure 2