Precise Placement of a Single Quantum Dot in a Bowtie Nanoantenna Gap

Baoquan Ding*, Alan Chang, Scott Dhuey, Bruce Harteneck, Bruce Cohen, Ronald Zuckermann, James Schuck, Stefano Cabrini and Jeffrey Bokor*

Molecular Foundry, Lawrence Berkeley National Lab, 1 Cyclotron Rd, Berkeley, CA 94720

Email: BDing@lbl.gov, JBokor@eecs.berkeley.edu

The recent invention of single metallic optical nanoantennas has greatly improved the mismatch between wavelength of light and nanometer-scale objects [1, 2]. Metallic bowtie nanoantennas are engineered to enhance fields at visible and near-infrared (NIR) wavelengths and confine them to nanoscale regions in size; significantly defeating conventional diffraction limited photon localization [2]. A simulation study has shown that a nanostructure with a semiconducting quantum dot placed in the gap of a bowtie nanoantenna can work as a nanolaser [3]. Here we demonstrate the precise placement of a single colloidal quantum dot into the gap of a gold bowtie antenna. The optical properties of this structure will be characterized.

E-beam lithography combined with a directed assembly approach was utilized here to fabricate the device structure. e-beam lithography, dip-pen lithography, or scanning force microscopy have previously been used to generate a surface pattern that can be chemically modified and used to template the assembly of guest nano-objects such as biological material or nanoparticles [4, 5, 6]. However, these reported patterns are usually larger than 50nm and difficult to use for single particle assembly. We have successfully fabricated a surface pattern of ~10nm dimensions and used it to assemble a single semiconductor quantum dot at a specific location: the gap in a bowtie nanoantenna structure. The fabrication process is shown in Figure 1. At first, a gold bowtie antenna with edge length 85 nm was fabricated on silicon dioxide using standard e-beam lithography and lift-off patterning. Hexamethyldisilazane (HMDS) was then deposited on the surface by vapor diffusion. The hydrophobic HMDS layer helps decrease the non-specific binding of quantum dots to the wafer surface. A second E-beam exposure using PMMA resist was performed to generate a 10nm hole in the bowtie gap. Using our Vistec VB300 e-beam tool, alignment accuracy is about 2 - 8 nm. Then (3-aminopropyl) triethoxysilane (APTES), a cationic SAM precursor, was deposited from aqueous solution onto the exposed silicon dioxide at the bottoms of the opened holes. The remaining PMMA was cleanly stripped off with hot N-methylpyrrolidone (NMP). Finally, mercaptopropionic acid (MPA) capped quantum dots of ~6 nm diameter selectively bind to the positively charged APTES spots formed in the bowtie antenna gap. Figure 2 shows the SEM image of fabricated structure. The APTES template spot can be further chemically modified with different molecules. Thus this method can be use to assemble various nano-objects with under 10nm precision, good selectivity and reproducibility.

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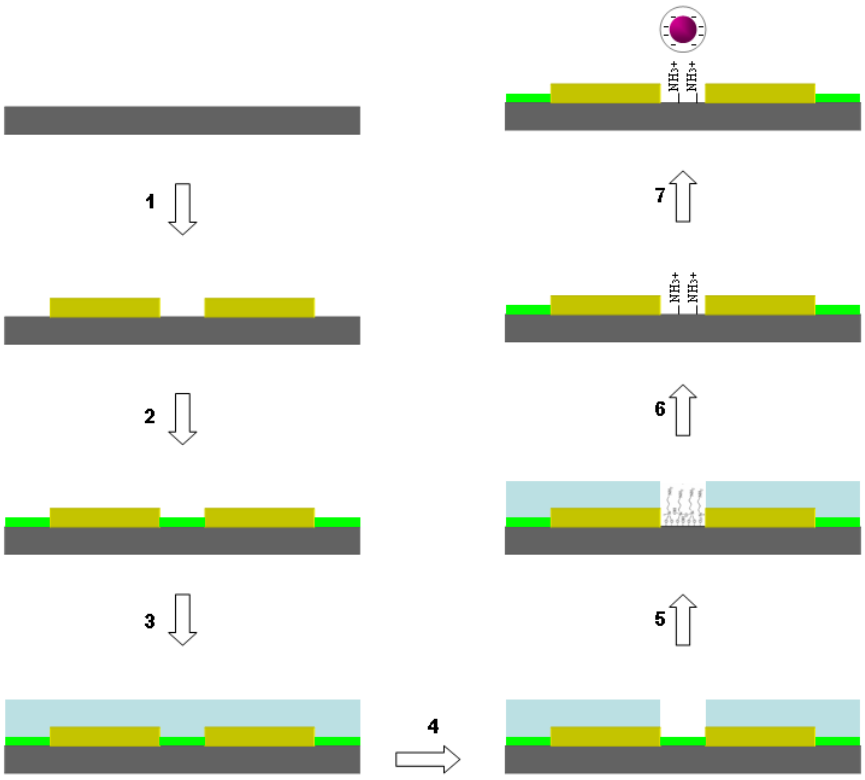

Figure 1, Fabrication process. 1): Gold bowtie antenna was fabricated on thermo silicon dioxide wafer through standard lift-off process with alignment marker around them. The distance between two triangles ranges from 10nm to 20nm. 2): HMDS was deposited on the surface by vapor diffusion. 3): PMMA resist layer was spin-coated on the wafer surface. 4): E-beam exposure of 10nm hole between the bowtie structures. The alignment accuracy is about 2- 8 nm. 5): APTES was deposited from aqueous solution onto the exposed silicon dioxide at the bottoms of the opened holes. 6): The remaining PMMA was cleanly stripped off with hot NMP. 7): MPA capped quantum dots selectively bind to the APTES spots between bowtie antennas. .

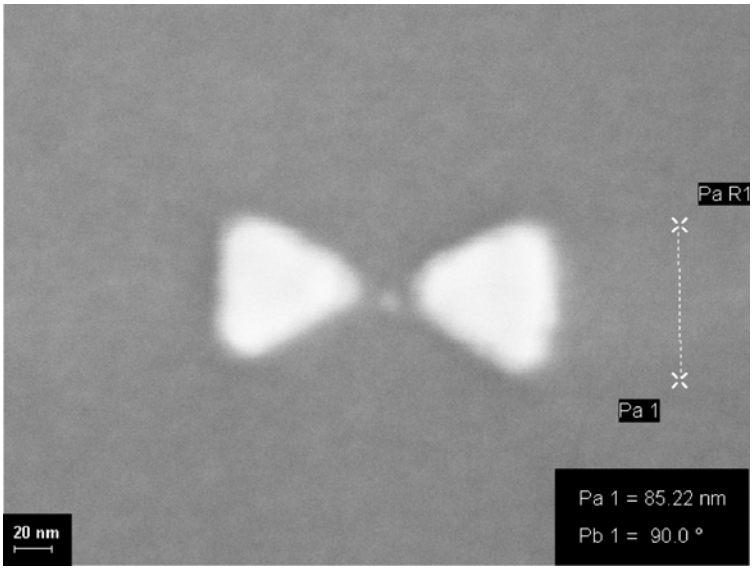

Figure 2, SEM image of fabricated nanostructure. The size of assembled quantum dot is around 6 nm.