Electronic Supplementary Information (ESI) for

Photocurrent Enhancement of SiNW-FETs by Integrating Protein-Shelled CdSe Quantum Dots

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Supplementary Materials and Methods

Sample preparation and characterization

All chemicals used in this study were obtained from Sigma-Aldrich without further purification (Sigma, MO, USA). Ion-free water prepared in a Millipore Milli-Q system (conductivity ≤ 0.1 μS cm^{-1}) was used for the study. The protein-shell ClpP from *Helicobacter pylori* was prepared as reported previously[1]. The concentration of ClpP was determined by Bradford assay with BSA as the standard. The CdSe nanoparticles were synthesized according to a previously reported procedure[2]. In brief, the reaction solution for the synthesis of CdSe nanoparticles in ClpP cavities contained cadmium, selenium, and ammonium ions along with ClpP. The 0.5-mL reaction mixture with a final concentration of 1.5 μM ClpP, 1 mM cadmium acetate, 40 mM ammonium acetate, 7.5 mM ammonia water, and 5 mM selenourea was prepared and left overnight at room temperature under stirring. Then, it was centrifuged at 13,200 rpm for 30 min at 4°C. The supernatants were used for further experiments.

Transmission electron microscopy (TEM) images were taken using a JEOL JEM-2100 microscope (JEOL, Tokyo, Japan) operated at 200 kV. TEM samples were prepared as described previously[3] by applying the ClpP-CdSe solution on a copper grid covered with a thin carbon film (JEOL, Tokyo, Japan) and by dehydrating the grid overnight at room temperature. The negatively stained ClpP-CdSe samples were prepared by staining the sample on the copper grip with 2% uranyl acetate for 30 s. Energy dispersive X-ray spectroscopy (EDS) data were confirmed from the samples prepared for TEM. The size of the CdSe particles was estimated by averaging 100 individual particles using Gatan Digital Micrograph software (Gatan, Pleasanton, CA).

Si-NW FET device fabrication

We followed the process described in previous work[4]. Silicon nanowires (SiNWs) were fabricated simply by a conventional micro-machining technology based on photolithography, anisotropic etching, and thermal oxidation processes. In general, for the fabrication, we used a single-crystalline silicon substrate, with a p-type (100)-oriented substrate characterized by 0.01–0.02 Ωcm and 10–30 Ωcm and an n-type (100)-oriented substrate. All substrates were 100 mm in diameter (4-inch wafers). The electrical properties of silicon nanowires can be controlled by choosing a silicon substrate with a specific dopant type and concentration. Starting with the thermal oxidation of the silicon substrate, 0.8- to 1-μm-wide lines of the oxide layer are defined using stepper photolithography. Silicon bulk anisotropic etching, using deep silicon reactive-ion etching (DRIE) and potassium hydroxide (KOH) solutions in sequence, provides an inverted triangular shape, in cross-section, of silicon lines supported by narrower silicon pillars. Thermal oxidation of the silicon substrate follows, producing silicon nanowires with a sub-100 nm diameters near the center of an inverted triangle, while the supporting silicon pillar becomes completely oxidized. The nanowire becomes free-standing after the surrounding SiO_2 is removed. In brief, the overall size of each chip was 2×2 cm^2, including eight detection regions (out of eight only one detection region is used for this work), which had electrodes for probing. In the selected sensing area of each chip, two hundred fifty highly ordered SiNWs were located, and each SiNW was 150 nm in width and 20 μm in length.

SPQ-FET device fabrication

The procedure used to functionalize the SiNW surface with aldehyde-terminated monolayer is described previously[5]. Organic materials were cleaned off with oxygen plasma for 5 minutes. Subsequently, aqueous solution (1 μL) containing ClpP-CdSe QDs was placed on the SiNWs using the non-contact dispensing instrument (sciFLEXARRAYER S11, Scienion AG, Germany). The SiNW-FET is then placed in the desiccator for complete dry of the ClpP-CdSe QDs solution. SPQ-FET is ready for the characterization and further evaluation.

Experimental setup

The SiNW device was electrically connected to Semiconductor Parameter Analyzer (SPA, 4200, Keithley, USA) to measure the current-voltage (I-V) characteristics using a micro probe station (MS Tech, Korea). For illumination, a monochromator (Newport, USA) was used as the light source during experiments. Data from the SPA were recorded on a PC to analyze the sensing response of the fabricated device. Photocurrents were measured under illumination with visible light (480 nm) using a monochromator. Experiments were carried out at room temperature at standard atmospheric pressure.

Supplementary Figure

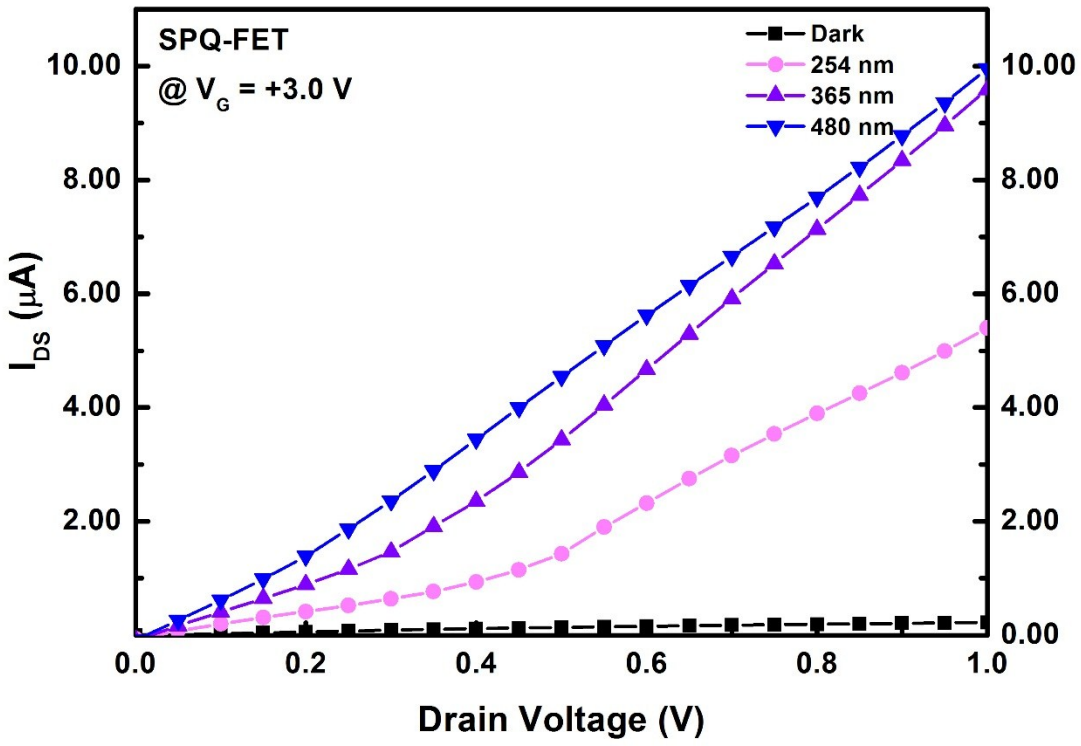

Figure S1. Photocurrent response of the SPQ-FET to dark (no light), 254-nm, 365 nm and 480-nm illumination.

Supplementary References

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