CdSe Nanoparticle Arrays Contacted on Electron Transparent Substrates

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Abstract. Arrays of CdSe clusters were obtained by deposition of the clusters (diameter $d \approx 4$ nm) on 20 nm thin, electron transparent Si_3N_4 substrates using a self-assembly process. The obtained cluster arrangements were characterized by transmission electron microscopy. To contact the cluster arrays, metal electrodes were defined by electron beam lithography on the Si_3N_4 substrates. A metallic layer evaporated onto the rear side of the membranes served as a backgate. The investigated junctions showed a very high resistance in spite of closely packed CdSe cluster monolayers.

INTRODUCTION

To perform electrical transport investigations on individual clusters it is necessary to contact these clusters to external sources and probes. Achieving electrical contact to one individual CdSe cluster [3] with diameter $d \approx 4$ nm in a reproducible way still constitutes a formidable technological challenge [1]. It is especially challenging to characterize the obtained cluster/electrode arrangement since transmission electron microscopy is required. In the present work, this is realized by using an electron transparent substrate. Suitable for this purpose are Si_3N_4 membranes that can be prepared using conventional silicon processing techniques [2]. The obtained Si_3N_4 membranes have a uniform thickness of 20 nm over an area of 200 μm x 200 μm with a roughness of less than 0.5 nm, can be easily handled using normal tweezers and are able to withstand several cooling cycles between room temperature and liquid helium temperature (T=4.2K).

DEPOSITION OF CDSE CLUSTERS ON SI_3N_4-SUBSTRATES

nearly monodispersed 4 nm diameter CdSe nanocrystals [3] are stabilized by shell consisting of trioctyl phosphine oxide (TOPO) and thus are soluble solvents. When nanocrystal solution is brought in contact with the surface of Si_3N_4-substrates, virtually no adsorption takes place.

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To appropriately modify the silicon nitride surface prior to attaching CdSe nanocrystals, the substrate was first exposed to UV (λ = 254 nm) radiation in order to improve the wetting of the surface by aqueous media. The second step consisted in covering the substrate with 20 μl of a solution of 10 mg chitosane and 10 μl of 3–mercapto–propionic acid in 20 ml of water. After drying of the droplet, excess polymer was removed by immersing the substrate in hydrochloric acid (5 wt%) for 15 minutes, followed by thorough rinsing with pure water and drying in air. Subsequently, the substrate was placed for 2 hrs into a solution of CdSe nanocrystals in toluene, then rinsed with pure toluene, and finally dried in air. Fig. 1 shows a TEM micrograph of a CdSe nanoparticle assembly obtained on a

FIGURE 1. TEM-micrograph of an array of CdSe clusters deposited on a Si_3N_4 membrane with a chitosane salt pre-adsorbed as binding layer.

Si_3N_4 substrate. The resulting pattern is determined by the microscopic interparticle and particle/surface interaction. As the concentration at the interface increases, the nanoparticles first behave like a two-dimensional gas and finally form a densely packed monolayer on the membrane substrate with, however, no hexagonal close packing due to the relatively strong particle/surface interaction.

CONTACTING OF CDSE CLUSTERS BY METAL ELECTRODES

In order to contact these cluster arrangements to external sources and probes for electrical transport investigations, devices like the one shown as a schematical cross section in Fig. 2 have been fabricated.

The small gap metal electrodes were defined using a standard bilayer PMMA resist electron beam lithography process. The gap sizes obtained are in the order of 20 nm, but can be reduced to 5 nm by using a special shadow evaporation technique [4]. The CdSe clusters were deposited onto the substrates with metal

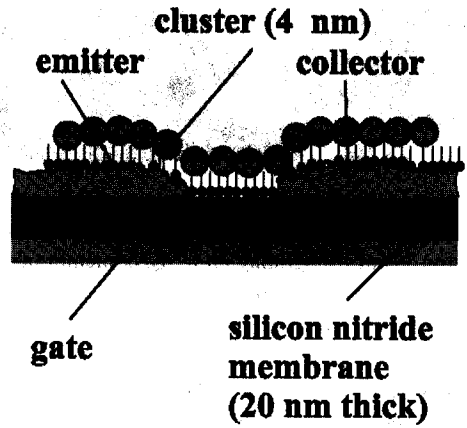

FIGURE 2. Schematic representation of a device consisting of CdSe clusters deposited into the gap between two Cr/AuPd electrodes using chitosane as a binding layer. The electrodes are defined by electron beam lithography on a Si_3N_4 membrane. The size of the gap can be as small as 5nm, if a special shadow evaporation technique is used.

electrodes as described in the previous section. A TEM micrograph of clusters deposited into the gaps between two metal electrodes is shown in Fig. 3. The size of the smaller gap in Fig. 3 is 20 nm whereas the size of the larger onbe is $\sim$ 50 nm. Electrical transport measurements of such devices revealed very high resistances in the TΩ range. This result is according to earlier findings [1], where only a very low yield of working devices was reported, and suggests that such metal electrodes are not the ideal means for directly contacting one *individual* cluster. Clusters with a few nm diameter are not accessible by lithographic techniques due to the limitation

FIGURE 3. A TEM micrograph of CdSe clusters deposited into the gaps of two Cr/AuPd electrodes defined by electron beam lithography on a Si_3N_4 membrane. The size of the top gap around is 20 nm, that of the bottom gap 50 nm.

in resolution of the PMMA resist. In addition, cluster-like grains formed during evaporation of the electrodes can be observed in transmission electron microscopy. These grains might influence the measured current-voltage characteristics.

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