Single-Nanostructure Device fabricated by alternative technologies

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For the last ten years, alternative technologies for nanofabrication and nanostructure localisation/assembly have targeted new approaches for low-cost, high throughput fabrication of single nanostructure devices. For example, NanoImprint Lithography (NIL) [1] is now competitive with electron beam lithography for nanopatterning and many novel techniques have already been introduced for manipulation and localization of colloidal nanostructures using chemical functionalization [2], capillary forces [3] [4], and dielectrophoresis (DEP) [5]. In this work, we demonstrate a new strategy to collectively fabricate Single Nanostructure Device (SND) by combining thermal NIL and carefully define an AC-DiElectroPhoresis (AC-DEP) trap.

First, a tri-layer NIL lift-off process detailed elsewhere [6] was developed to fabricate metallic nanoelectrodes with connexion pads on a 100 mm wafer using one imprint step (Fig1a). For localisation experiments (Fig.1 (b)), a droplet of gold colloid was deposited over the electrode gap, and the trapping of nanoparticles by AC-DEP was followed using real-time microscopic imaging (Fig.1b). Several dynamical regime were optically identified depending on the applied electric field: Brownian motion regime, Coulomb force regime and AC-dielectrophoresis regime (Fig.2).

The AC-DEP force ($\vec{F}_{DEP} \sim \Re e(f_{CM}) \cdot \vec{\nabla}|E|^2$) influences the motion of uncharged polarizable particles in a dielectric medium when a nonuniform electric field is present. Here, $\Re e(f_{CM})$ represents the real part of the Clausius-Mosotti (CM) factor, which gives a measure of the dielectric contrast between particles and the surrounding medium. As such, particles can be attracted to the electrodes or repelled from them using only the frequency dependence of $\Re e(f_{CM})$. Real-time tracking of nanoparticles was used to determine the transition frequency f_0 where the DEP force shifted from attractive to repulsive behaviour (Fig.3). By working in the attractive regime near f_0, we show that it is possible to find experimental conditions to trap a single gold particle (200 nm – 50 nm) with a rate of success up to 20% (Fig4.) for the biggest particles sizes. Figure 5 presents SEM pictures of several single nanostructure devices fabricated by this technique. Current-Voltage measurements from a 50 nm gold particule device show coulomb staircase in the temperature regime up to 50 K without any molecular tunnel barrier like observed in other works [2,6].

This talk will highlight electrode fabrication using NIL, real-time imaging and statistical control of the particle trapping process at the single nanostructure level. We will also detail electronic transport on these systems.

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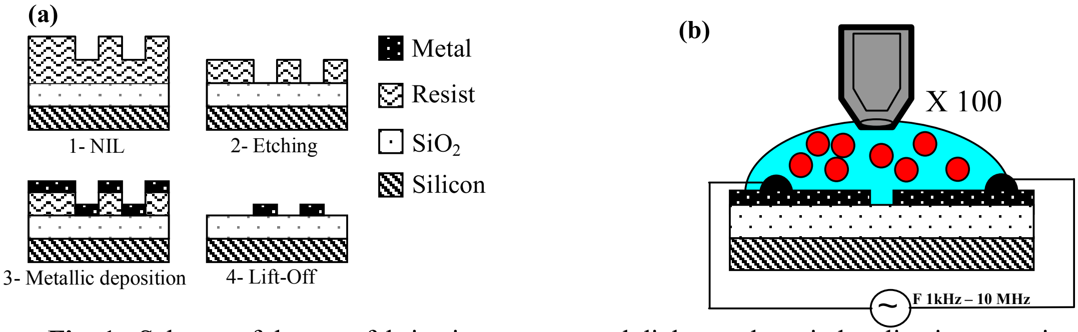
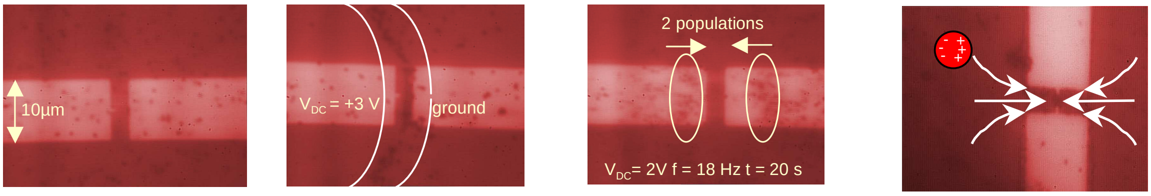


Fig. 1 : Scheme of the nanofabrication process and dielectrophoretic localization experiments.
(a) NIL process for metallic (Ti 5nm /Au 35 nm) nanoelectrodes fabrication on SiO_2 (100nm)/ Si.
(b) Dielectrophoresis experimental set-up for direct imaging of gold colloïd trapping.



(a) No electrical field applied (Brownian motion).
(b) DC electric field
(c) AC electric field **(f < 1 kHz)**
(d) AC electric field **(f > 500 kHz)**

Fig. 2 : Real time optical observation of 200 nm gold nanoparticles repartition inside the drop.

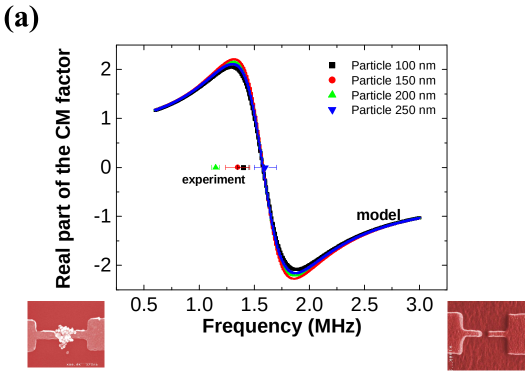


Fig. 3 : Experimental determination of the real-part of the Claussius-Mossoti factor and comparison with a bilayer model.

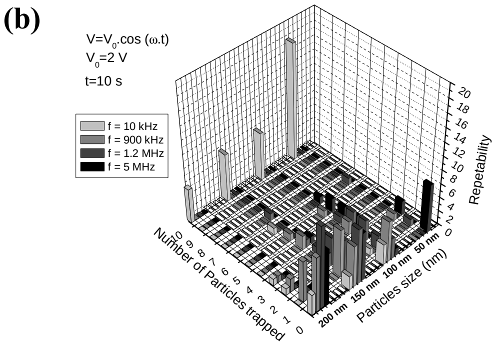


Fig. 4 : Statistical analysis of the number of particles trapped for different AC-DEP frequencies and for several nanoparticle sizes.

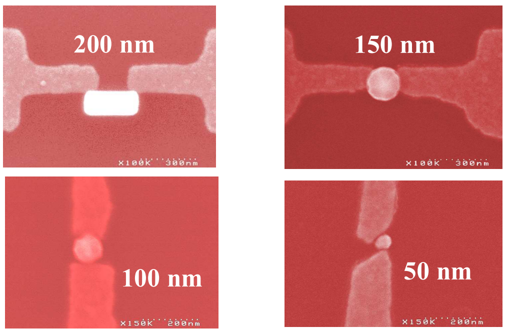


Fig. 5 : SEM pictures of single Au nanoparticle trapping from different sizes by combining nanoimprint lithography and dielectrophoresis.

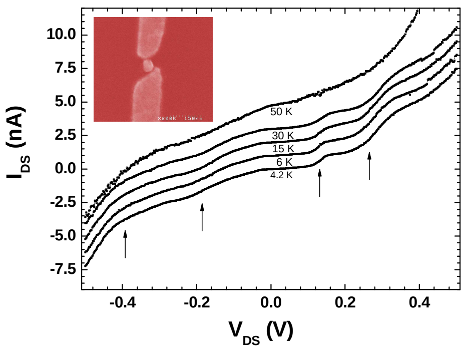


Fig. 6 : Current-Voltage curves measured for a junction with a single 50 nm Au nanoparticle as a function of the temperature (4K < T < 50K).
[inset: SEM picture of the device]