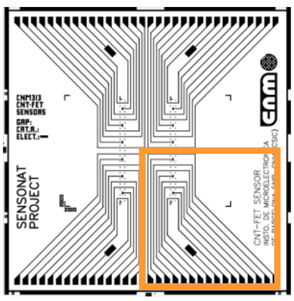
Supplementary Information

Fabrication of the CNT-FET devices

The detailed fabrication process of the CNT-FET device has been reported previously and here some additional issues are only discussed[1,2]. The design of a single chip (Fig. S1 a) contains 24 structures as the one schematized in Fig. 1 of the paper with an additional pad for the back gate electrode. All these electrodes are disposed in four identical quadrants. The chip concentrates the CNT-FET structures at the center of the chip, far from the connection pads in order to have space for placing a liquid cell. The figure S1b shows a zoom of one of the four quadrants. Each quadrant contains 6 CNT-FET devices, a back gate electrode and 3 liquid polarization electrodes. The external electrical connections are made from the 16-big pad matrix.

As mentioned in the manuscript the CNT-FETs need to be passivated in order to get a good performance in the liquid medium. A poor passivation of the device can result in leakage currents or undesired side electrochemical reactions (such as metal oxidation or electrolyte decomposition) which can smear the FET response or destroy the electrode contacts.
Complementary to the Figure 1b-c in the paper, figure S2 shows an AFM image of the PMMA passivated device in which the open groove free of PMMA (for delimiting the region of the CNT that will be in contact with the liquid) can be observed more clearly. The leakage current (gate current as a function of the gate voltage) for such passivated CNT-FETs has been observed to decrease dramatically when using such kind of passivation[2]. A very low leakage current is a critical parameter for the electrochemical sensing operation of the CNT-FETs since it will determine the sensitivity and stability of the sensor device.

a) 

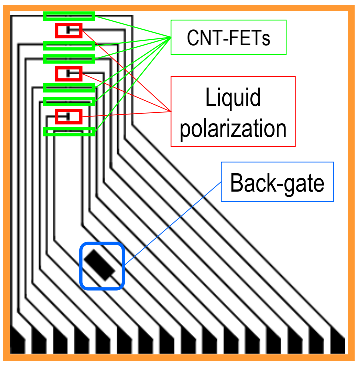
 b)

Figure S1. a) Schematic of 0.5x0.5 cm^2 chip platform. b) Elements on a quadrant: 6 CNT-FET structures, back-gate electrode and 3 liquid polarization electrodes and 16 pad matrix.

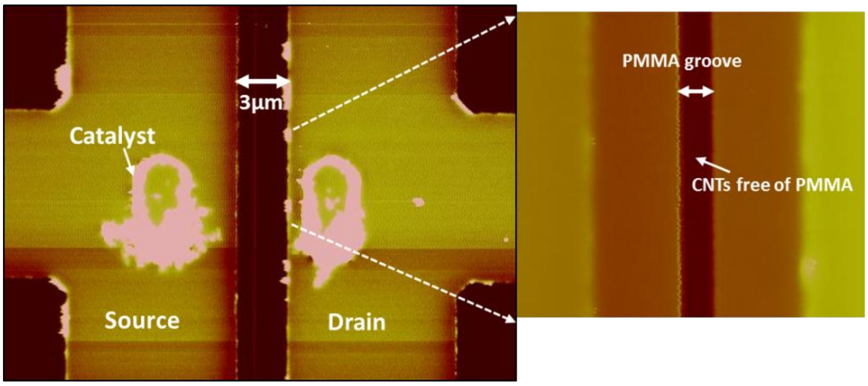


Figure S2. A closer look of the source and the drain electrodes after they had been passivated with PMMA. A zoom of the 500 nm groove on the PMMA layer is also shown.

Verification of the functionalization process

A simple way to confirm adsorption of pyrenes via π-π stacking is by confocal fluorescence microscopy. We have followed pyrene immobilization using fluorescent pyrenes which are emitting in the green wavelength region (λ_{em}~515 nm). The pyrene linkers tested were dichlorotriazinepyrene (DCTP, λ_{exc}~458 nm) and pyranine (λ_{exc}~460 nm). Figure S3 shows the reflection and fluorescence images of pyrene functionalized single-walled carbon nanotubes. It can be observed that pyrene is indeed adsorbed on the CNT walls provided by the green appearance of the CNT fluorescence images.

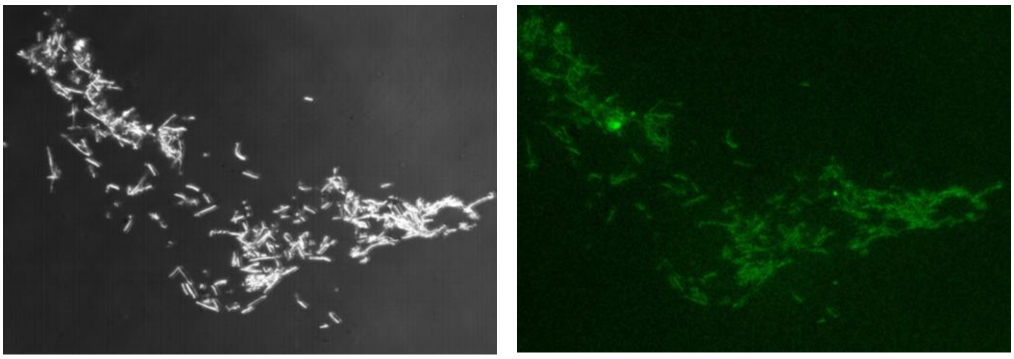


Figure S3. Reflectance and confocal fluorescence images of single-walled CNTs treated with DCTP.

After having verified pyrene adsorption on the CNT walls, we have characterized the anchoring of amine terminated aptamers on the carboxylic ends of pyrene linkers. For that we have performed X-ray photoelectron Spectroscopy (XPS). The XPS data in Fig. S4 show mainly two different electron binding energies for N1s: the first one, around 399.95 eV (black spectrum) coming from a reference sample which only contains the aminated aptamer and the second one, around 401 eV (grey spectrum) acquired after subjecting the pyrene modified CNT sample to carbodiimide reaction. That shift in the binding energy with respect to the aminated one is due to the amide formation.

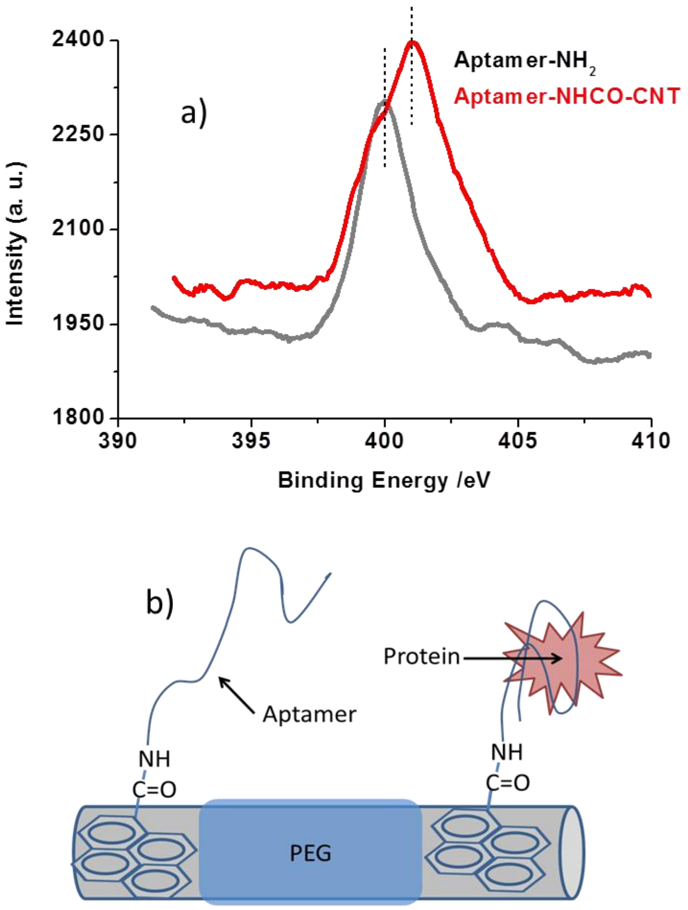


Figure S4. a) XPS spectra of the aminated aptamer and the amide formation on the pyrene modified CNT. b) Scheme showing the functionalized carbon nanotube.

These results demonstrate that aptamer probe has been successfully fixed on the electrode and that the sensing interface is obtained.

Behavior of the liquid polarization electrode

One advantage of having the liquid gate electrode integrated into the FET device is that it is easy to miniaturize with standard lithographic techniques and that the position of the electrode is always fixed. The disadvantage is that it is not a real reference electrode and under certain conditions it can induce an unstable gate potential. Under such situations, the applied gate voltage can not only drop in the tube-liquid interface but also in the gold electrode/liquid interface due to interactions of gold with species in the solution. Therefore we have additionally tested the role of the gold electrode as pseudo-reference electrode. For that we have measured the open circuit voltage of the gold electrode vs. an Ag/AgCl reference electrode in a buffer solution containing the target protein. We have observed a short transient of some minutes and then the signal became stable as shown in Figure S5. Accordingly, we can consider that the in-chip gold electrode can be used as a pseudo-reference electrode for liquid gating. The potential almost does not change at the time at which the measurement is taking place (which was around 15-20 minutes).

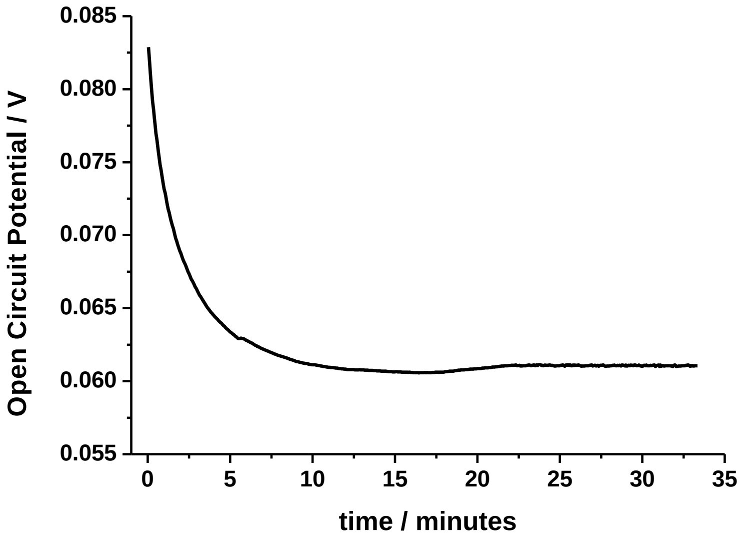


Figure S5. Open circuit potential for a gold electrode vs. Ag/AgCl reference electrode at a thrombin concentration of $1x10^{-8}$ M.

CNT-FET response in liquid

In Figure S6, a comparison between the conductance response of a passivated CNT-FET with a back-gated electrode in dry conditions and with liquid-gate electrode is depicted. It can be observed that the Vg scale for the liquid gate is significantly narrower than that of the back gate due to its better gating efficiency. The enhanced gate coupling between the liquid and the CNT and the high mobility under liquid environment generate high transconductances as observed in the graph. The figure inset shows the CNT-FET characteristics when the CNT is functionalized with the aptamer. A positive electrostatic gating is recorded due to the negatively charged backbone of the DNA.

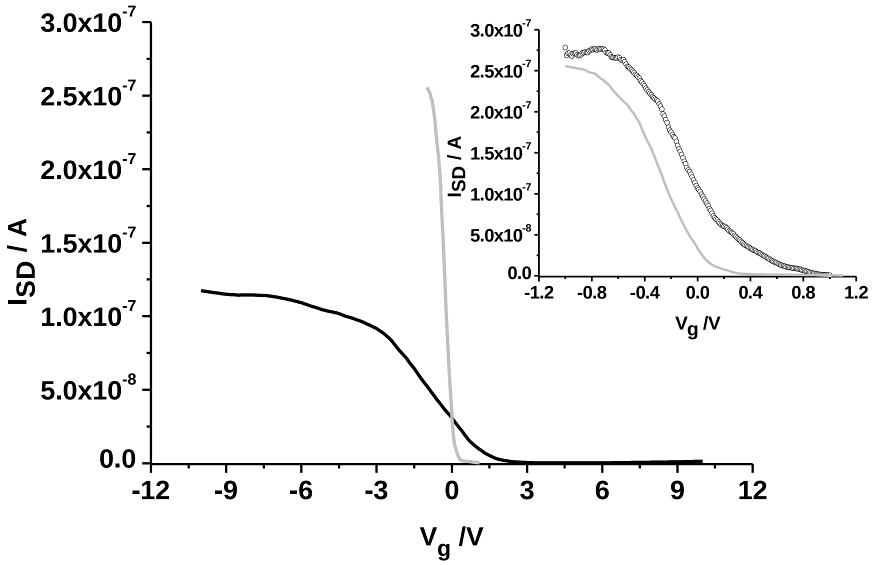


Figure S6. Comparison between the liquid-gated CNT-FET (grey line) and a back-gated CNT-FET in dry conditions (Black line). The difference in gate-coupling strength can be estimated by comparing the voltage axis scaling when changing from a back-gated to a liquid-gated layout. The inset of the Figure shows the behavior of the CNT-FET device in PBS with and without aptamer functionalization (symbols and grey line respectively)

References

1 I. Martin-Fernandez, M. Sansa, M.J. Esplandiu, E. Lora-Tamayo, F. Perez-Murano and P. Godignon, *Microelectron. Eng.*, 2010, **87**, 1554-1556.

2 I. Martin-Fernandez, X. Borrise, E. Lora-Tamayo, P. Godignon and F. Perez-Murano, *J. Vac. Sci. Technol. B*, 2010, **28**, C6P1-C6P5.