Nanoscale interdigital electrode arrays for smart water sensing

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Interdigital capacitive arrays (IDA) or interdigital transducers (IDT) refers to a fingerlike periodic pattern of parallel in-plane electrodes used to build up the capacitance associated with the electric fields for material under test (MUT). The mechanism of sensing takes advantage of electrical double-layer (EDL). Under electrolyte, ions accumulate on the interface of electrode to neutralize the potential and this double-layer of ions reflect the properties of the electrode and electrolyte. The double-layer can be regard as additional capacitor, which contribute to the whole capacitance we measured. By reading the real-time capacitance, we could get information of the solution we concerned. The special geometry of IDAs greatly increase the capacitance compared to traditional double electrode capacitor. Also, when the electrodes are coated with a thin layer of material that is sensitive to the concentration of chemicals to be detected, the high relative surface ratio will further increase the sensitivity under material as labeled biosensors.

The nano-IDA devices were usually fabricated by e-beam lithography. However, in our study, we apply commercial Surface Acoustic Wave (SAW) device that are used in RF communication to be IDA biochemical sensors. The core part of the SAW device is always interdigital capacitive structure, even though the circuit may be very different from different vendors and the circuit structure may be quite complicated due to high frequency consideration. The advantages of applying SAW device to be IDA sensors are that the commercially produced chips are very identical, also cheaper and faster to access compared to e-beam lithography. When the frequency is approximately above 1.2GHz, the IDA structure will be in the nanoscale, the devices we studied are shown in Figure 1.

The IDA chips were bonded onto PCB boards so that we can use probe station to measure the capacitance of the devices. To protect the bonding wires and other part of the circuit, we use proxy to cover the chip and only leave the IDA sensing area exposed to liquid. In the label free water sensing, the target water solutions were directly dropped on the IDA chip surface in an epoxy micro-well. The capacitance measured by probe station was correlated with the properties of the solution. We first used the nano-IDA sensor to test for salt concentration in water for calibration purpose. As we can expect, with increasing of ion concentration in water, the relative dielectric will increase and the capacitance measure through the IDA will increase accordingly. Repeatable measurements give the deviation regards to each salt concentration and the result shows that the IDA sensor is sensitive and reliable (Figure 2). For the first time, we attempted to use nano-IDA sensor to detect free chlorine in swimming pool or in water supply. In our experiments, the free chlorine solutions were prepared by diluting a commercially available hypochlorite bleach solution. As label-free sensor the impedance of nano-IDA sensor can be influenced by conductivity and free chlorine concentration. The impact of conductivity has been controlled and testing result is shown on Figure 3. A nearly monotonic correlation was observed between measured capacitance and chlorine concentration with feasible sensitivity. Future work will focus on improving the surface chemistry to enhance surface selectivity to Chlorine and mitigate salt and pH interference for practical use.

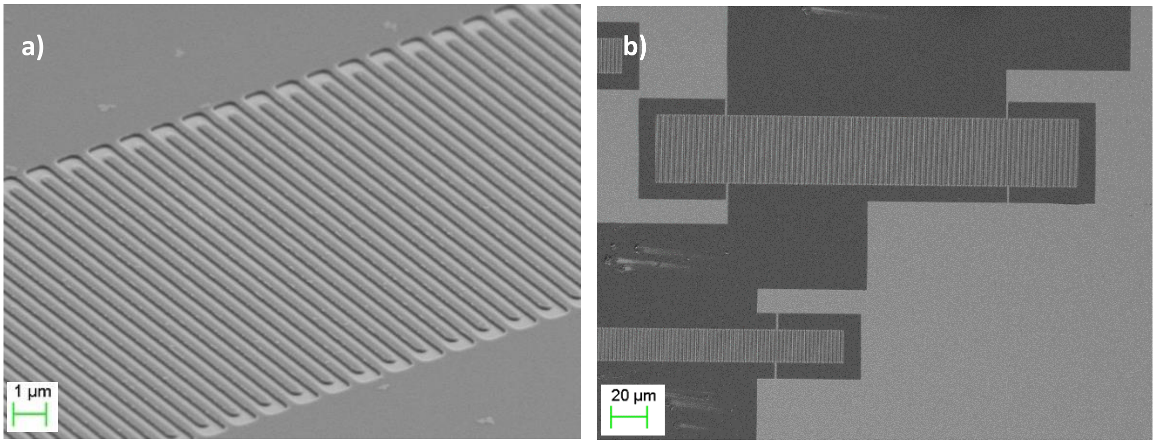

Figure 1：(a) SEM micrographs show the geometry of interdigital nano-electrode chips made of Al electrode finger on underlying Tantalum substrate. The width of electrode finger is 585.8nm and the gap between electrode fingers are 283.8nm. (b) sensor area and circuit.

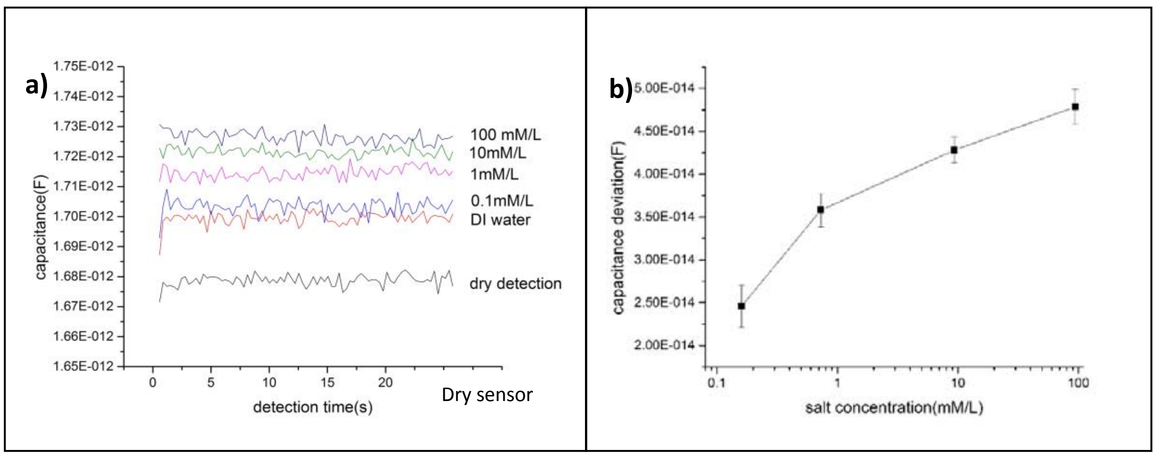

Figure 2： Salt concentration test: (a) The capacitance measured under different salt concentration over time. For reference, the dry sensor is the nano-IDA sensor with no liquid solution on the surface. (b) The measured capacitance plotted as a function of salt concentration.

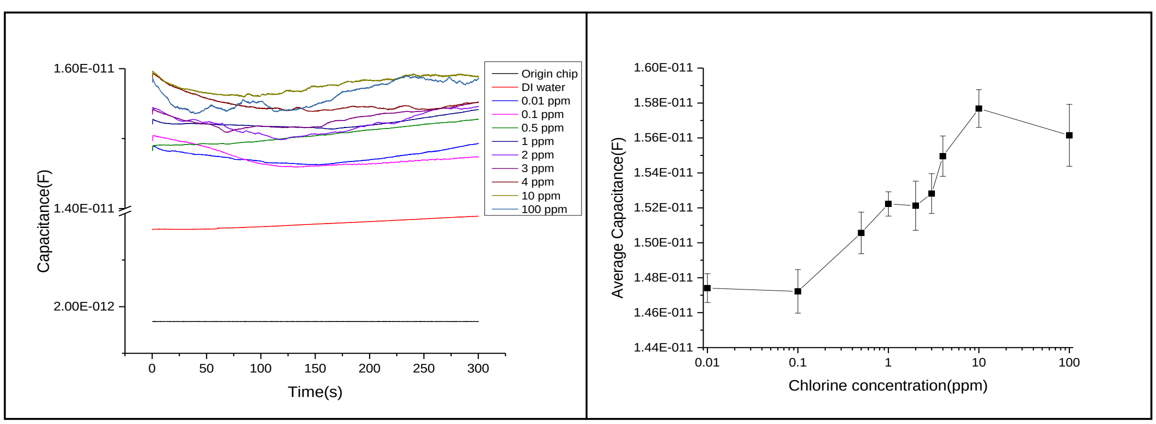

Figure 3：Sensing of free chlorine concentration. All the solutions has been controlled to have identical conductivity around 771 µS/cm. The capacitance measured vs. different Cl_2 bleach concentrations: (a) rough data over time (b) capacitance correlation with Cl_2 concentration.