

# PLANAR NANOGAP CAPACITOR ARRAYS ON QUARTZ FOR OPTICAL AND DIELECTRIC BIOASSAYS

Ho Kwan Kang, Jeonggi Seo, Dino Di Carlo,  
Yang-Kyu Choi, and Luke P. Lee

Berkeley Sensor and Actuator Center, Department of Bioengineering  
University of California at Berkeley, Berkeley, CA 94720

## Abstract

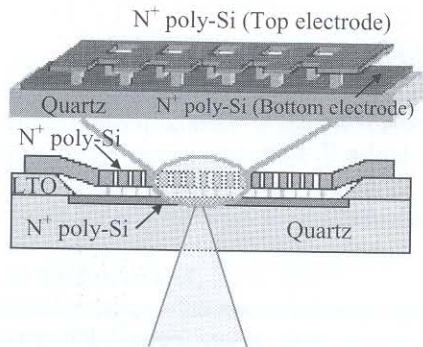
We report the fabrication of transparent nanogap capacitor arrays on a quartz substrate for nanoscale dielectric spectroscopic studies coupled with *in-situ* optical bioassays. Planar nanogap capacitors with 50~100 nm spacing are achieved by time controlled in-plane sacrificial oxide etching. Label-free dielectric detection of DNA hybridization with a planar nanogap capacitor is demonstrated using dielectric spectroscopy. The measured permittivity change is about 30 % at 100 Hz for  $10^{-5}$  mol/L of target DNA. A simple optical characterization of transparent nanogap capacitor is also described by fluorescent microscopy.

**Keywords:** Dielectric spectroscopy, DNA hybridization, Nanogap , Optical bioassay

## 1. Introduction

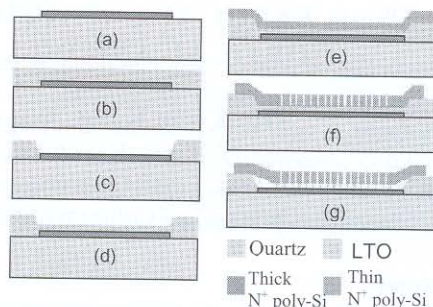
Nanogap junction arrays for label-free detection of DNA hybridization and immunosensing with high sensitivity were demonstrated in our previous papers [1, 2]. However, the integration of an optical window combined with a dielectric nanocavity not only provides a solution for the calibration problem of the number of molecules in the nanocavity, but also allows developing advanced biophotonic devices with electrical read out circuits. The correlation of the dielectric spectroscopy data and optical characterizations (i.e. fluorescent spectroscopy, surface enhanced Raman scattering, or surface plasma resonance) can be applied in functional genomics or single molecule detection biochips. Figure 1 illustrates the main concept of a transparent planar nano-gap capacitor with a quartz optical window. *In-situ* fluorescent microscopic observation from the back-side can be done simultaneously with dielectric measurements.

Nanogap electrodes-based dielectric spectroscopy is suggested to minimize the effects of electrode polarization for ultrasensitive biomolecular sensors. The electrode polarization is a major source of error in the impedance analysis of biological samples in solution. By using nanogap electrodes, the electrode polarization effect can be minimized by overlapping the double layers in the nanogap (<100 nm) [2]. However, only dielectric analysis is not enough to describe exact numbers and the dynamical behaviors of biomolecules (i.e. protein folding/unfolding) inside nanoscale cavity. Therefore, the transparent nanogap capacitor is ideal to provide *in-situ* optical analysis to verify biological events between nanogap electrodes as well as dielectric measurement.



**Fig. 1.** Schematic diagram of floating planar nano-gap capacitor.

Fluorescent Microscope



**Fig. 2.** Schematic diagrams of fabrication process flow: (a) the bottom thin Poly-Si electrode definition, (b) Thick LTO deposition & (c) patterning, (d) Thin LTO (nano-gap width) deposition, (e) & (f) the upper Poly-Si electrode deposition and patterning, and (g) in-plane etching of thin LTO.

## 2. Experimental

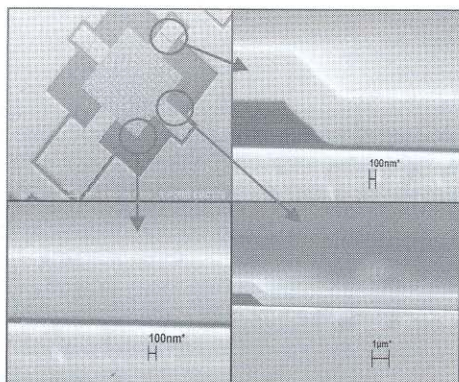
A parallel plate capacitor with 50~100 nm gap is fabricated by transparent poly-Si layers and silicon oxide layers on a 4-inch quartz wafer. A 300×300 μm<sup>2</sup> membrane-type N<sup>+</sup> poly-Si upper electrode (700 nm) is floated by a selective in-plane time-controlled etching technique. Mechanical supports are implemented by remaining sacrificial oxide columns between etch-holes on the bottom N<sup>+</sup> poly-Si electrode (500 nm). Figure 2 illustrates fabrication procedures for nanogap capacitors. The final width of nanogap was defined by low temperature oxide (LTO) deposition of 50~100 nm. Figure 3 shows SEM images of the fabricated floating nanogap capacitor of a 50 nm nanogap between the top and bottom electrodes. Dielectric and optical analysis are performed by capacitance measurement and a fluorescent microscopic verification. The permittivity changes of DNA hybridization is measured at the sweeping frequency from 100 Hz to 1 MHz. The materials used in DNA experiment and the details of the experimental procedures are described in Table I and a previous report [3]. Also, fluorescent microscopic observation is performed by using fluorescent bead solutions.

## 3. Results and discussion

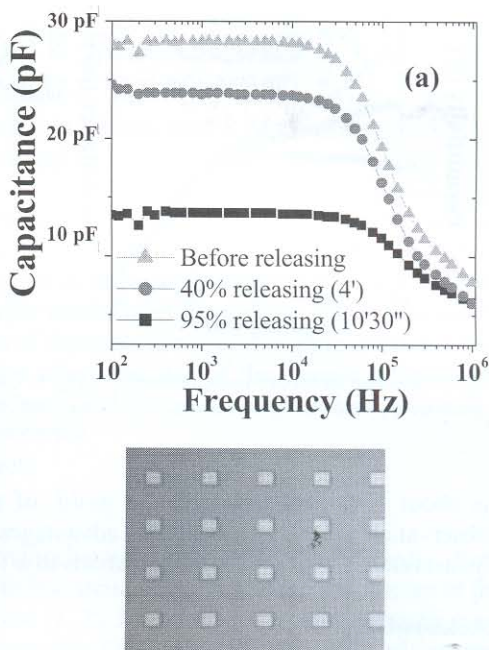
Figure 4 (a) shows the change of nanogap capacitance in air as the in-plane etching progresses for sacrificial layer removal. Before releasing the capacitance value of nanogap is about 28 pF with the 75 % of estimated effective electrode area considering 4 μm etch-hole and 3 μm hole spacing, 100 nm gap width, and the remaining support oxide areas. The capacitance decreases from 28 pF to 13 pF at 100 Hz after a releasing process of the nanogap structure and the measured in-plane etch rate is about 130 nm/min. Optical image after releasing shows self-oxide supports between etch holes in Figure 4 (b).

**Table I** Materials in experiment

Item	Description
SAM	(3-Aminopropyl)triethoxysilane
DNA for immobilization	poly T (35mer)
Buffer solution for immobilization	0.1M/L N-methylimidazole buffer containing 0.1M/L EDC (pH 6)
DNA for hybridization	poly A (35mer)
Buffer solution for hybridization	300mM/l NaCl + 30mM/L sodium citrate
Washing Solution	PBS



**Fig. 3.** SEM images of fabricated floating nanogap capacitor with 50 nm width.



**Fig. 4.** Capacitance of nanogap capacitor vs. etching time (a) and optical microscope image after releasing (b).

The changes of dielectric properties before and after DNA hybridization steps are observed in Figure 5. First oligonucleotides (35 mer poly T sequence) were immobilized on the SAM coated nanogap electrodes and then the dielectric properties of the immobilized DNA coated device were measured. For hybridization, matched probes (35 mer poly A sequence) were added and the dielectric property change due to the hybridization was measured. As shown in Figure 5, the largest changes (over 30%) of capacitance are observed at 100 Hz after DNA hybridization with  $10^{-5}$  mol/L concentration of target DNA. In figure 6, the fluorescent image of 20 nm fluorescent bead solutions in the transparent nanogap capacitor confirms the penetration of beads into the nanogap. These results simply demonstrate the feasibility of the fluorescent detection for biological event by using our transparent nanogap capacitors.

#### 4. Conclusions

The transparent nanogap capacitor is fabricated on a quartz wafer successfully for simultaneous detections of dielectric and optical dynamic behaviors of biomolecules. Planar nanogap capacitors with 50~100 nm gap width are achieved by in-plane sacrificial oxide etching and self-remaining oxide supports. Label-free dielectric detection of DNA hybridization is accomplished by transparent nanogap capacitor. The permittivity change

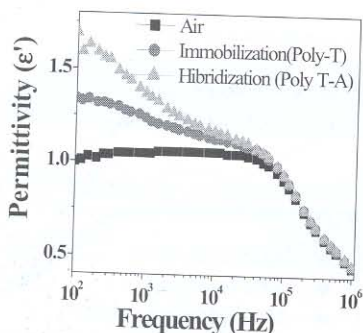


Fig. 5. Nanogap electrodes-based dielectric spectroscopy for DNA hybridization

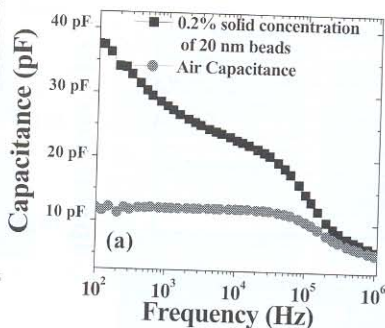


Fig. 6. Capacitance of Nanogap capacitor with fluorescent beads (a) and fluorescent microscope image after beads solution dispensing. This shows that sample can be located in nanocavity.

is about 30% at 100Hz for  $10^{-5}$  mol/L of target DNA. Also, fluorescent microscopic observation shows the potential advantages for optical bioassays combined dielectric measurement. Further characterizations of a few different bioassays will be carried out.

### Acknowledgements

This work was partially supported by the post-doctoral Fellowship program (H.K. Kang) of Korea Science & Engineering Foundation (KOSEF) and DARPA research program. The authors wish to acknowledge K. Jeong, S. Kwon, Dr. Zeng, and James Moon for many key discussions and helps.

### References

1. D. Di Carlo, H. K. Kang, X. Zeng, K. H. Jeong, L. P. Lee, *Transducer'03* (2003), pp 1180-1183
2. S. Oh, J. S. Lee, K. H. Jeong, and L. P. Lee, *IEEE the 16th Annual International Conference on MEMS'03* (2003) pp 52-55
3. J. S. Lee, Y. Choi, M. Pio, J. Seo and L. P. Lee, *MRS symposium proceedings* (2002) Vol. 729, pp185-190