Aalto University
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Engineering

Suspended Carbon Nanotube Varactor

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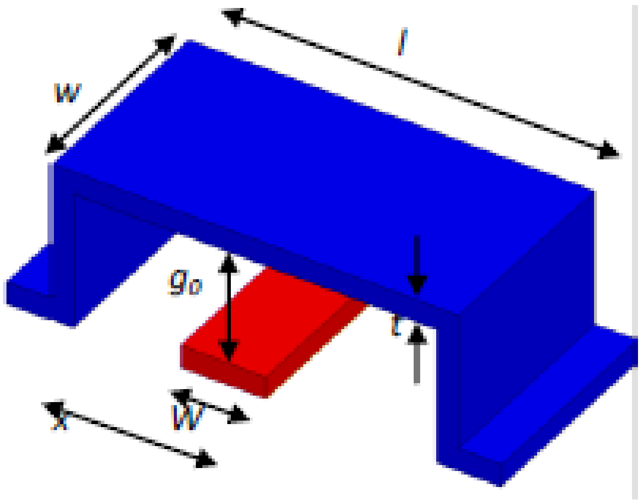
Outline

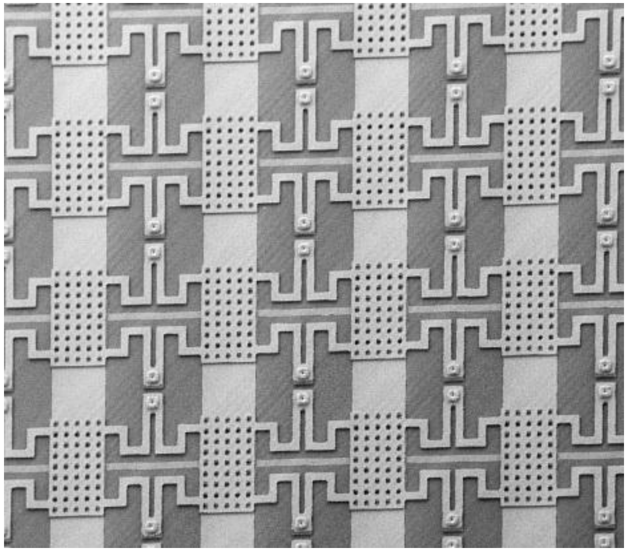
1. MEMS varactors
2. Design of a CNT varactor
3. Fabrication
4. Measurements
5. Calculations
6. SEM verification
7. Results

MEMS varactor

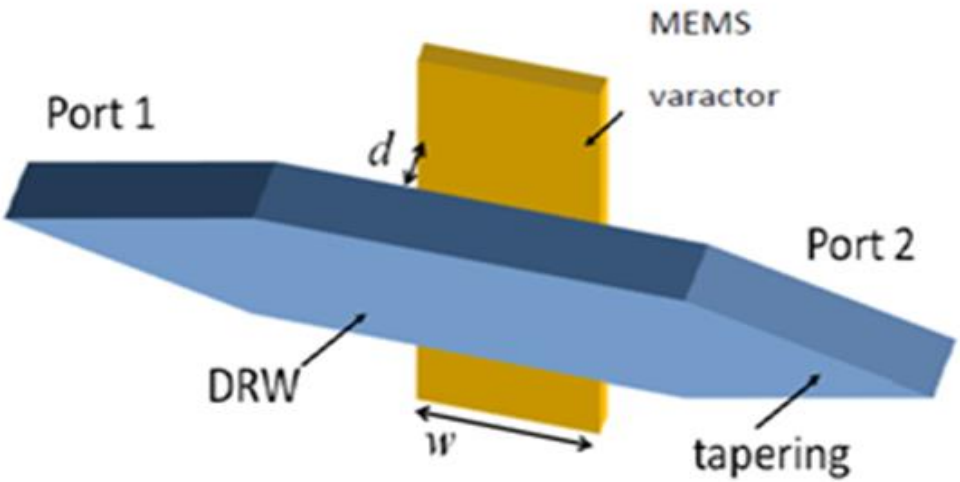
MEMS – microelectromechanical system

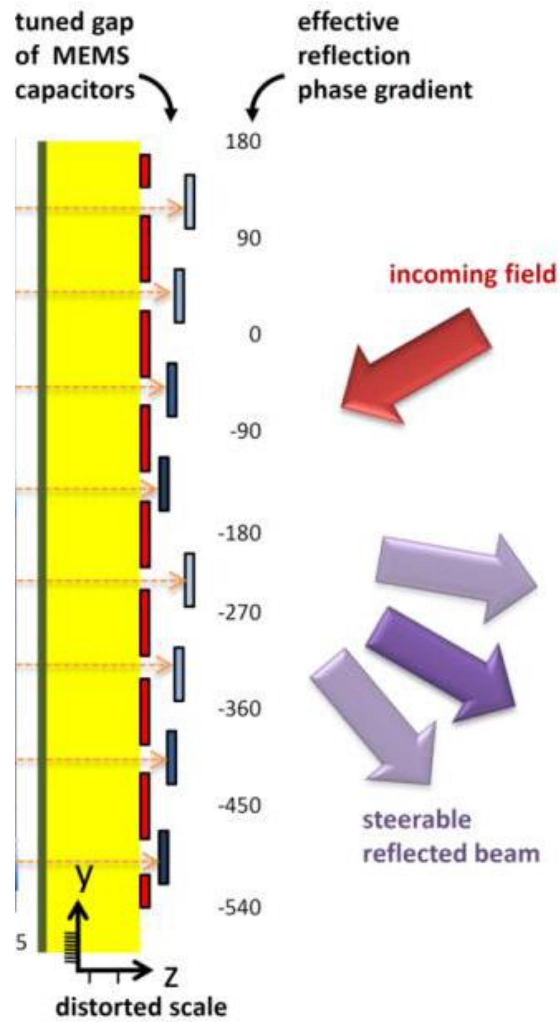
Can be used as a high impedance surfaces





MEMS applications





MEMS varactor membranes and materials

Graphene, single carbon nanotubes (CNT)
strong, low actuation voltage
hard to manufacture

E = 1 TPa
t = 0.3 – 5 nm

Metals
not strong, high actuation voltage
relatively easy to manufacture

E = 100 – 200 GPa
t = 100 – 500 nm

CNT networks
strong, low actuation voltage
relatively easy to manufacture

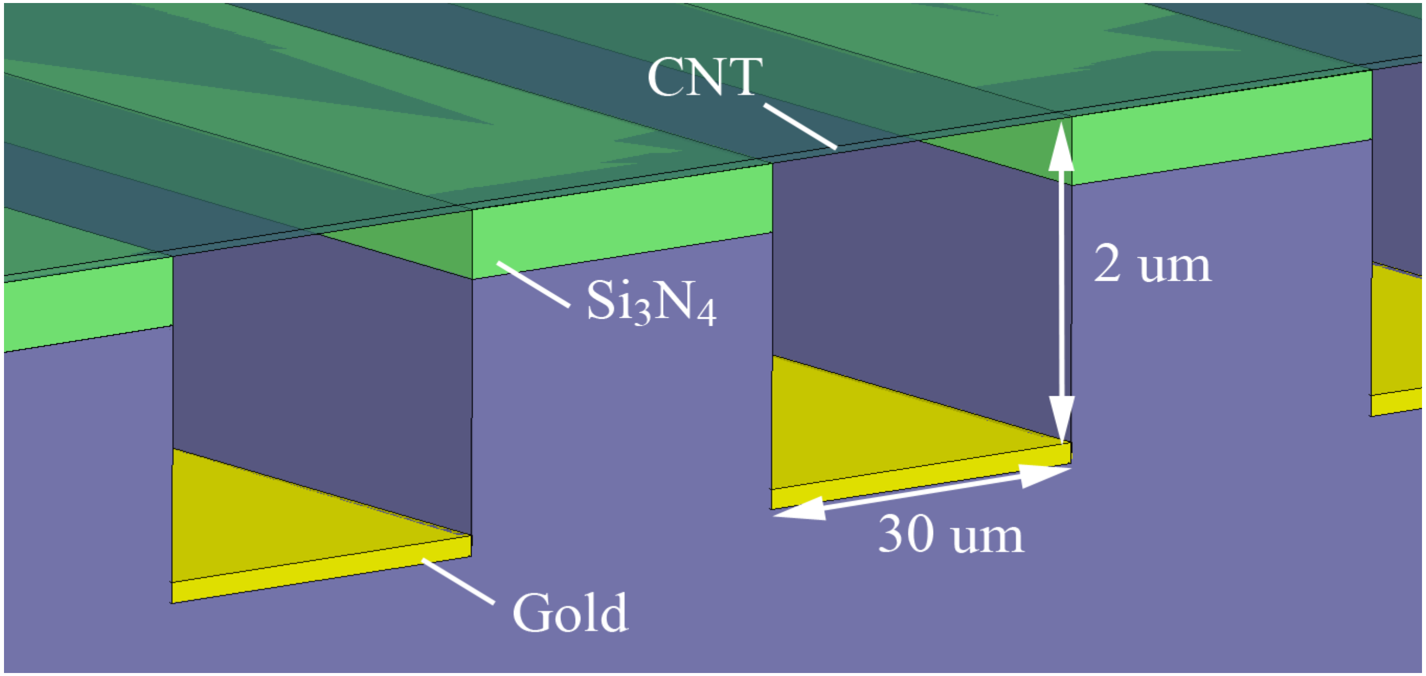
E = 60 MPa – 1 Gpa
t = 5 – 200 nm

Design

CNT network is suspended in the air

Gold lower contacts

Si_3N_4 for insulation

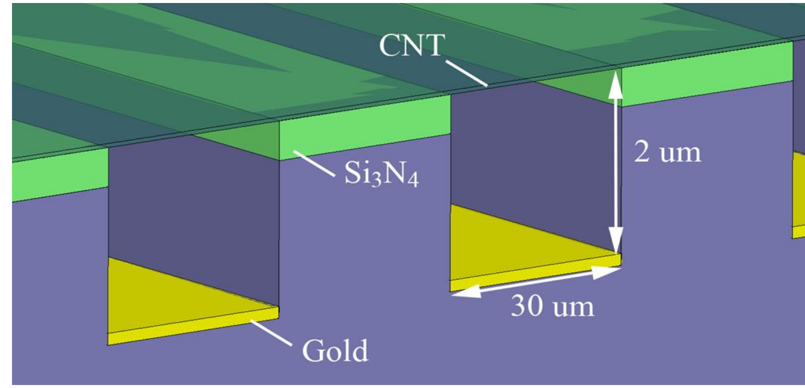


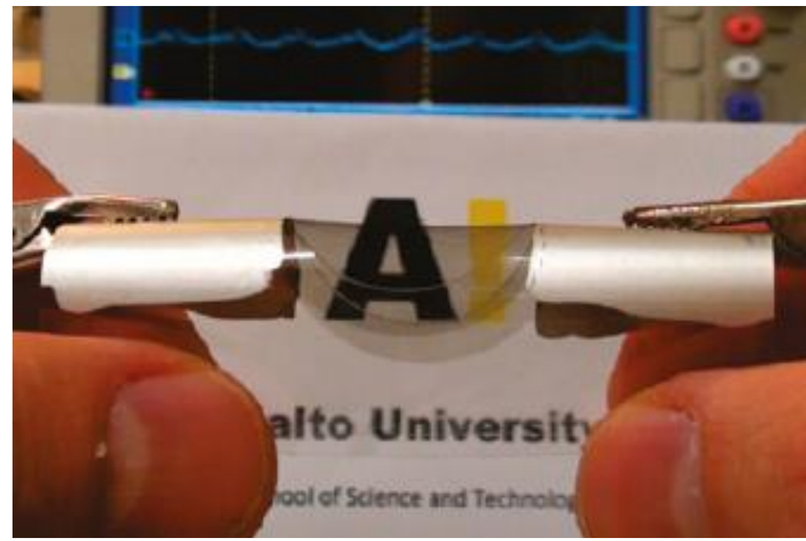
Fabrication

1. High resistive Si substrate
2. Si_3N_4 layer PECVD deposition
3. Upper Au contacts deposition
4. Grooves etching by RIE
5. Au deposition
6. Lift off
7. CNT deposition by direct layer transfer from nitrocellulose filter

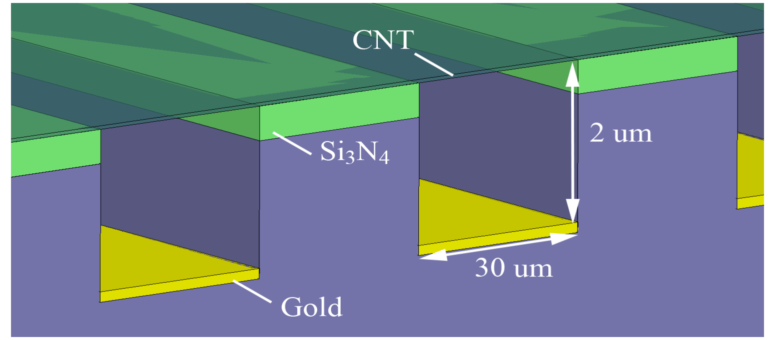
CNT thickness is 30 nm

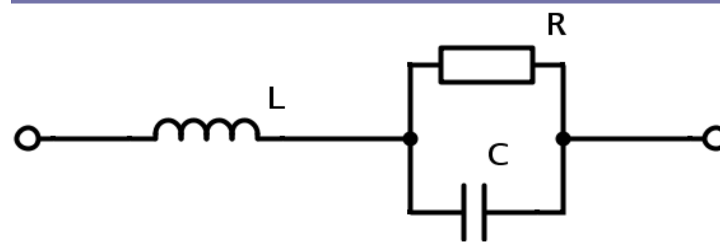
CNT Young‘s modulus is $E \approx 80$ MPa





Measurements

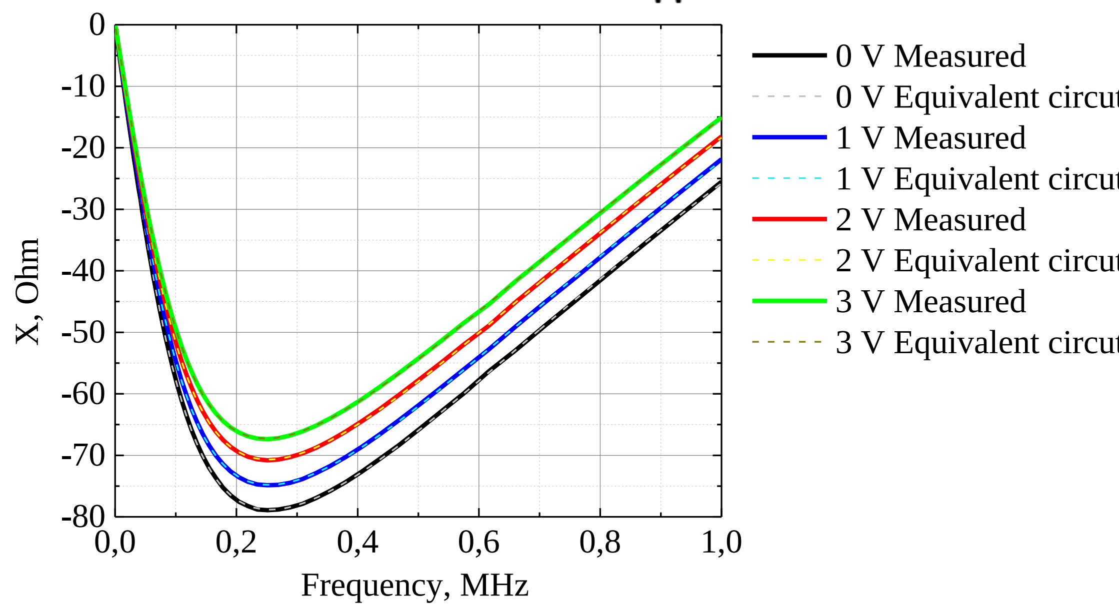




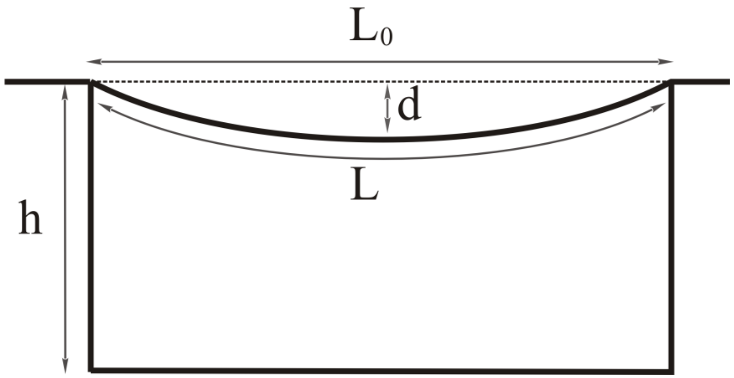
The complex impedance of the structure was measured vs bias voltage

The reactance was approximated by the equivalent circuit model

The values of R, L, C were extracted



Calculations



Electric force:

$$F_C = \frac{1}{2}\frac{\varepsilon_0 A_C V^2}{(h-d)^2}$$

Elastic force:

$$F_E = E A_{CS} \frac{L(d) - L_0}{L_0}$$

Capacitance:

$$C(V) = C_0 \frac{h}{h - d(V)}$$

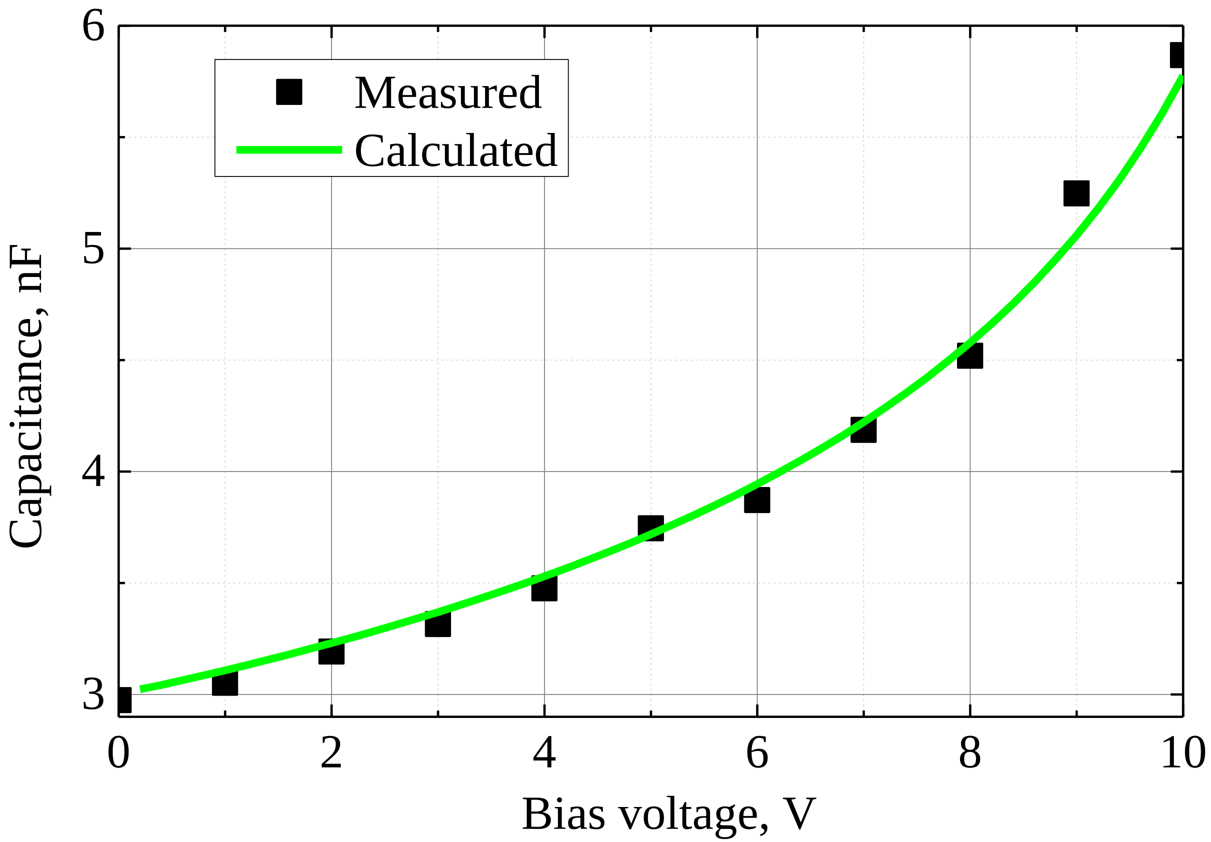
Results

Low actuation voltage

Tunability of 100%

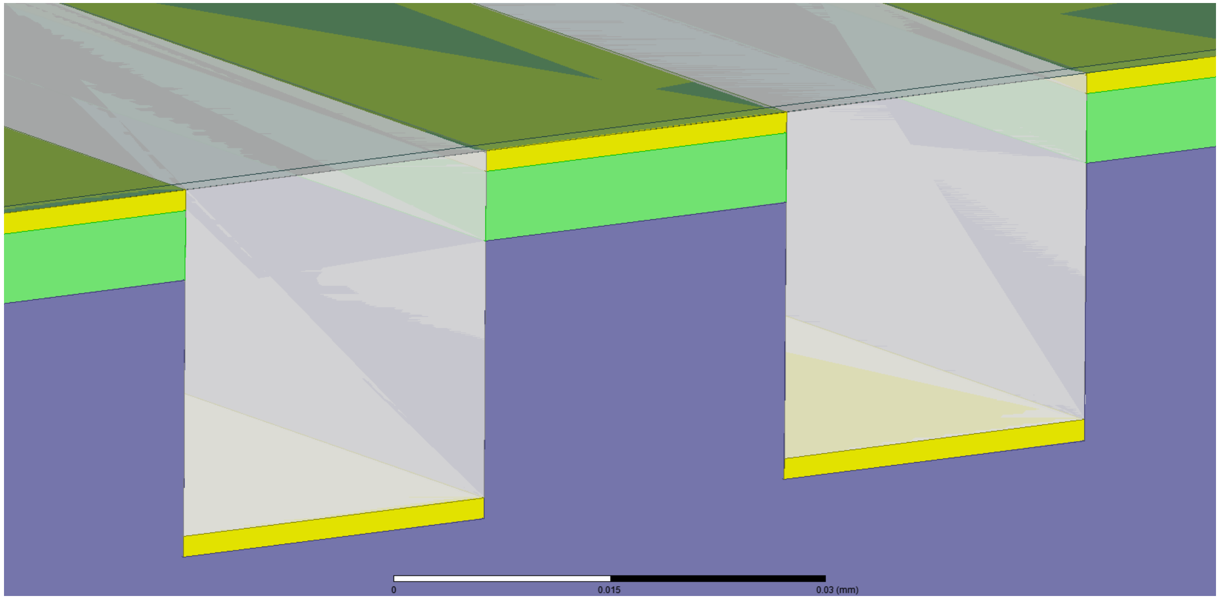
***E* = 80 MPa**

***R* = 50 – 80 Ω**



Nanocellulose deposition

Good insulator, soft, good plasticity

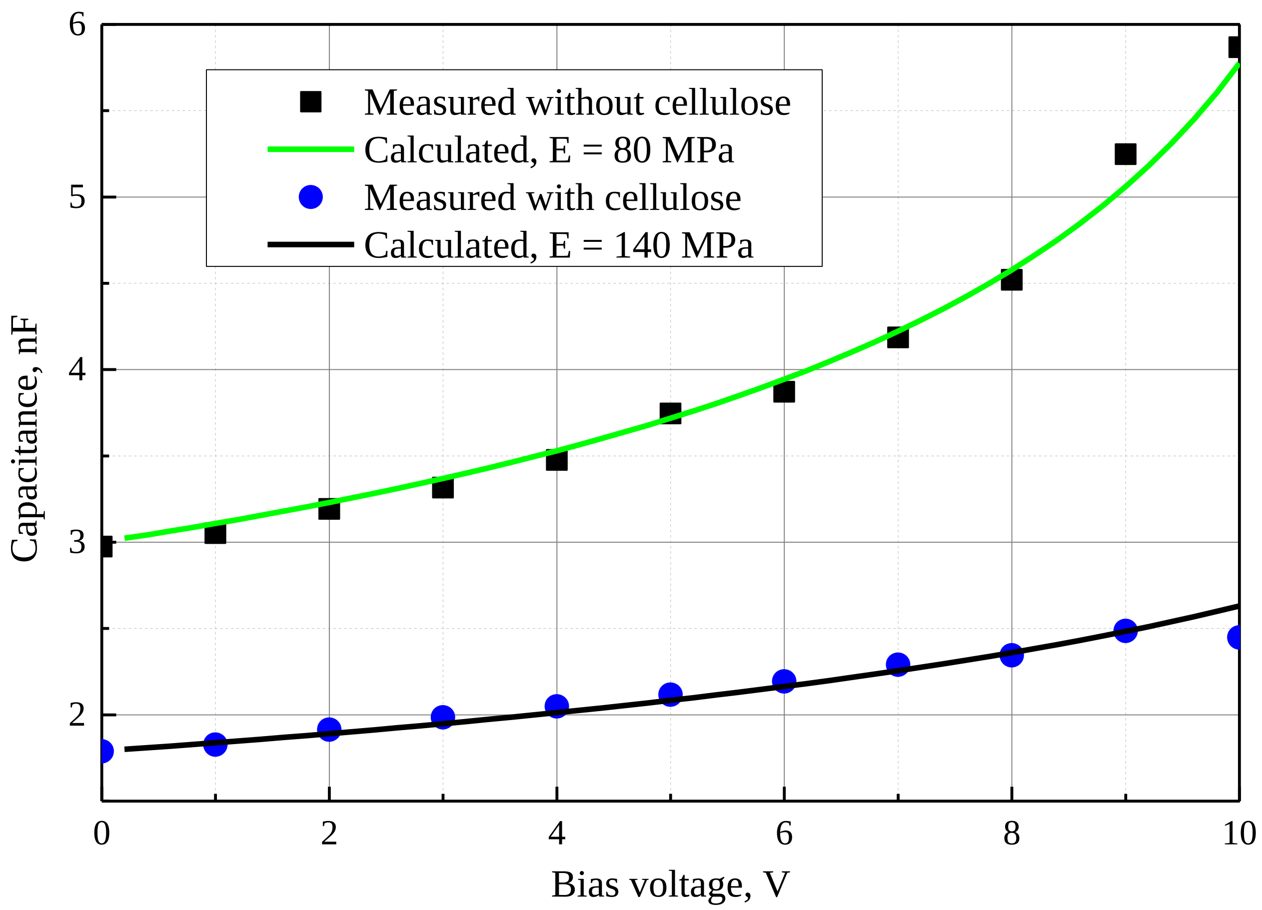


Results with nanocellulose

E **= 140 Mpa**

R **= 1.8 kΩ**

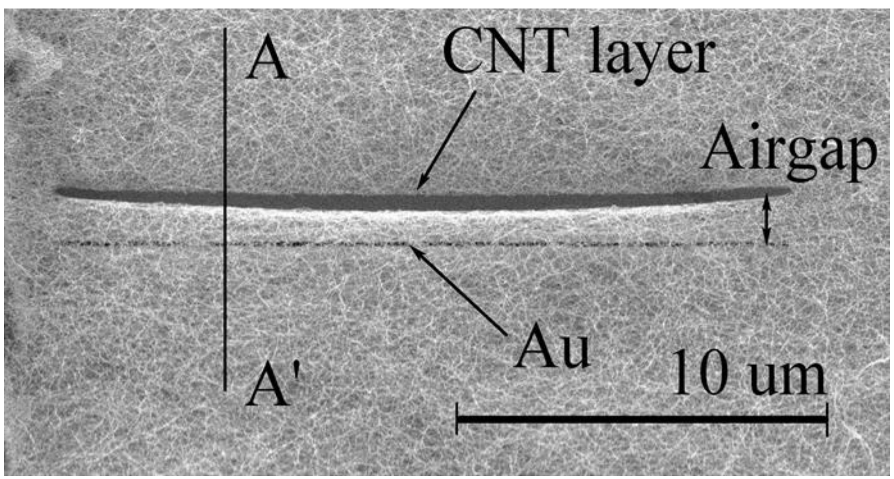
Tunability of 44 %

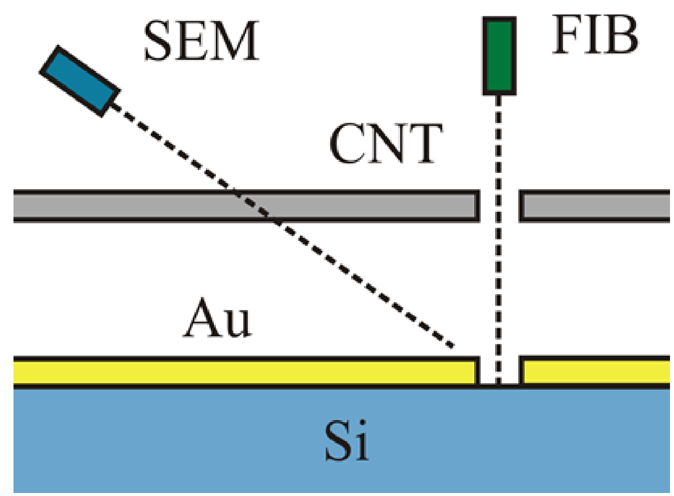


Verification of suspended CNT

CNT layer is ablated by focused ion beam to verify that the CNTs are suspended in the air.

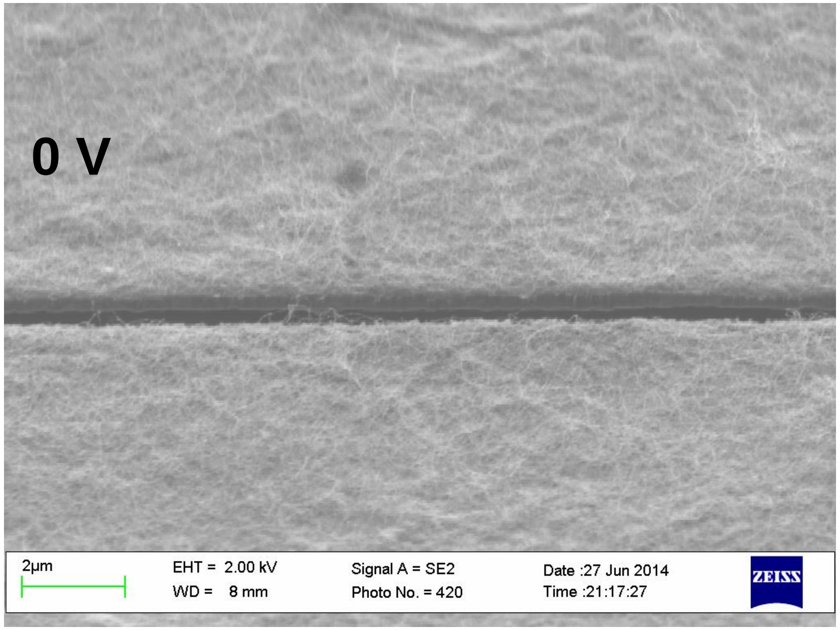
Air gap is clearly visible.

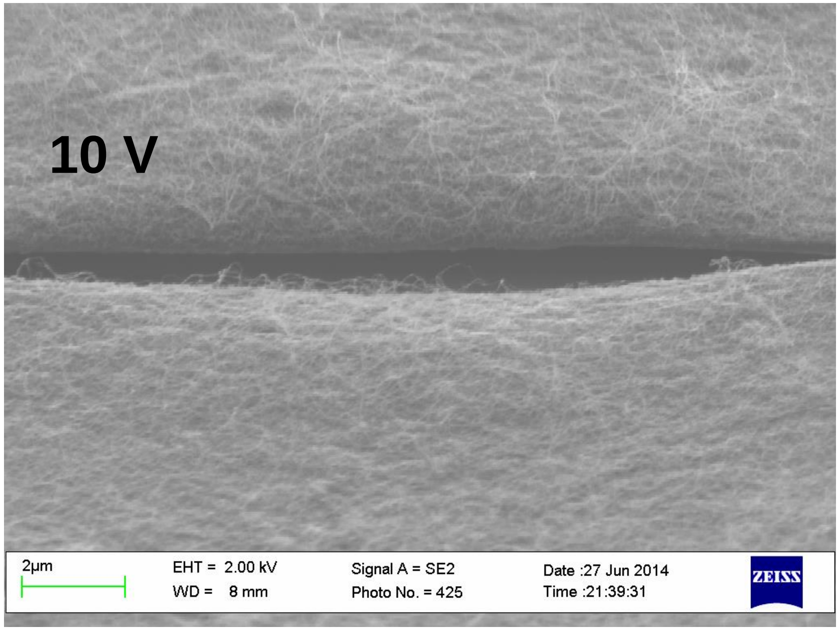




Bended CNT layer

Voltage applied inside the SEM chamber, sample is tilted





Conclusions

- **Very first prototype of CNT varactor is demonstrated**
- **The actuation voltage is less than 10 V**
- **Tunability is 100%**
- **Better insulation can be achieved with nanocellulose**
- **CNTs open a good perspective for future MEMS**