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Capacitive Sensing: an Emerging Non-Destructive Evaluation Technique

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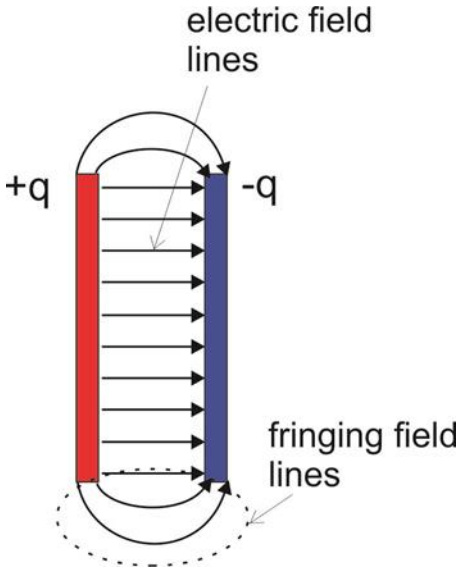
Outline

- Capacitive sensing
  - Principles
  - Applications
- Experiments
  - Setup
  - Specimen
- Results
  - Sensor size
  - Lift-off effect
  - Addition of a top layer
- Conclusion / Further work

Capacitance – general concepts

- A capacitor is a two-terminal electrical device that stores energy in an electric field

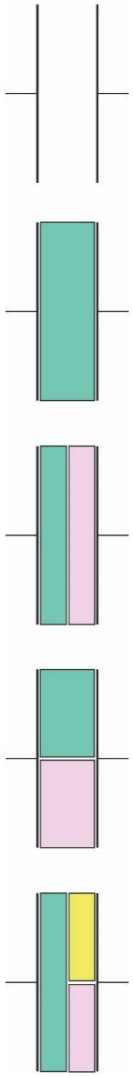


$$q = C \cdot V$$

- Uses of a capacitor:
  - Energy storage
  - Filters
  - Sensing

Capacitance – general concepts

Parallel-plate capacitor of area *A* and distance between terminals *d*



$$C_0 = \frac{\varepsilon_0 \cdot A}{d}$$

$$C = \frac{\varepsilon_0 \cdot \varepsilon_1 \cdot A}{d} = \varepsilon_1 \cdot C_0$$

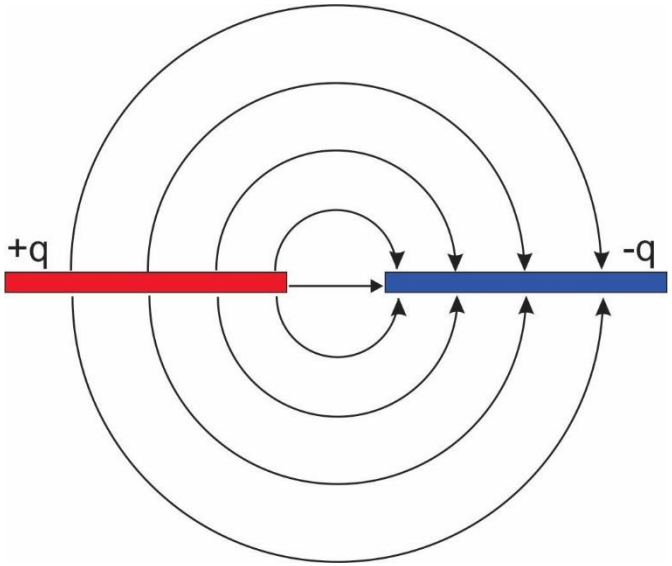
$$C = \frac{2C_0 \cdot \varepsilon_1 \cdot \varepsilon_2}{\varepsilon_1 + \varepsilon_2}$$

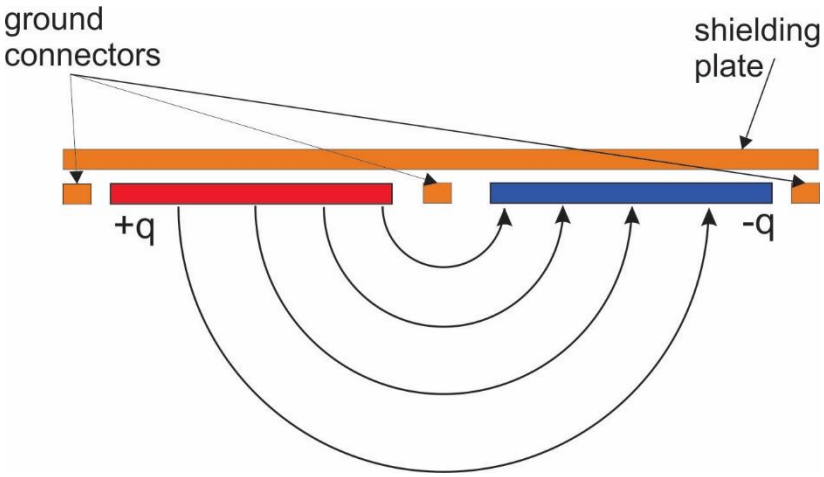
$$C = \frac{C_0 \cdot (\varepsilon_1 + \varepsilon_2)}{2}$$

$$C = \frac{2C_0 \cdot \varepsilon_1 \cdot (\varepsilon_2 + \varepsilon_3)}{2\varepsilon_1 + \varepsilon_2 + \varepsilon_3}$$

Principles of capacitive imaging

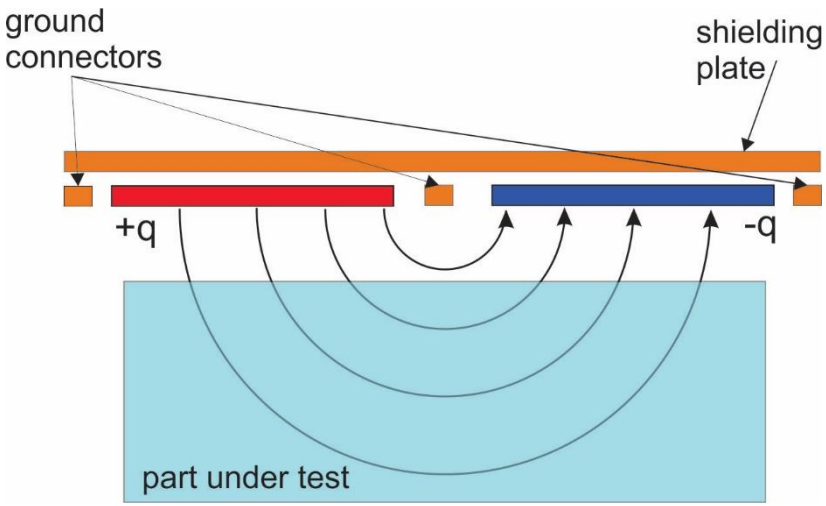
- At the interface between a conductor and the free space, the electric field has no tangential component.





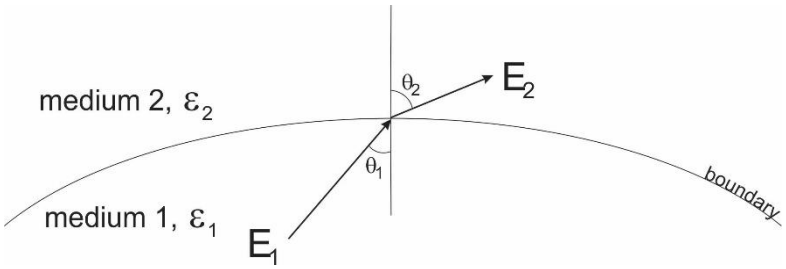
- Planar capacitors can be used for sensing the dielectric properties of materials
- One terminal can act as the actuator part, and the other as the sensor (both in relation to a common ground/shielding plate)

Principles of capacitive imaging



- Capacitive imaging has the potential to be an electromagnetic NDT technique for the inspection of dielectric materials.
- Non-contact
- Single-side access

Electric field - boundary conditions



The tangential component of the electric field remains unchanged:

$$E_1^t = E_2^t$$

The normal component of the electric flux is conserved at an interface:

$$D_1^n = D_2^n$$

Therefore, the electric field satisfies the following normal boundary condition:

$$\varepsilon_1 \cdot E_1^n = \varepsilon_2 \cdot E_2^n$$

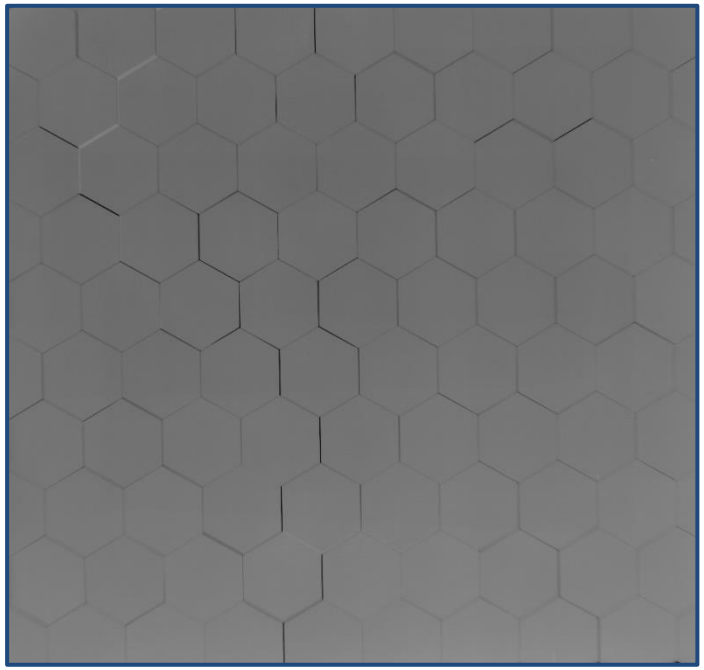
NDT Applications of Capacitive Imaging

- Water ingress in honeycomb structures
- Water ingress in aircraft radome
- Reinforced concrete, localization and qualification of rebars in concrete
- Delaminations and debonding in composites
- Measuring moisture content in composites, food products
- Determining the integrity of electrical insulation

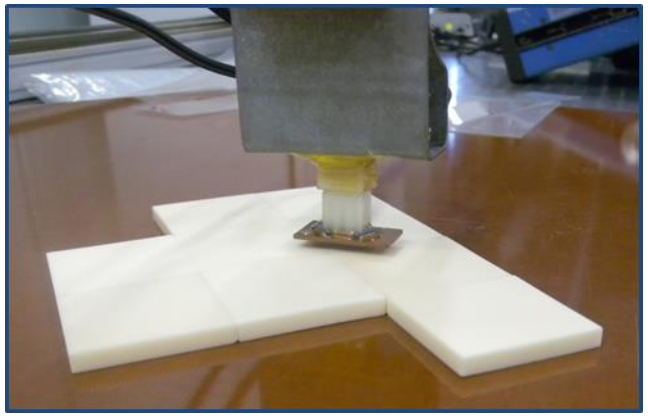
Add-on mosaic ceramic armour for land vehicles

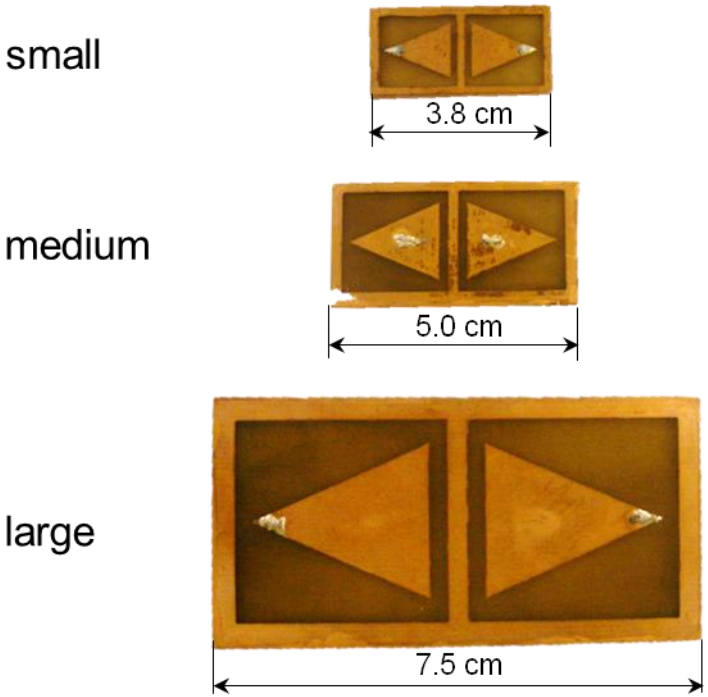
modified from www.ceramtec.com

- Gaps between tiles reduce the armour effectiveness
- X-ray radiography is the preferred solution, but…



Experimental setup

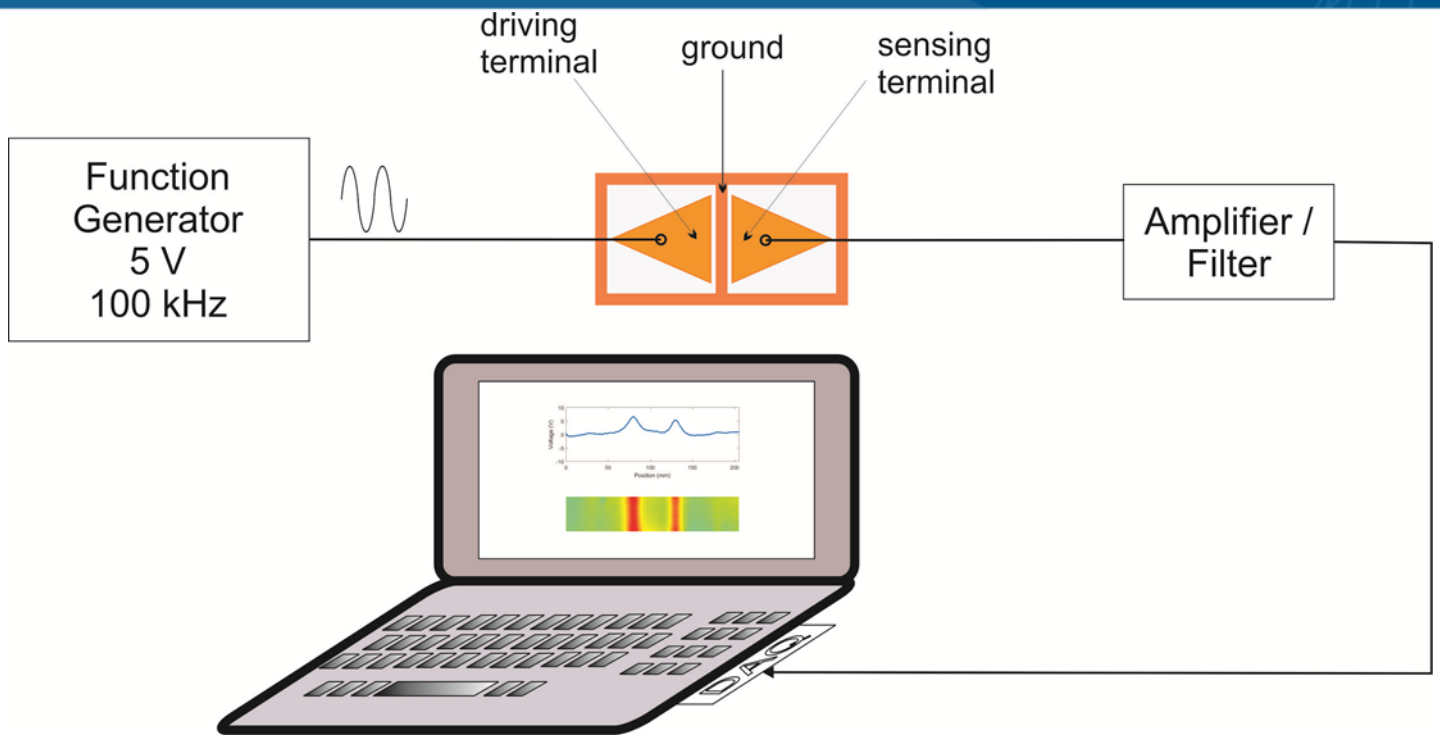


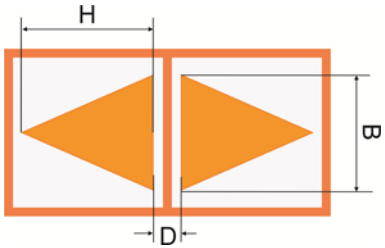


Sensor fabrication:

- chemical etching
- mechanical milling

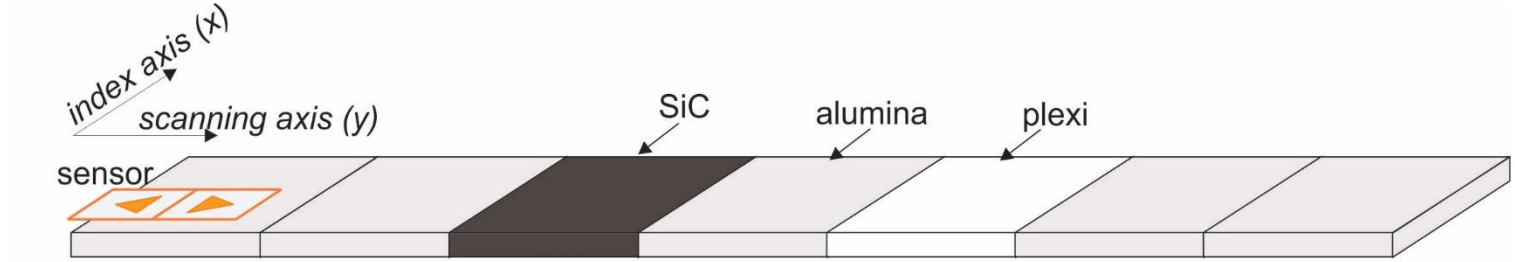
Experimental setup

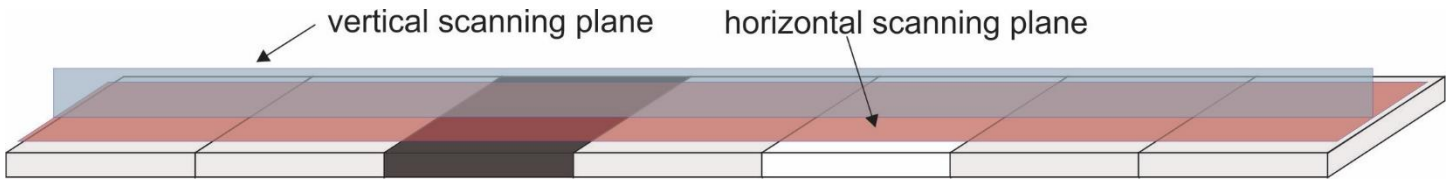




	D (mm)	B (mm)	H (mm)	Area (mm^2)	C (pF)
small	4	12	14	84	6.4
medium	6	16	18	144	7.8
large	9	24	27	324	11.1

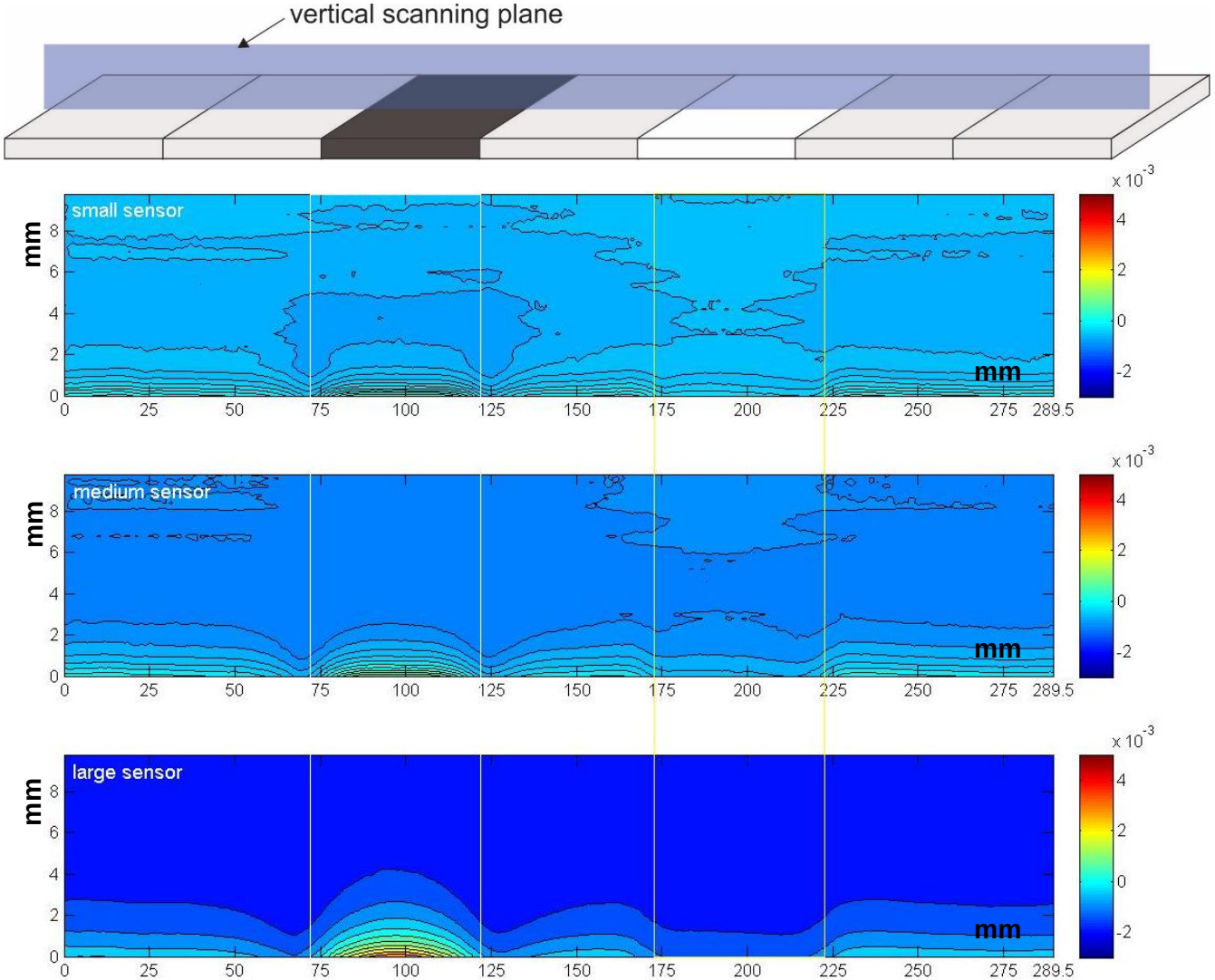
Specimen, Scanning arrangements



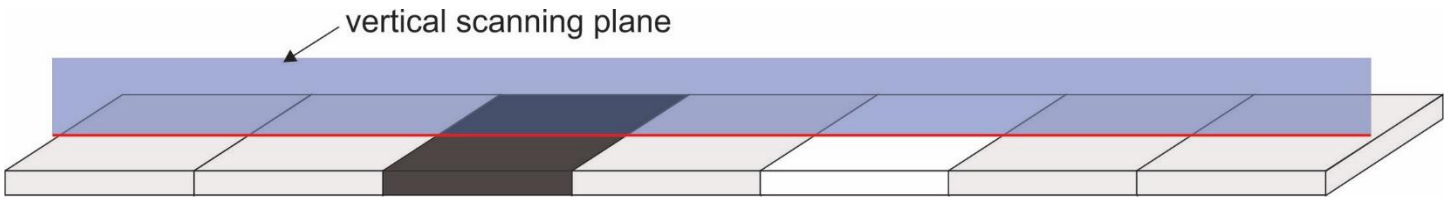


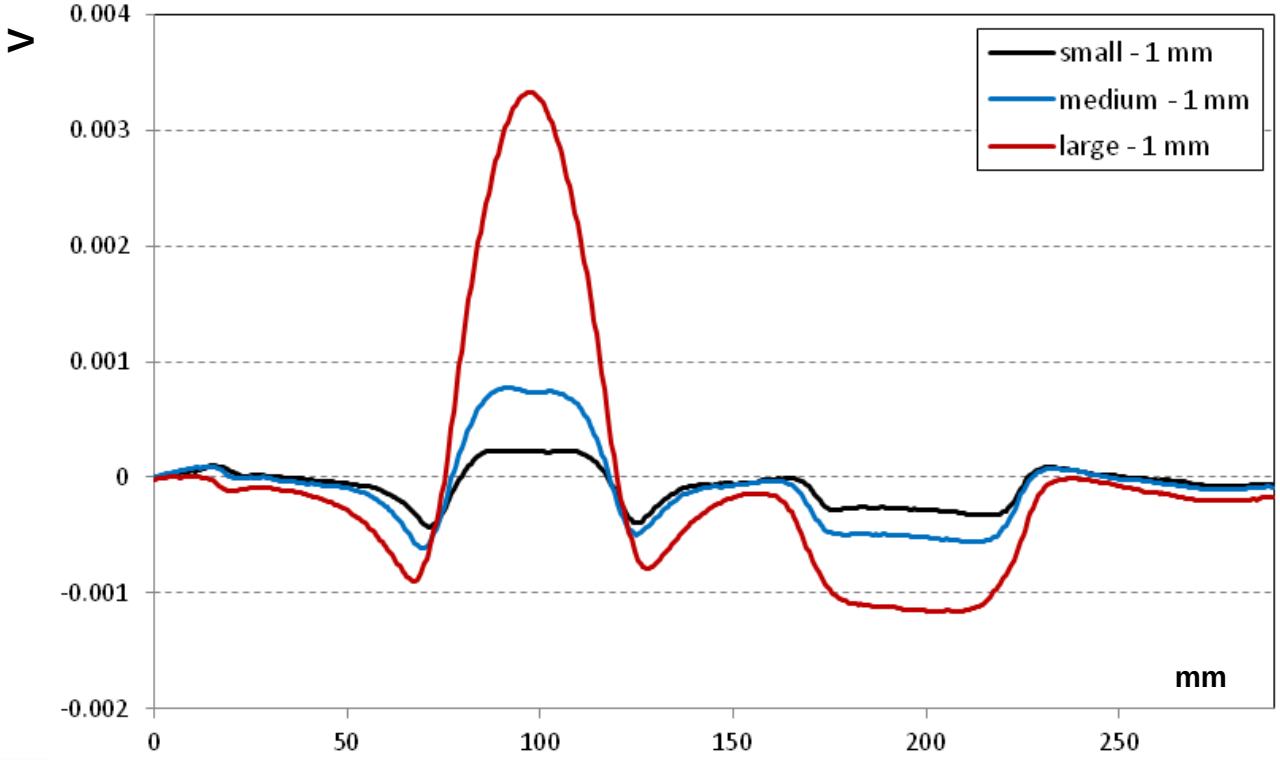
Material	Dielectric constant
Alumina	8.0 – 9.0
SiC	9.5 – 11.0
Plexiglas ®	2.5 – 3.5

Vertical plane from specimen

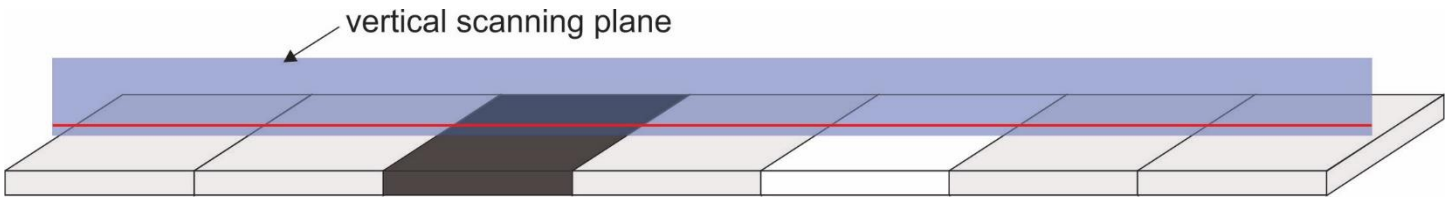


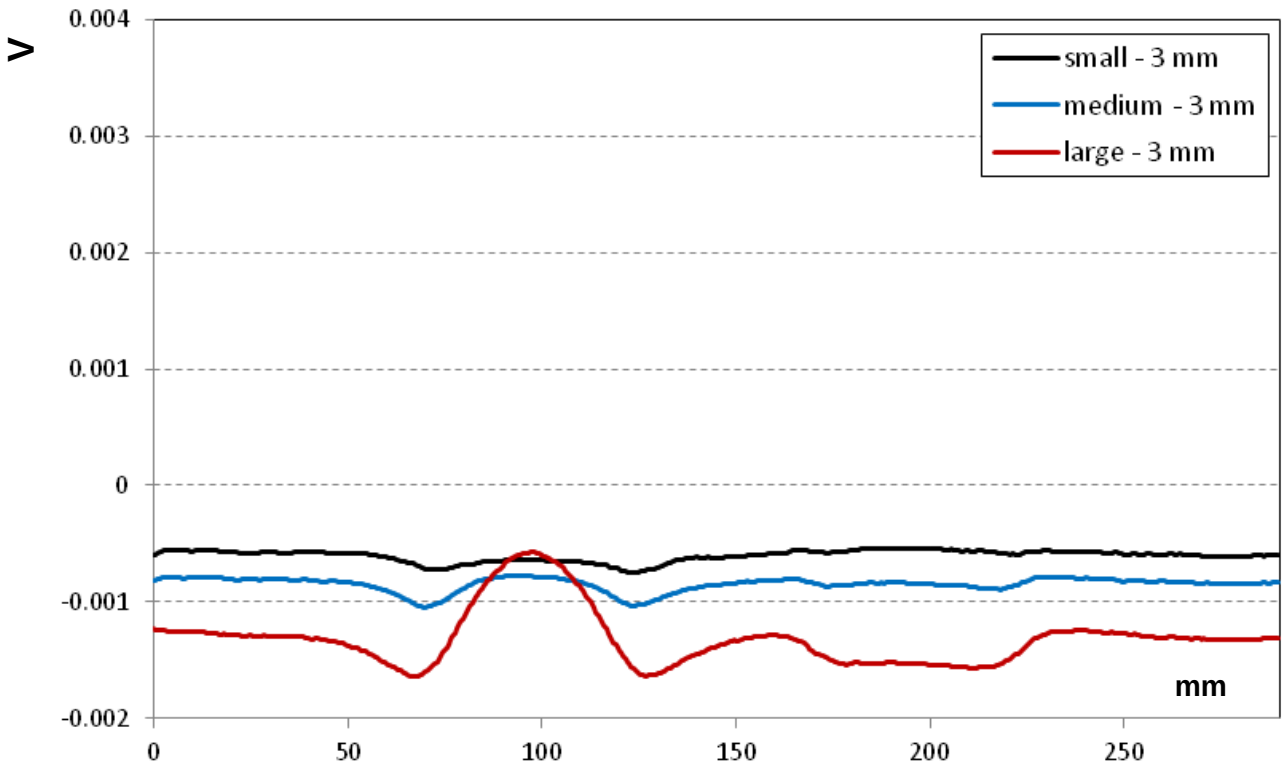
Horizontal Profiles – 1 mm from specimen



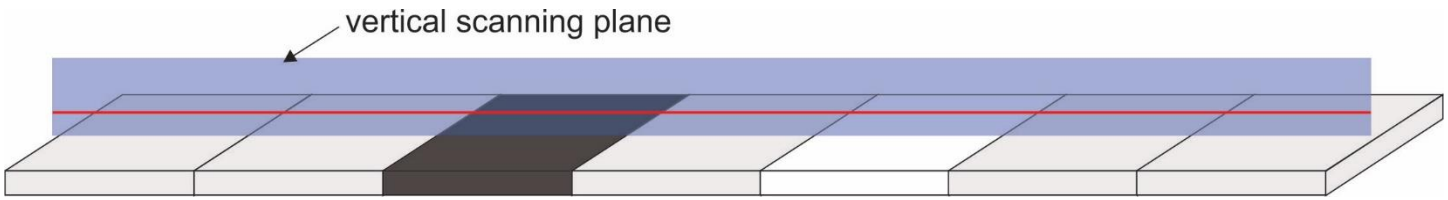


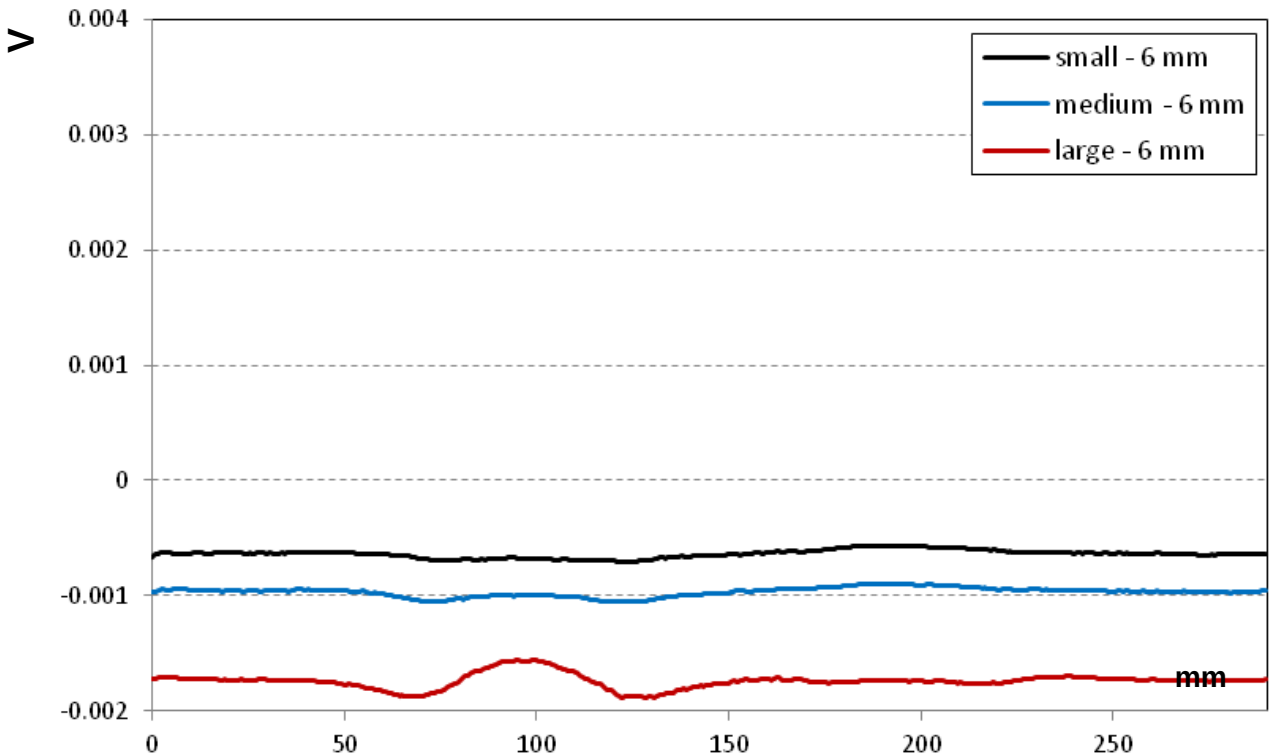
Horizontal Profiles – 3 mm from specimen



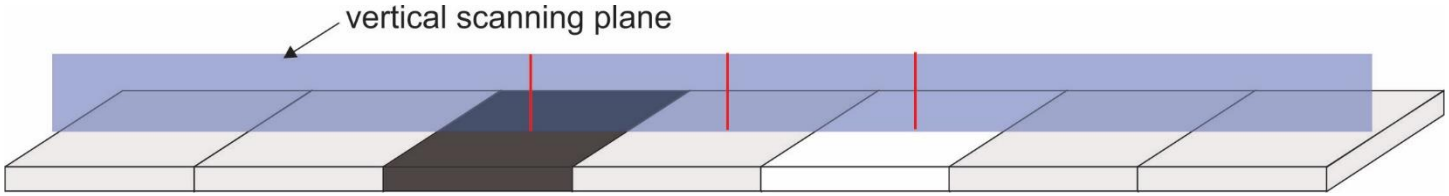


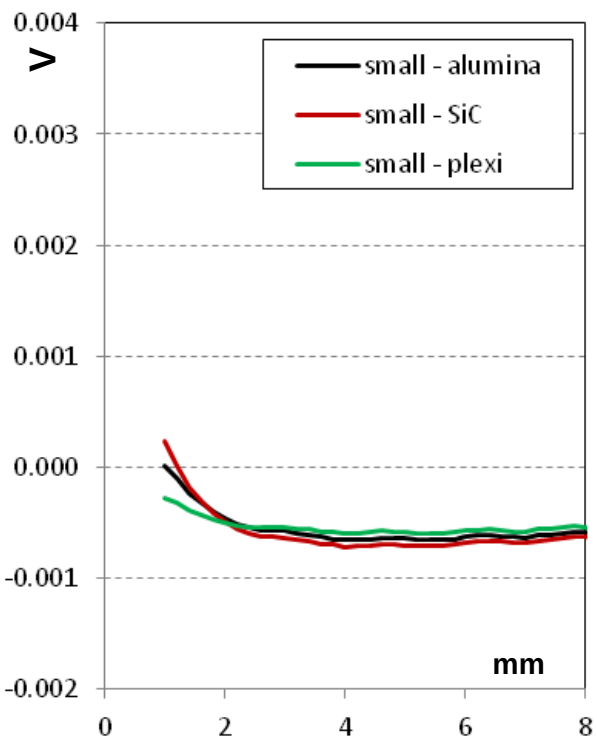
Horizontal Profiles – 6 mm from specimen

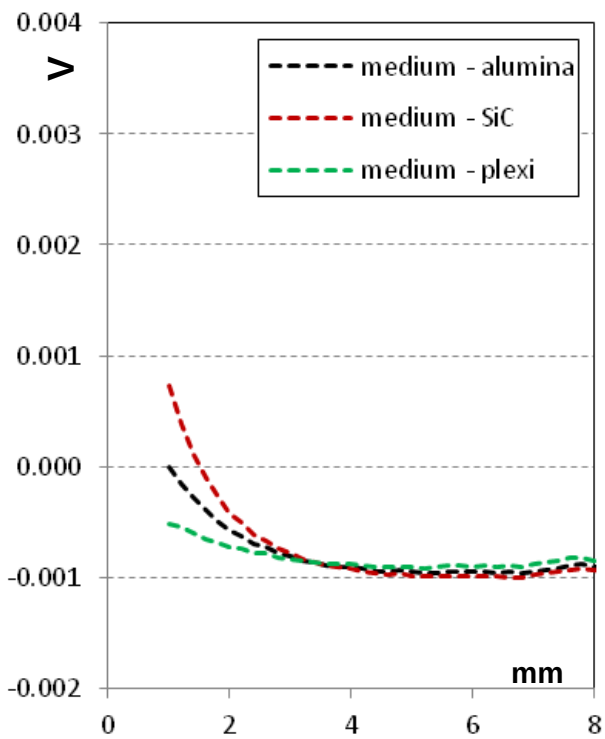


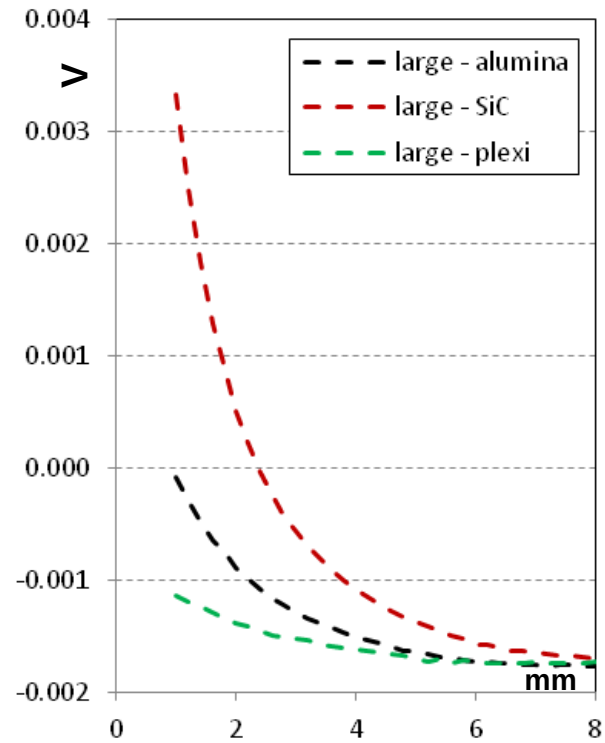


Vertical profiles

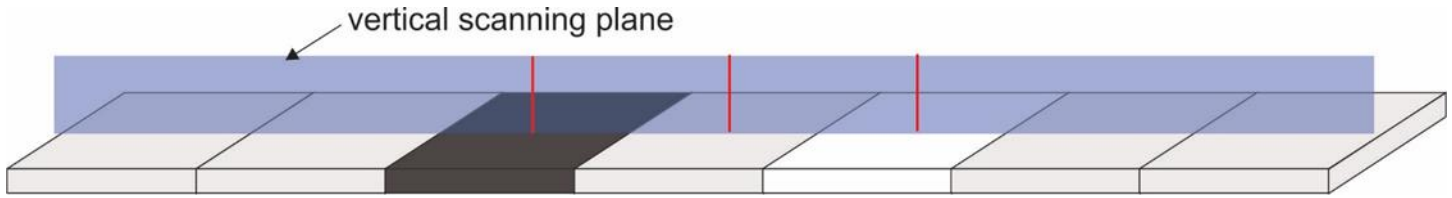


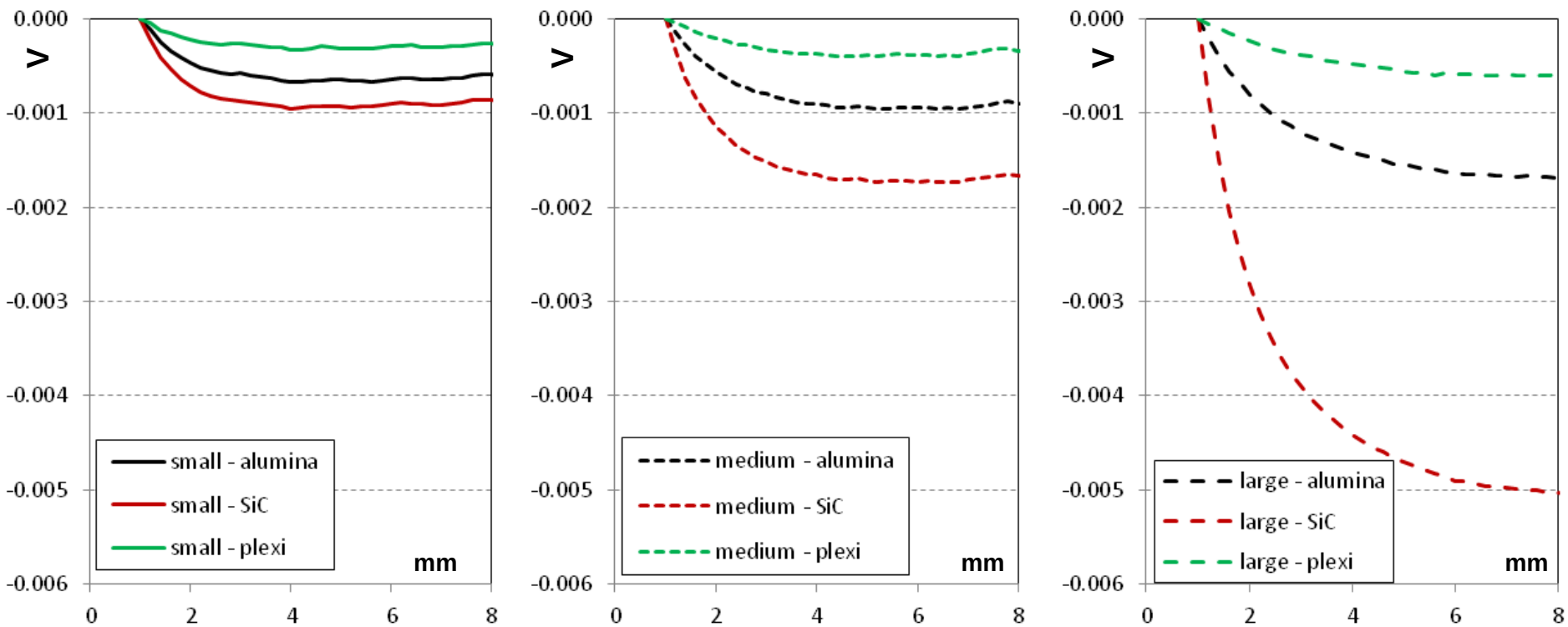




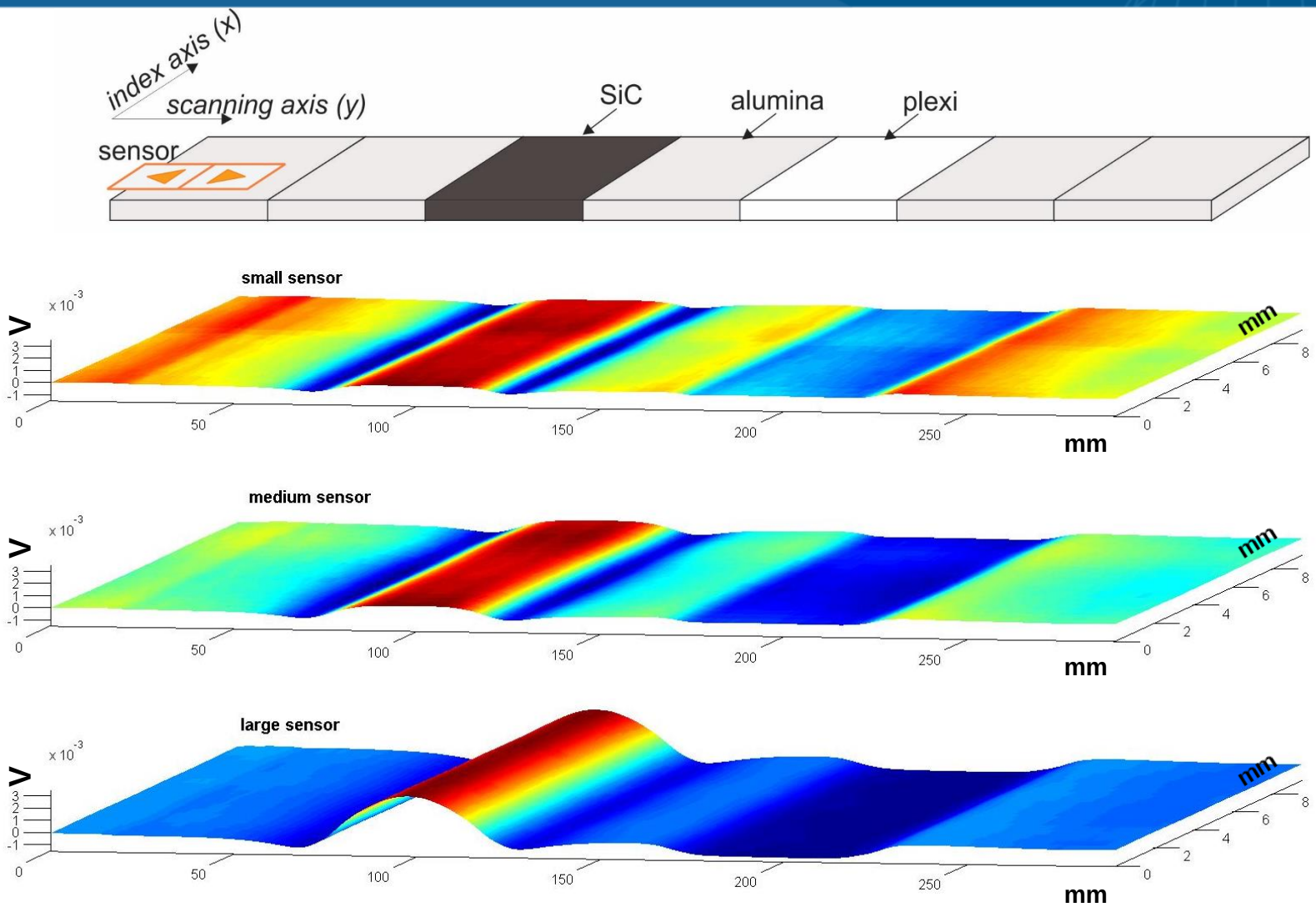


Vertical profiles

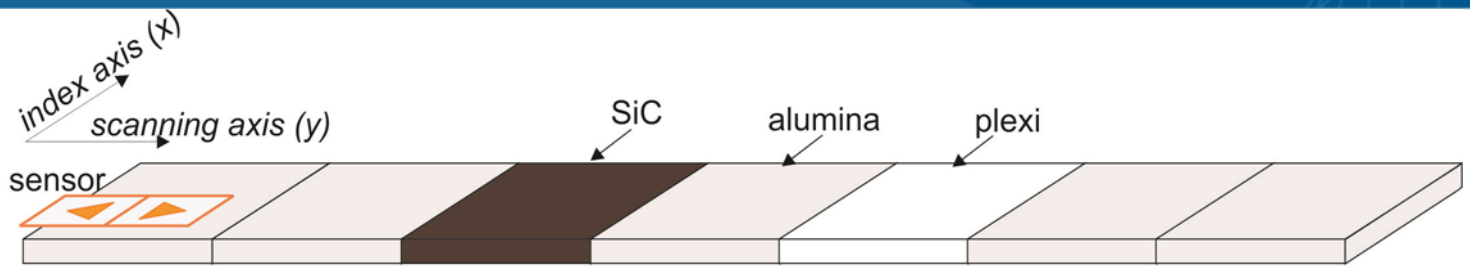


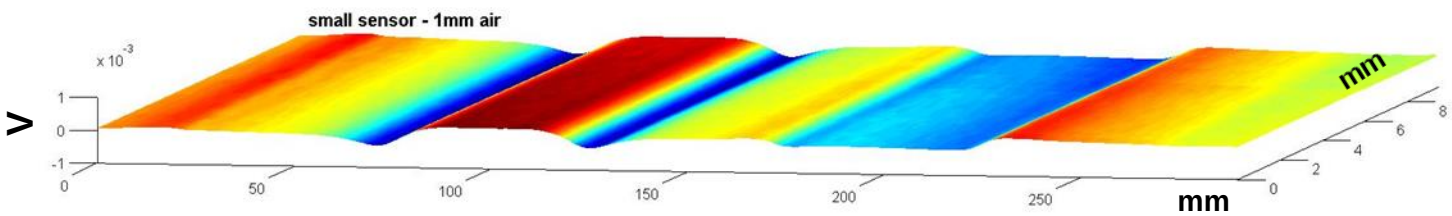


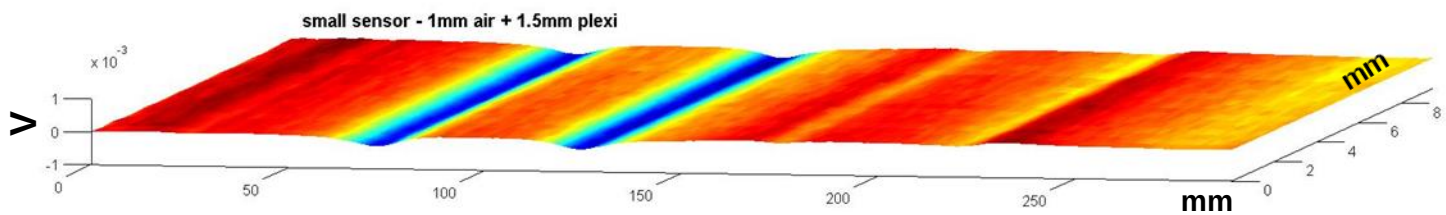
Horizontal scans – 1mm stand-off air – All Sensors

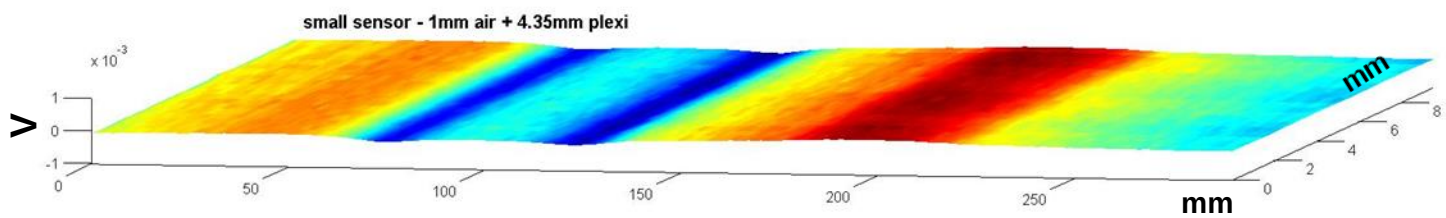


Small sensor – horizontal scans (air and Plexiglas tops)

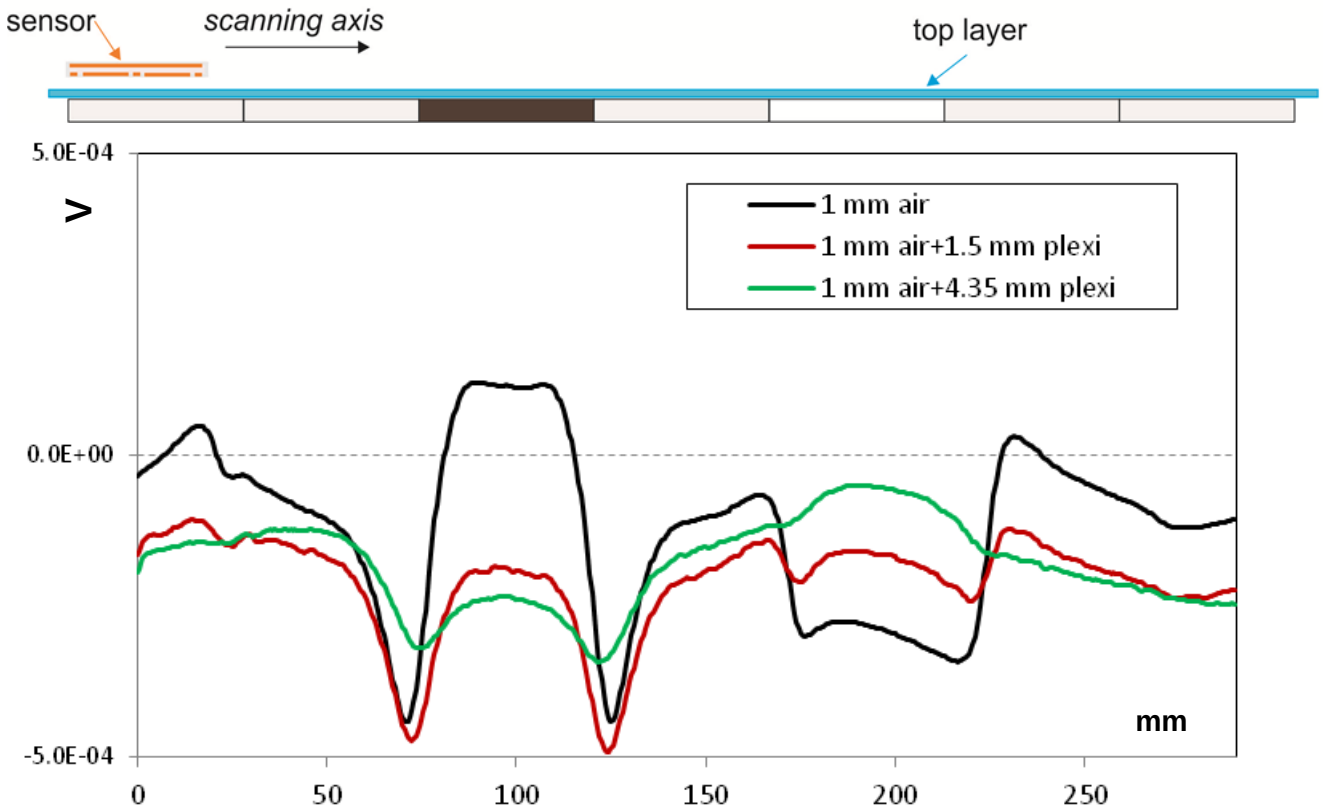




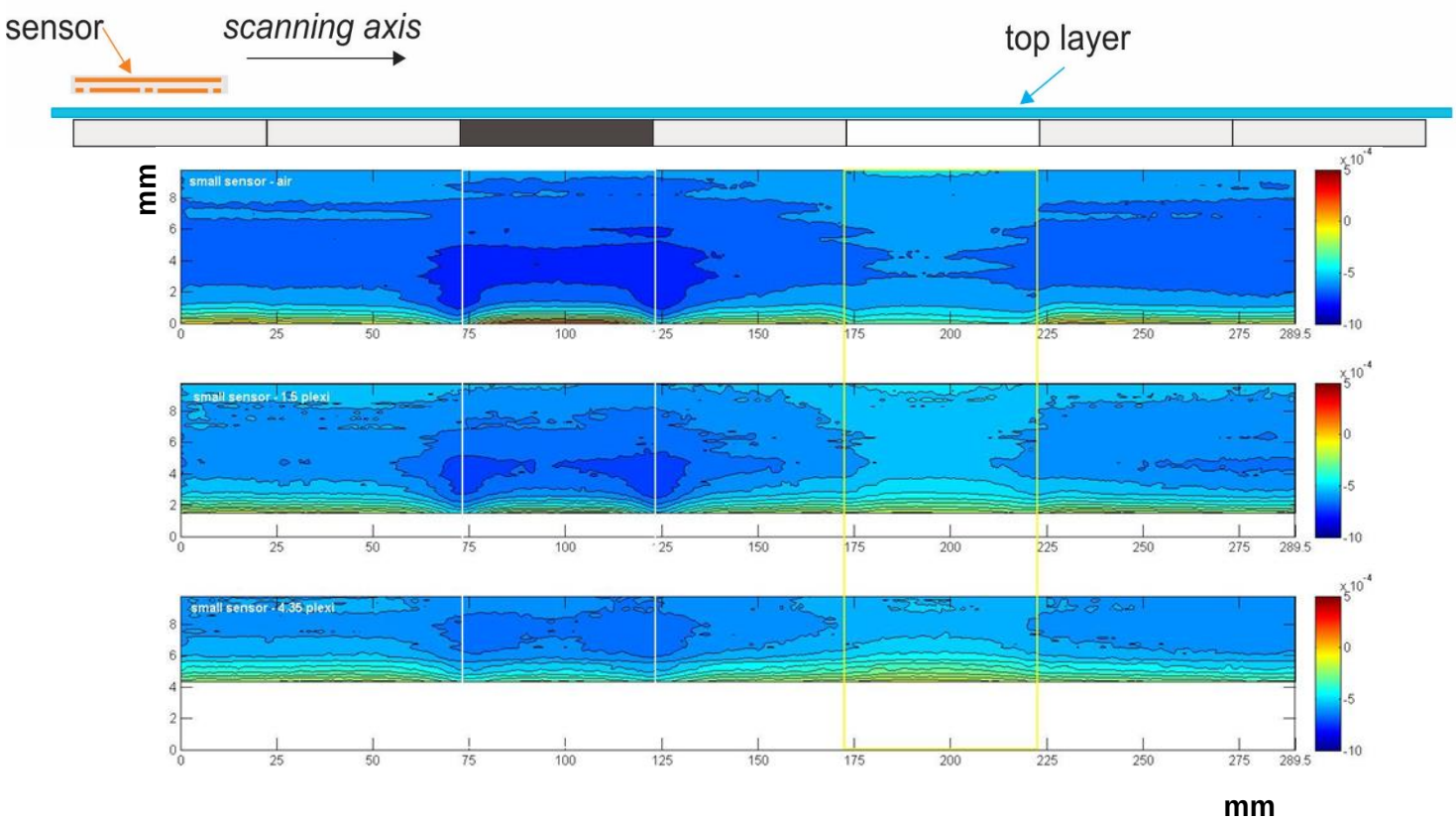




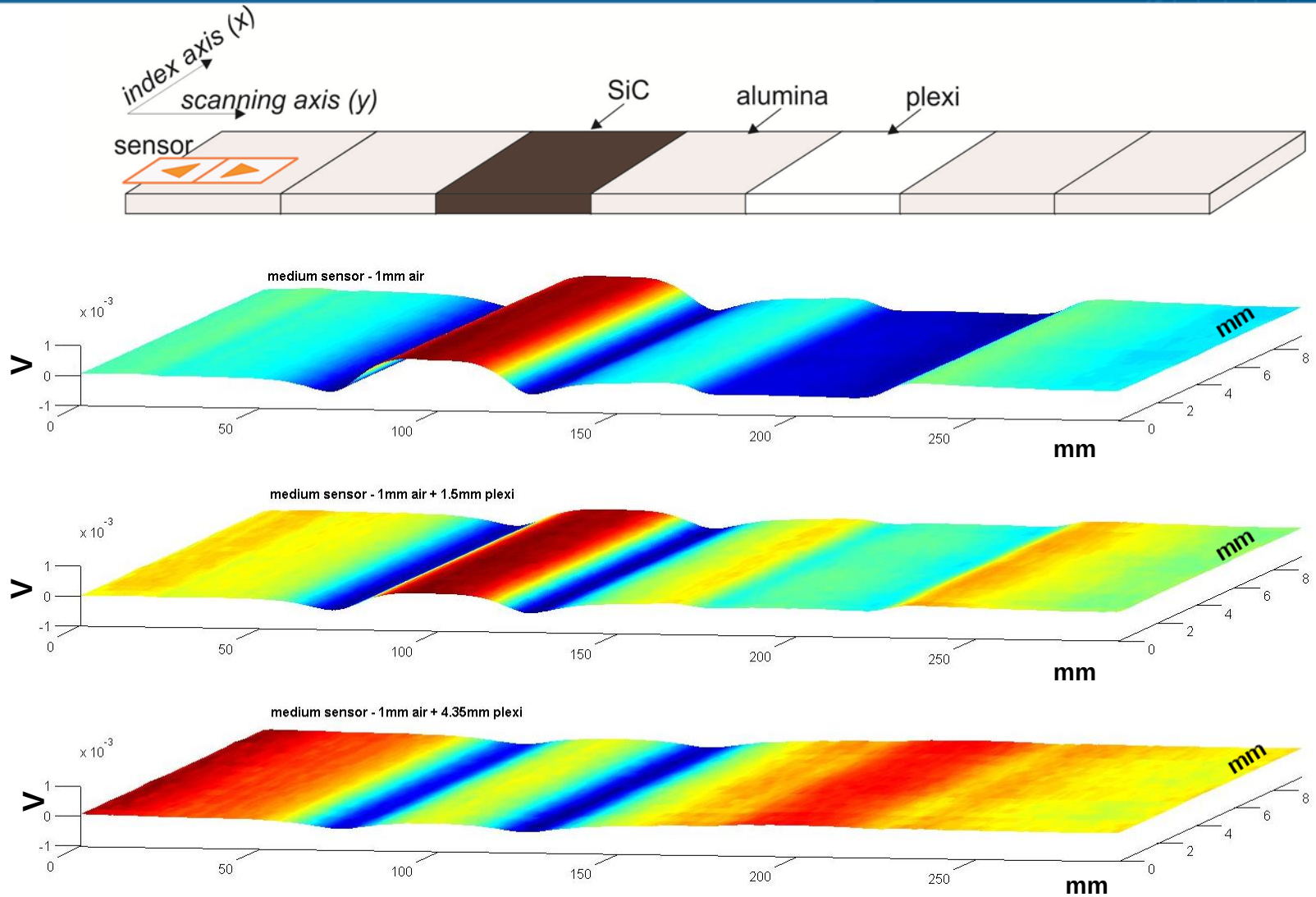
Small sensor – horizontal profiles (air and Plexiglas tops)



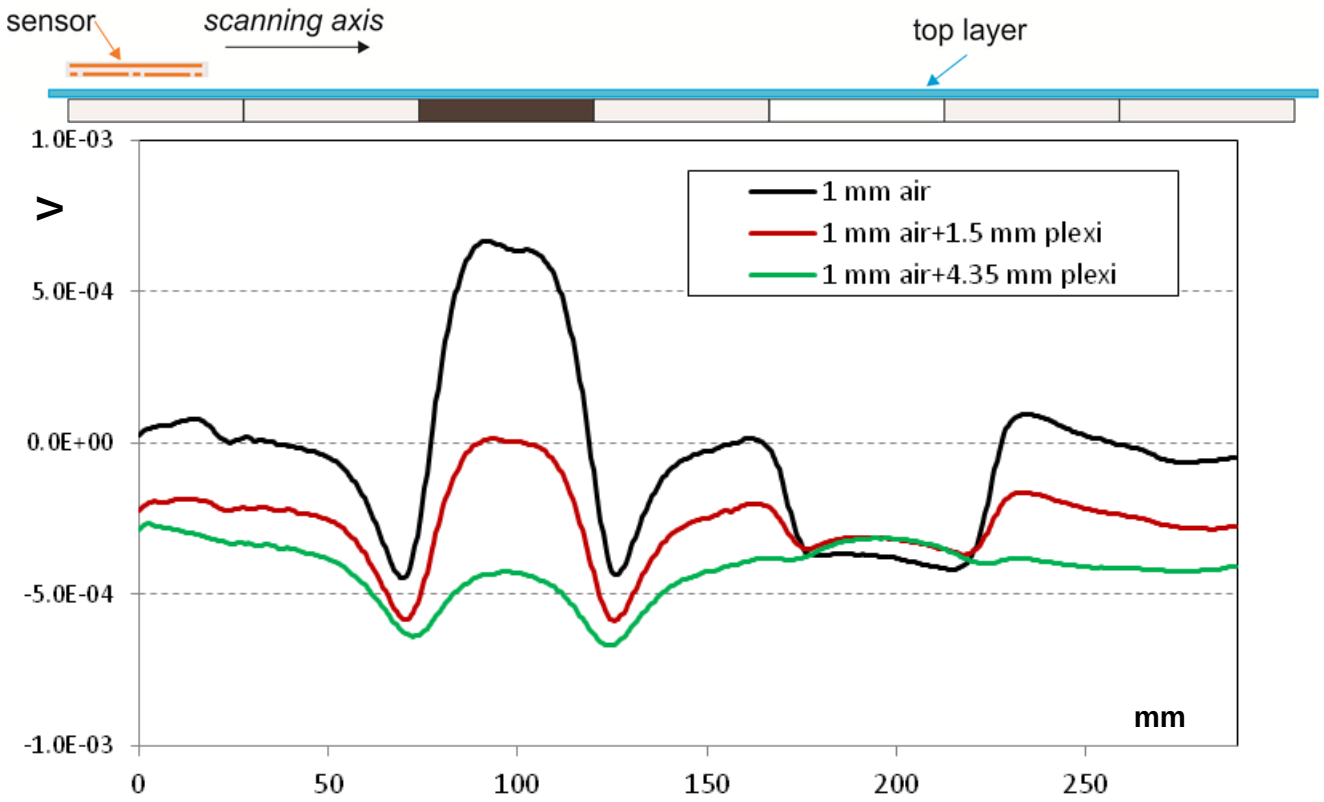
Small sensor – vertical scans (air and Plexiglas tops)



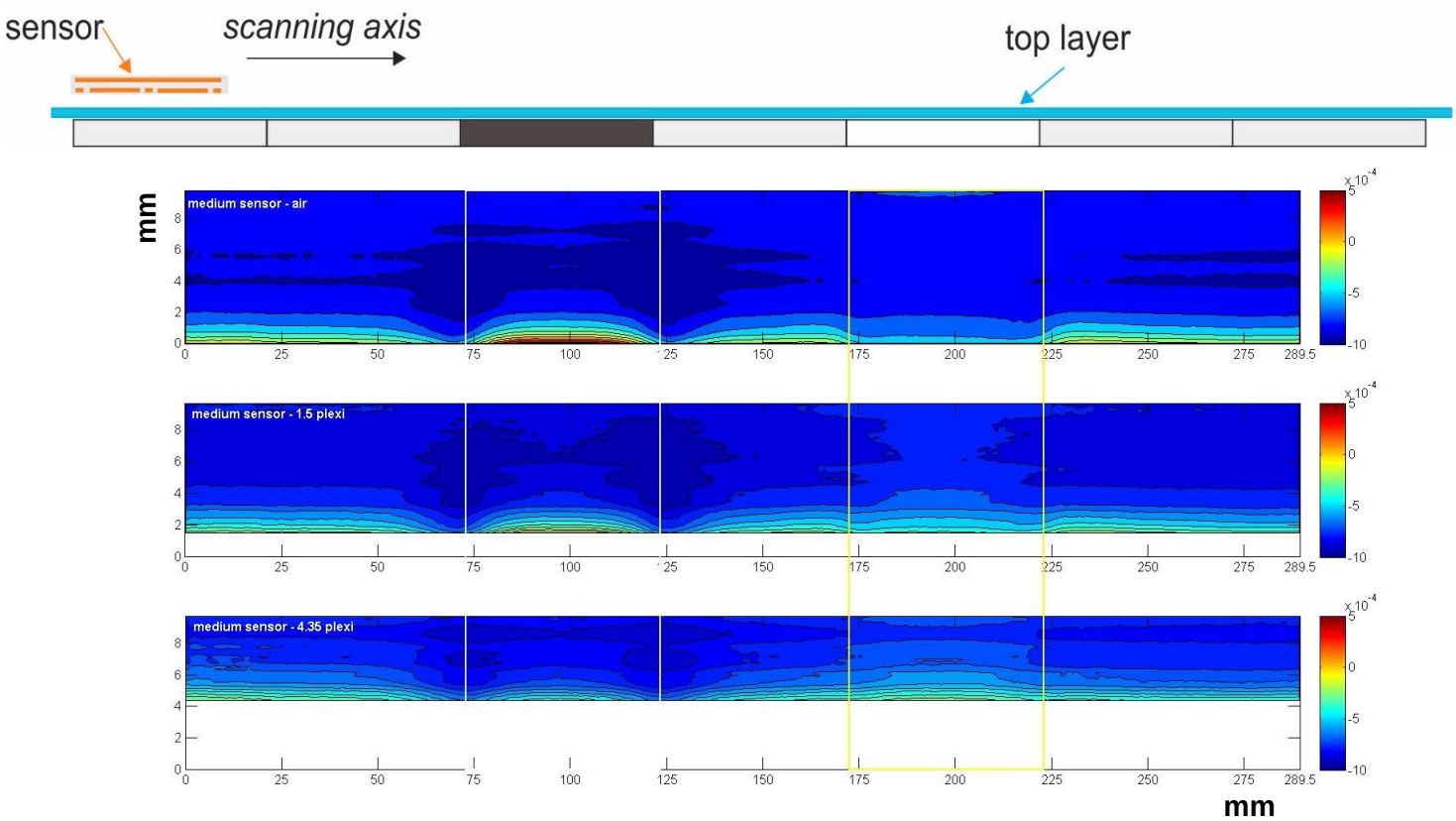
Medium sensor – horizontal scans (air and Plexiglas tops)



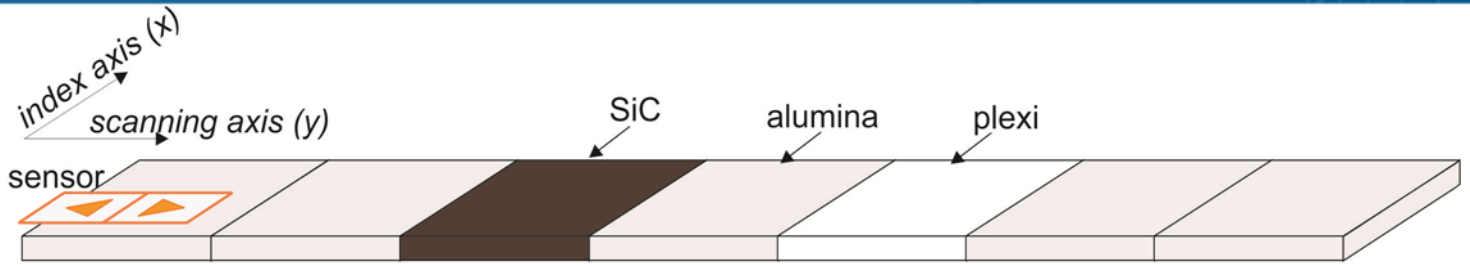
Medium sensor – horizontal profiles (air and Plexiglas tops)

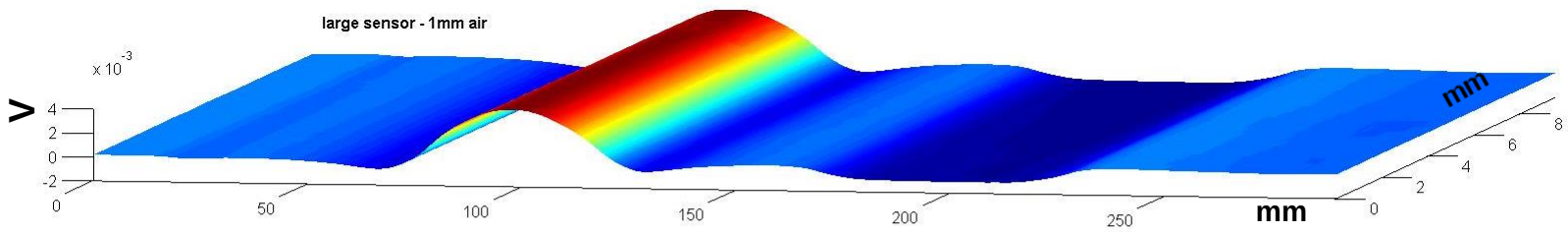


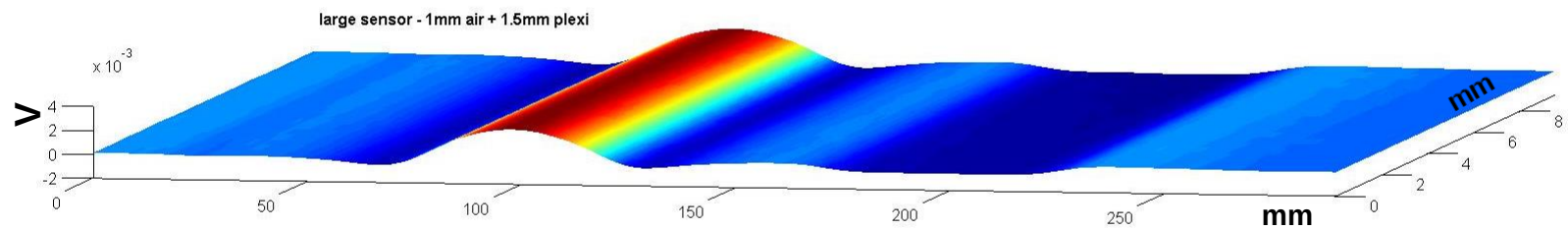
Medium sensor – vertical scans (air and Plexiglas tops)

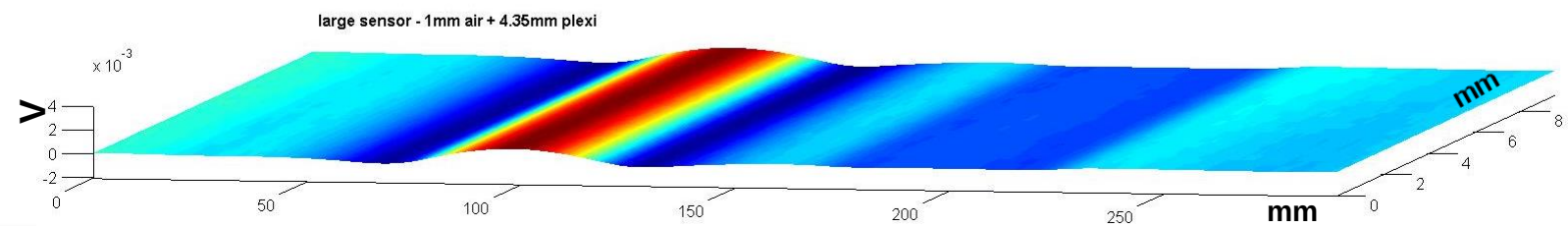


Large sensor – horizontal scans (air and Plexiglas tops)

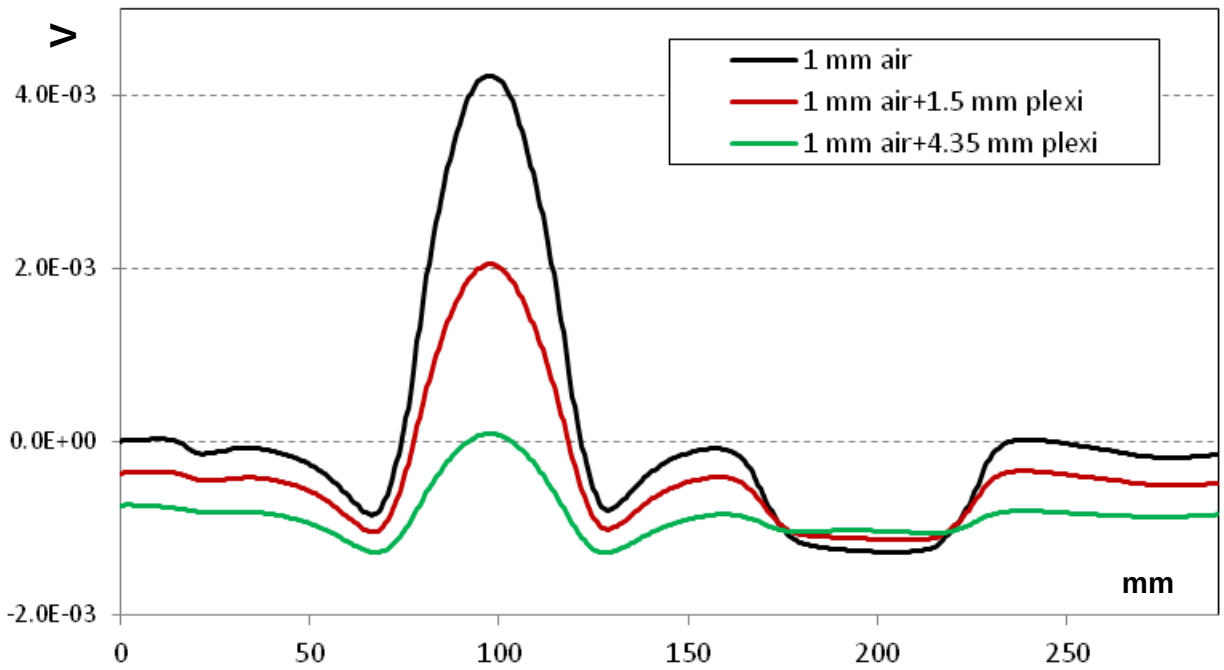




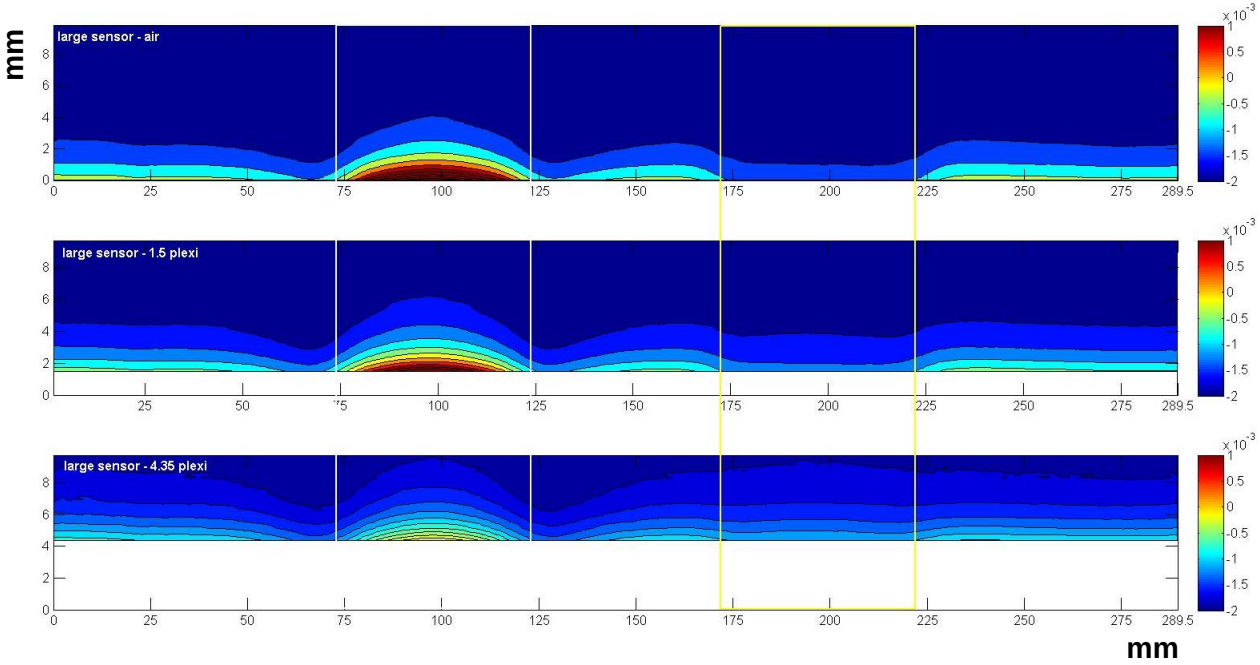




Large sensor – horizontal profiles (air and Plexiglas tops)



Large sensor – vertical scans (air and Plexiglas tops)

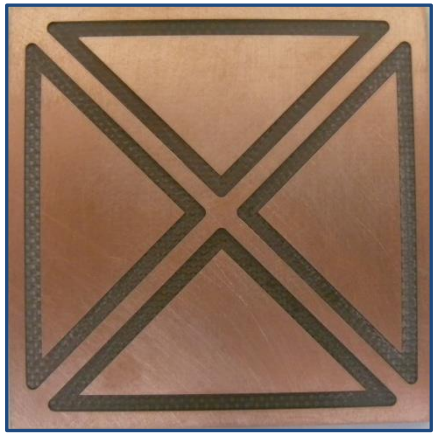


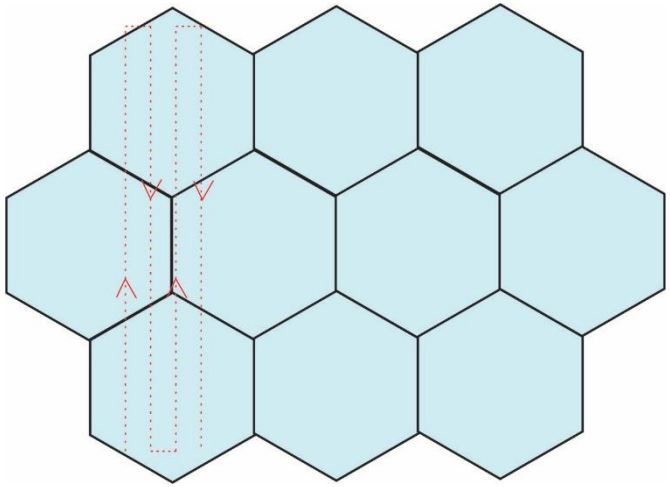
Conclusions

- The larger the sensor, the higher the penetrability in the dielectric material
- The sensitivity of the method decreases with stand-off/lift-off distance
- The direction of variation of the permittivity affects the shape of the signal
- Smaller area sensor increases the technique's resolution, but decreases the SNR
- Larger area sensor provides better SNR
- The presence of a dielectric surface (such as Plexiglas) increased the strength of the signal, as compared to air only (between sensor and specimen)

Future plans

- Two-directional sensor
- Numerical modeling for sensor and inspection optimization





Thank you

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