Tunability measurements of ferroelectric ceramic-polymer composites for sub-THz range

Konrad Godziszewski

Institute of Radioelectronics, Warsaw University of Technology

KAPITAŁ LUDZKI
NARODOWA STRATEGIA SPÓJNOŚCI

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Outline

- Motivation of the research
- Ferroelectric ceramic-polymer composites for sub-THz range
- Measurement setup for tunability measurements
- Results of measurements
- Conclusion

Motivation of the research

- Research project „Ferroelectric ceramic-polymer composites as new materials for tunable and flexible microwave sensors" realized by the Faculty of Chemistry and the Institute of Radioelectronics, Warsaw University of Technology
- The aim of the project is the development of methods for preparation of flexible and stable at temperatures from -40 to 60°C ferroelectric ceramic-polymer composites. Another aim of the project is to determine the possibility of using developed tapes and ceramic materials for planar structures with ferroelectric ceramic-polymer composites in the design of tunable electronic devices, including antennas, filters and phase shifters.
- Electrical properties (complex permittivity and tunability) of developed composites have to be measured in order to determine their suitability for the use in tunable microwave devices.

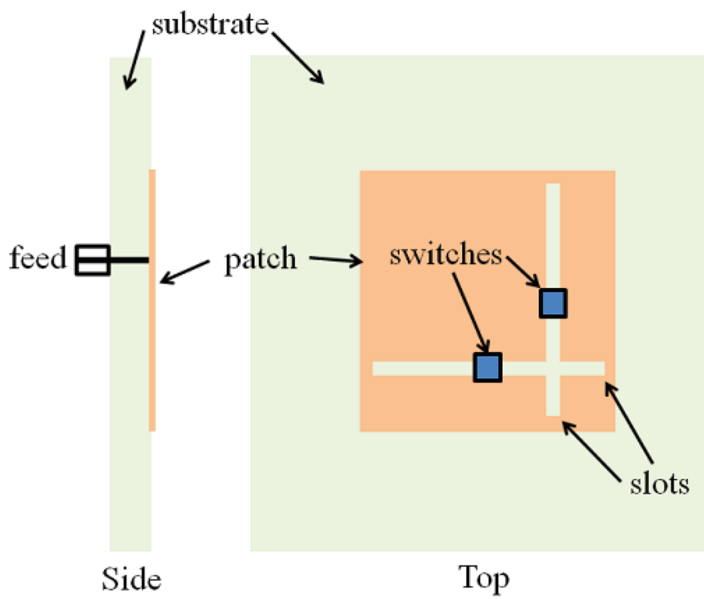
Expected results of the project

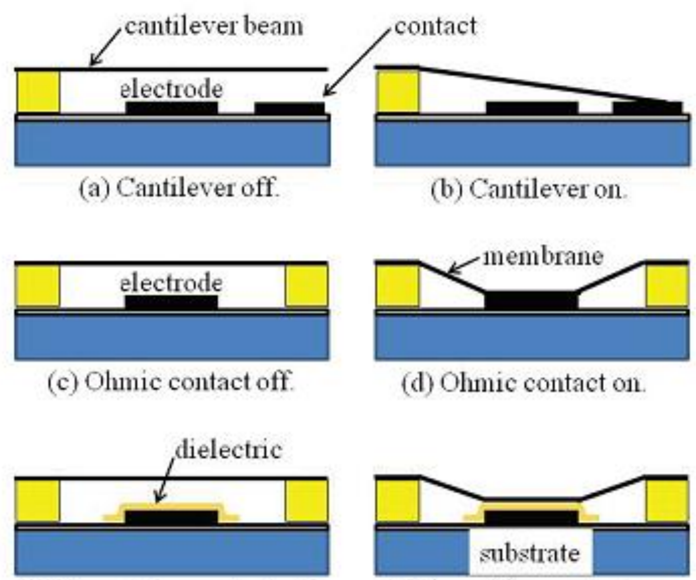
- improvement of properties and reduction of manufacturing costs of materials
- large changes of dielectric constant (up to 50%) as a function of applied electric field
- the use of tape-casting method for forming of composites

- the use of barium strontium titanate ($Ba_xSr_{1-x}TiO_3$) and environmentally friendly compounds
- obtaining ferroelectric tapes with high uniformity and flexibility

Methods to change properties of electronic devices

- To design tunable microwave devices many methods can be used:
  - microwave switches – semiconductor (transistors, PIN diodes) and MEMS;
  - varactor diodes;
  - mechanical switches;
  - tunable materials (semiconductors, ferromagnetic and ferroelectric materials, liquid crystals).
- However, each of these methods has some drawbacks and limitations at very high frequencies (mm-wave and sub-THz). For this reason new solutions are developed, including tunable materials with improved electrical properties.

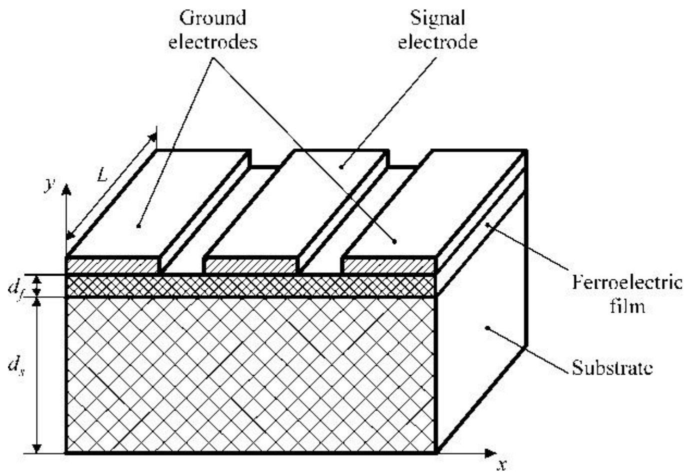


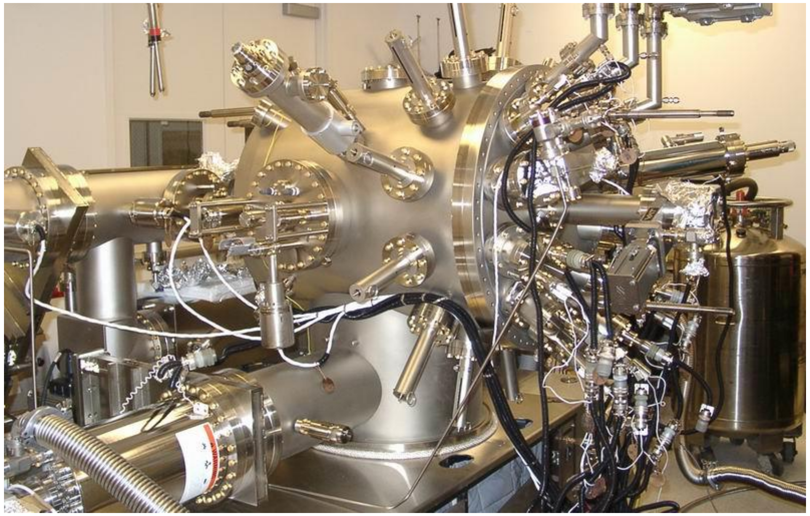


(a) Cantilever off. (b) Cantilever on.
(c) Ohmic contact off. (d) Ohmic contact on.
(e) Capacitive contact off. (f) Capacitive contact on.

Electrical properties of ceramic ferroelectrics in microwave range

- Pure ceramic ferroelectrics are characterized in microwave range by:
  - high related permittivity values
  - high losses
  - relatively low tunability $\eta(E) = \frac{\varepsilon_r(E) - \varepsilon_r(0)}{\varepsilon_r(0)} \cdot 100\%$
- Typically they are used as a thin layer applied on the surface of another material having better properties.

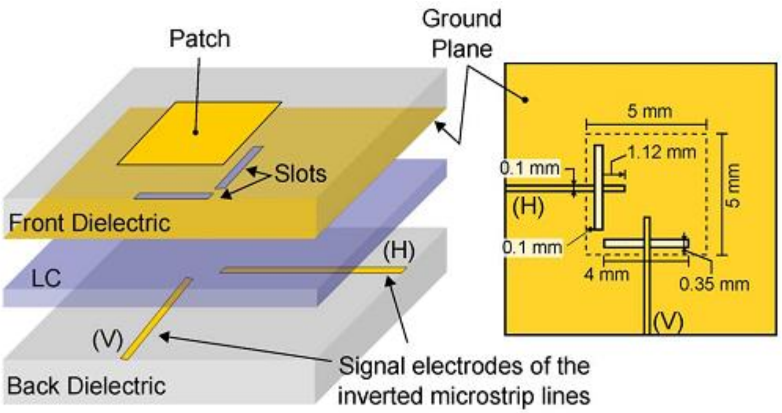


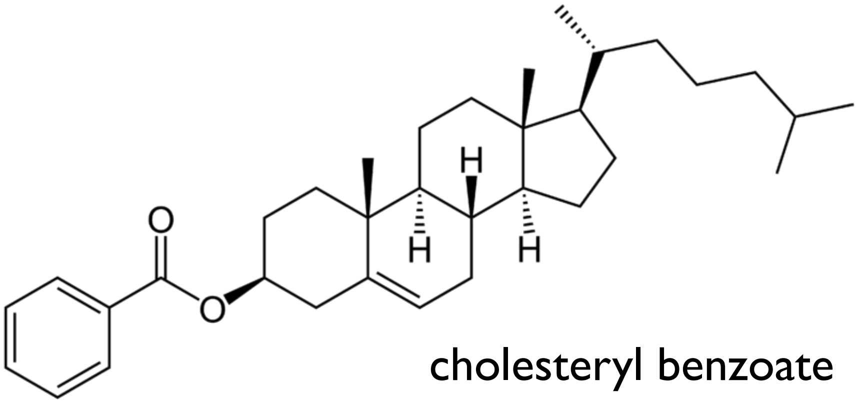


concept of creating appropriate composite consisted of ferroelectric ceramics and polymer to obtain better electrical and mechanical properties

Why ferroelectric composites?

- They allow to improve electrical and mechanical properties of ferroelectric ceramics by combining ceramic powder with a polymer.
- They do not have disadvantages of other ways to ensure tunability such as liquid crystals (low permittivity changes, the need of encapsulation).



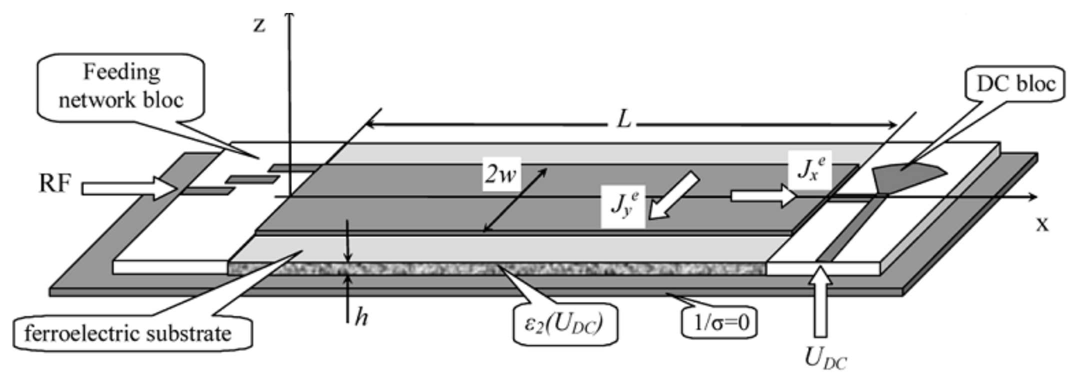


cholesteryl benzoate

- More degrees of freedom in developing of new material (stoichiometry, type of polymer, fabrication method…)
- Flexibility and mechanical strength
- Relatively low cost of production, low energy-consuming technology

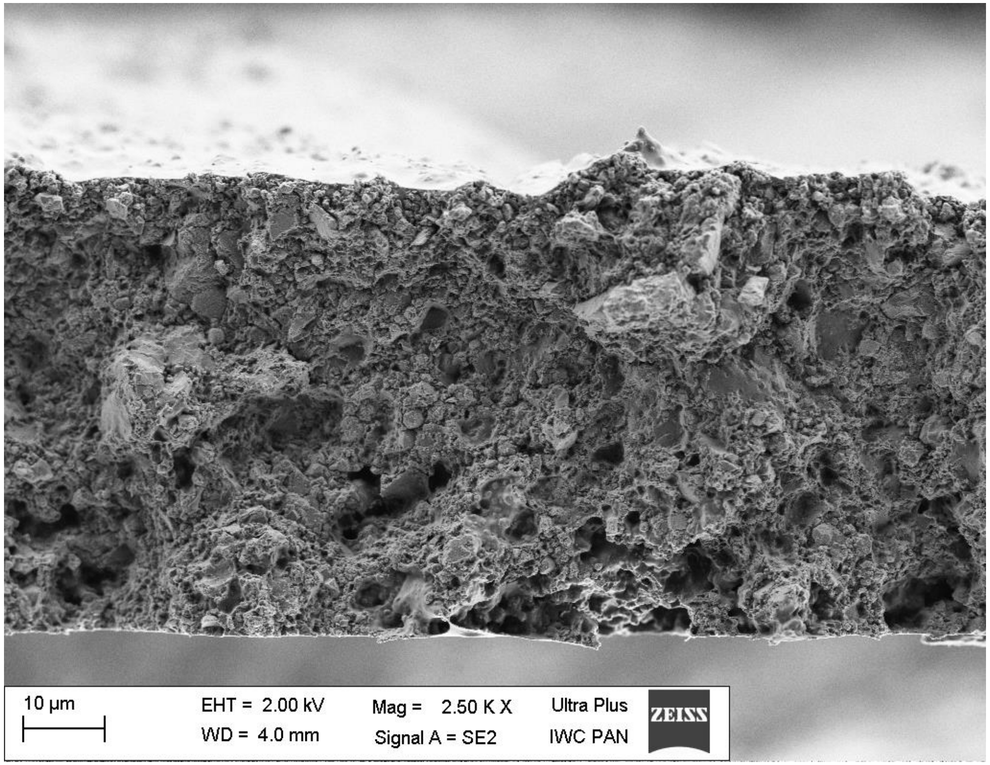
Ferroelectric ceramic-polymer composites – first research

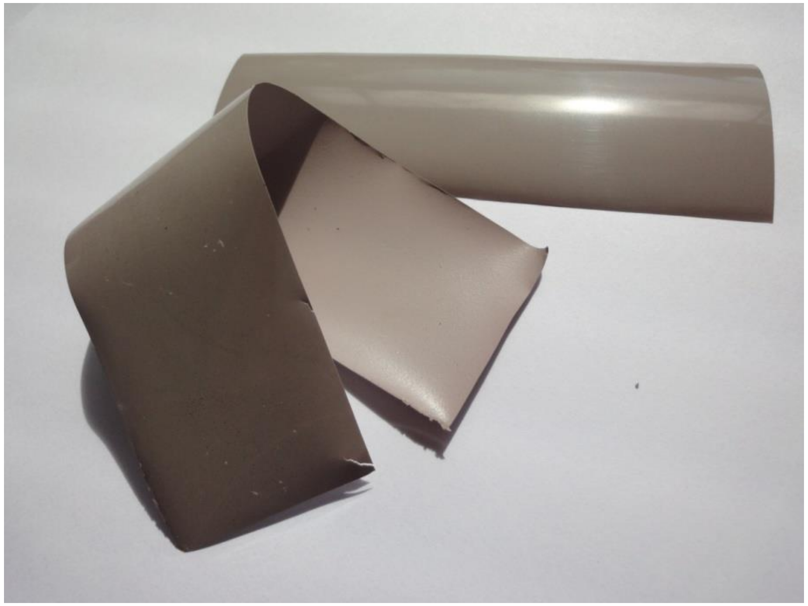
- To improve properties of ferroelectric materials a suitable composite consisted of ferroelectric ceramic powder and polymer can be made.
- This area of research is explored from about 15 years by the Faculty of Chemistry and the Institute of Radioelectronics, Warsaw University of Technology.
- As a result of these researches ferroelectric composites with high tunability (around 50%), as well as tunable microwave devices using these materials, have been developed:
  - concept of microstrip scan antenna on a ferroelectric substrate without phase shifters and attenuators for 7.5-7.8 GHz band;
  - phase shifter for 2.4 GHz band.



New ferroelectric composites (1)

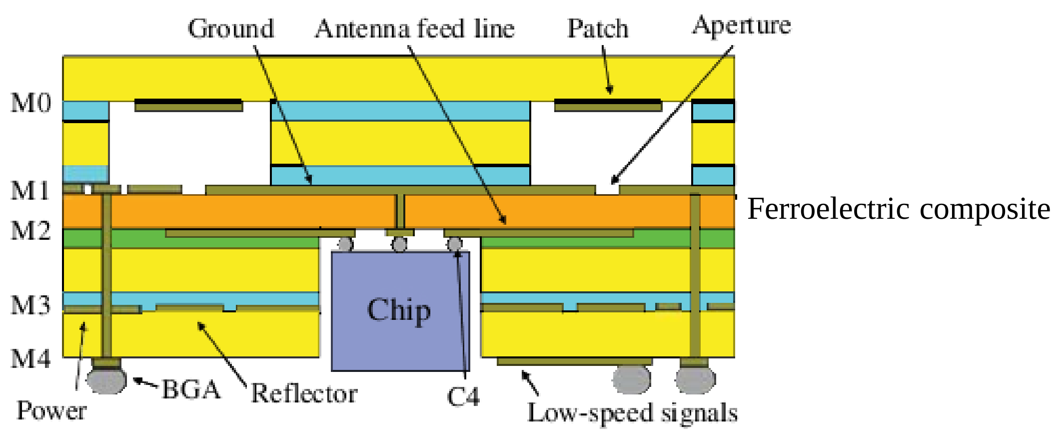
- The present research is a continuation of the previous work and aims to create ferroelectric composites that could be used in tunable devices operating at sub-THz range.





New ferroelectric composites (2)

- They could be used in tunable devices operating at higher frequency ranges than ever before (low material losses required).
- The potential use of these materials is creation of multi-layer structures in combination with commonly used technologies - LTCC (low temperature co-fired ceramics) or LCP (liquid crystal polymers). Ferroelectric layer enable local changes of permittivity resulting in a change of parameters of the device (e.g. frequency band, radiation pattern, polarization).



Measurement setup (1)

- For tunability measurements of developed ferroelectric ceramic-polymer composites microstrip transmission line method has been used. In this case ferroelectric tape under test has been a substrate for the microstrip line.
- To determine the permittivity of the FCPC substrate complex transmission coefficient has been measured.
- Simultaneously, a high DC voltage has been applied to polarize the ferroelectric composite.
- Measurements have been performed in the frequency range from 100 MHz to 20.1 GHz and for several values of biasing voltage.
- It is necessary to ensure good contact of the substrate with the bottom metallization, so that there is no air gap between these two surfaces.

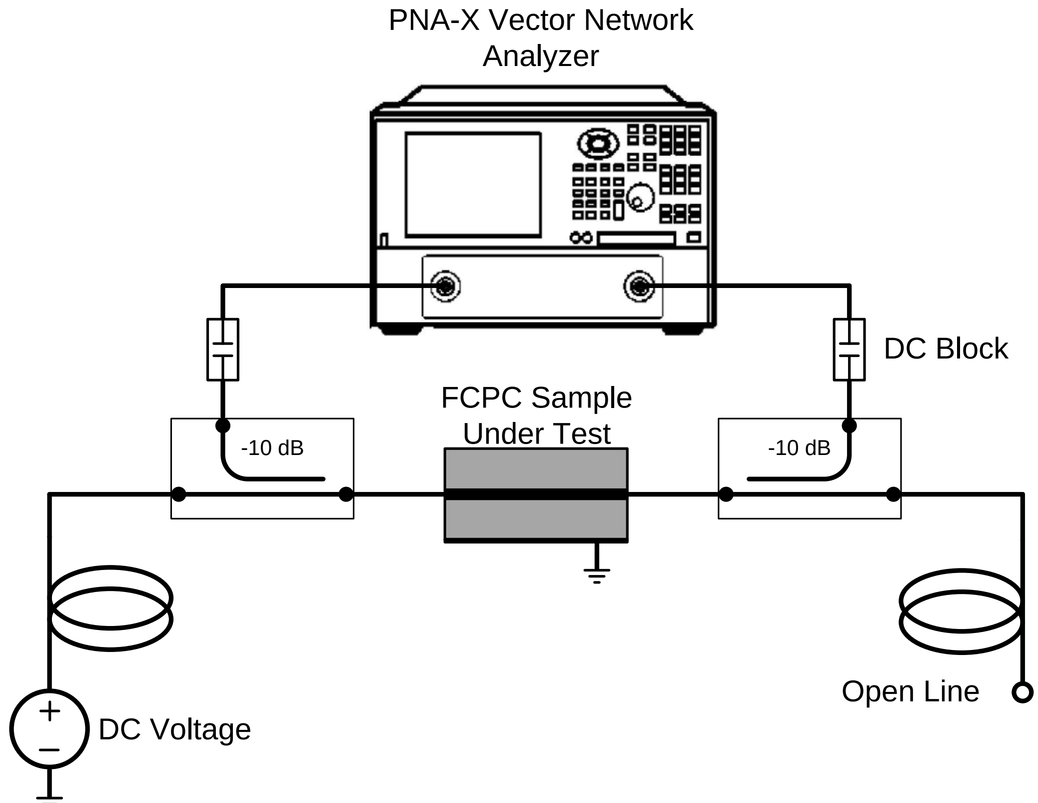
Measurement setup (2)

$$\varepsilon_{eff} = \left(\frac{\phi \cdot c}{2\pi \cdot f \cdot l} \right)^2$$

$$\varepsilon_r = \frac{2\varepsilon_{eff} - 1 + \left(1 + 12\frac{h}{w}\right)^{-1/2}}{1 + \left(1 + 12\frac{h}{w}\right)^{-1/2}}$$

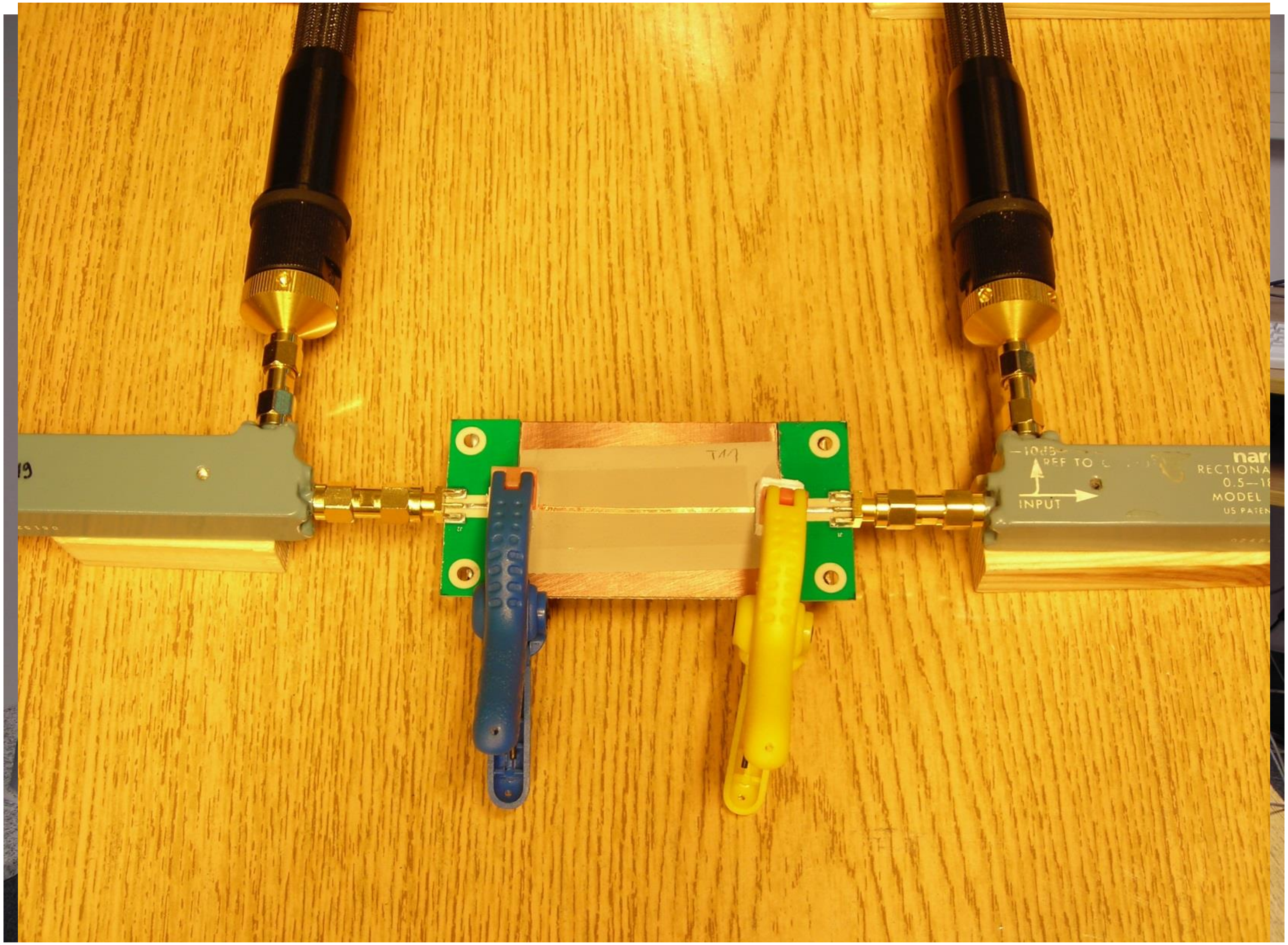
$$\eta(E) = \frac{\varepsilon_r(E) - \varepsilon_r(0)}{\varepsilon_r(0)} \cdot 100\%$$

where: ϕ – phase shift; ε_{eff} – effective relative permittivity; l and w – length and width of the microstrip line, respectively; h – thickness of the substrate



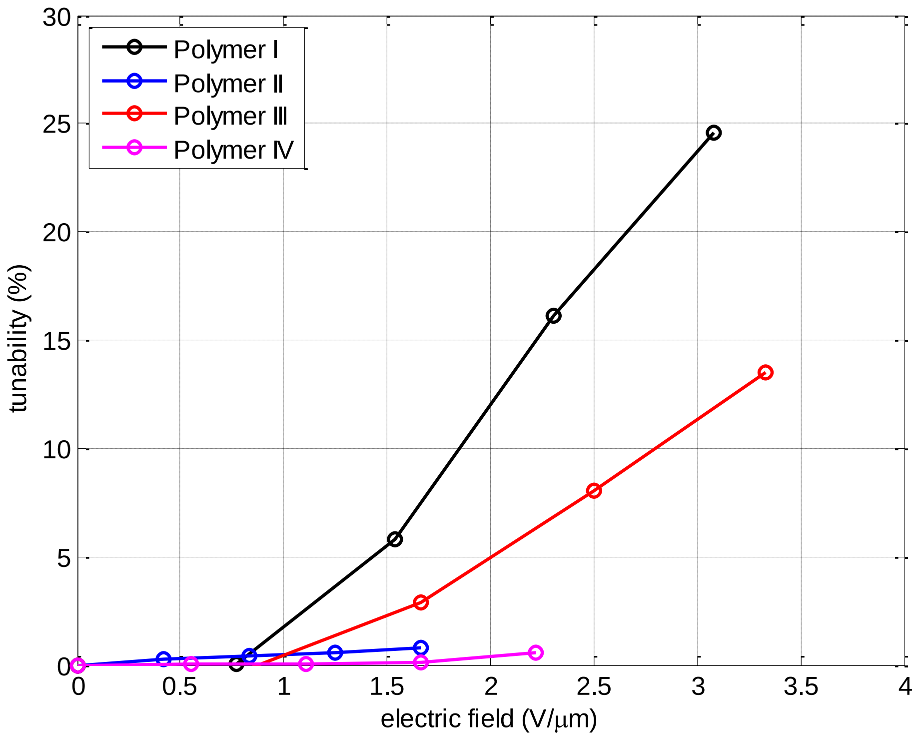
- To eliminate the influence of the DC voltage source and open end of coaxial line on the opposite side additional time-domain data processing was used. It was possible thanks to signal delay caused by 3 m long coaxial cables and broad measurement frequency band.

Measurement setup (3)



Tunability – influence of polymer

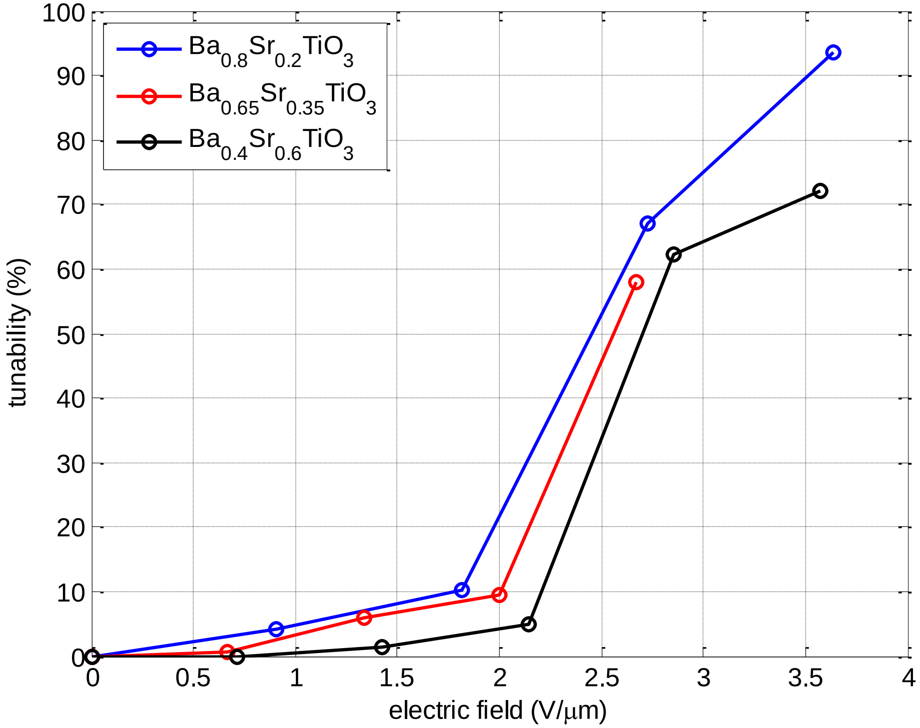
- Samples have the same ceramic powder in the same percentage content. However, other types of polymeric binder have been used.



It can be seen that not every polymer allows to obtain high tunability for the same electric field intensity. It may be connected with polymer topology.

Tunability – influence of stoichiometry

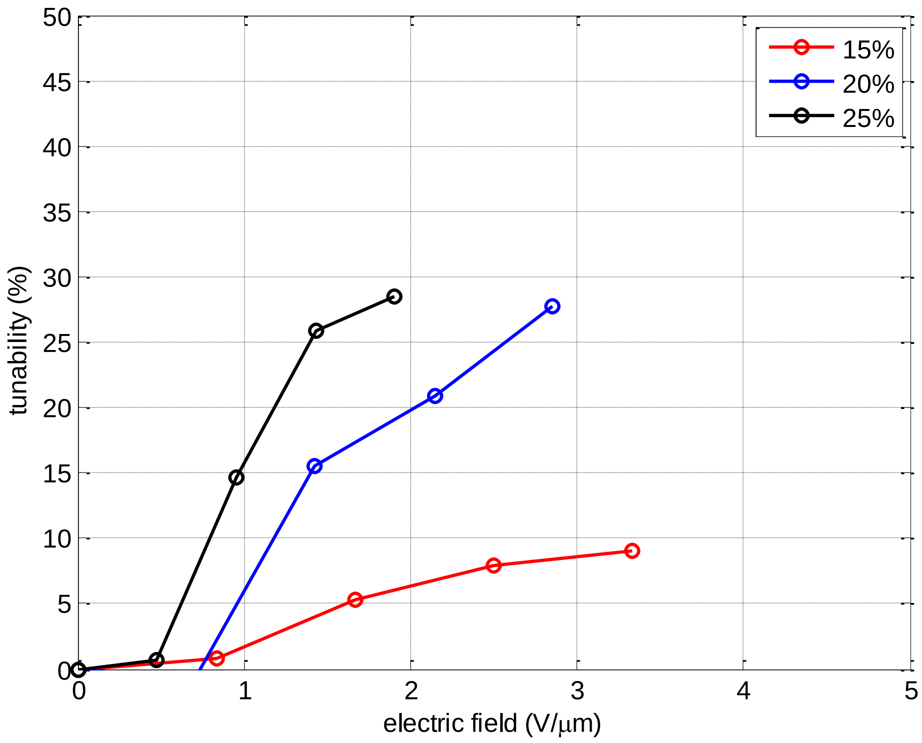
- In this case samples have been prepared using the same polymeric binder but different ceramic powder – different proportions of barium to strontium.



There are observed differences in the values of tunability for different stoichiometry. This is caused by change of Curie temperature.

Tunability – influence of amount of ceramic powder

- Samples consisted of the same polymer and ceramic powder but with different proportions.



The higher content of ceramic powder, the higher tunability values are obtained for a given field intensity. However, it is related to higher material losses.

Conclusions

- Ferroelectric ceramic-polymer composites are very promising group of materials. They can be used to design tunable devices operating at wide frequency range up to sub-terahertz frequencies.
- It is possible to obtain materials with desired electromagnetic and mechanical properties. However, not every set of composite components ensures high tunability.
- Presented composites have high tunability (up to 100%) and could be used to design many different tunable devices (antennas, phase shifters, filters).

Thank you for your attention