Conference on Nanoscience and Nanotechnology (n&n) Frascati, Italy, 18-20 December, 2018

Electromagnetic characterization of binary and ternary polyethylene nanocomposites based on GNPs and MWCNTs

Hristiana Velichkova

D. Meisak, D. Bychanok**, A. Paddubskaya**, J. Macutkevic***, R. Kotsilkova*, P. Kuzhir** , A. A. Oliveira****, G. J. M. Fechine******

* OLEM, Institute of Mechanics- BAS, Bulgaria, e-mail: hristiana_velichkova@abv.bg
** Institute for Nuclear Problems, BSU, Belarus
*** Vilnius University, Lithuania
**** Mackgraphe Research Institute, Presbyterian University Makenzie, Brazil

Introduction

RISE PROJECT GRAPHENE 3D
MULTIFUNCTIONAL GRAPHENE-BASED NANOCOMPOSITES WITH ROBUST ELECTROMAGNETIC AND THERMAL PROPERTIES FOR 3D-PRINTING APPLICATION

OBJECTIVES:

- **Develop and produce polymer nanocomposite material, doped by graphene and carbon nanotubes, with robust multifunctional properties for 3D printing application.**

- **Fabricate 3D printed cellular structures for power electronics application with predefined properties (electromagnetic wave absorption, thermal conductivity, mechanical strength and lightness) on the basis of modeling, simulation and experimental validation.**

- **Create "Joint Laboratory on Graphene-Polymer Research" for long-term knowledge impact.**

http://graphene3d.imbm.bas.bg
graphene3d.project@gmail.com

Materials and preparation

Powder of HDPE -> ROWALIT N100-20

- **Size of particles 0-80µm**;
- Melting Flow Index (MFI) 20;
- **Density 0.956 g/cm^3**;
- Melting range 125-128˚C;
- Heat resistance of 110˚C;

Graphene nanoplatelets -> TNGNP

- **Purity 99.5%**;
- Thickness 4-20nm;
- Number of layers < 20;
- Average size of 5-10 µm;
- **Aspect ratio ~500;**

MWCNTs-> NANOCYL® NC7000™

- **Purity 90%**;
- Surface area 250-300 m^2/g;
- Average diameter 9.5*10^{-9}m;
- **Aspect ratio ~150**;

Binary composites → Wrapped by ball mill → Melt mixing of binary and ternary nanocomposites

Characterization of nanocomposites

- ✓ X-ray diffraction of binary composites by Rigaku "MiniFlex" benchtop X-ray diffractometer

EMI shielding characterization of binary and ternary composites

- ✓ Measurements at low frequency by a capacitance bridge "HP4284 A"
  (20 Hz – 1 MHz)

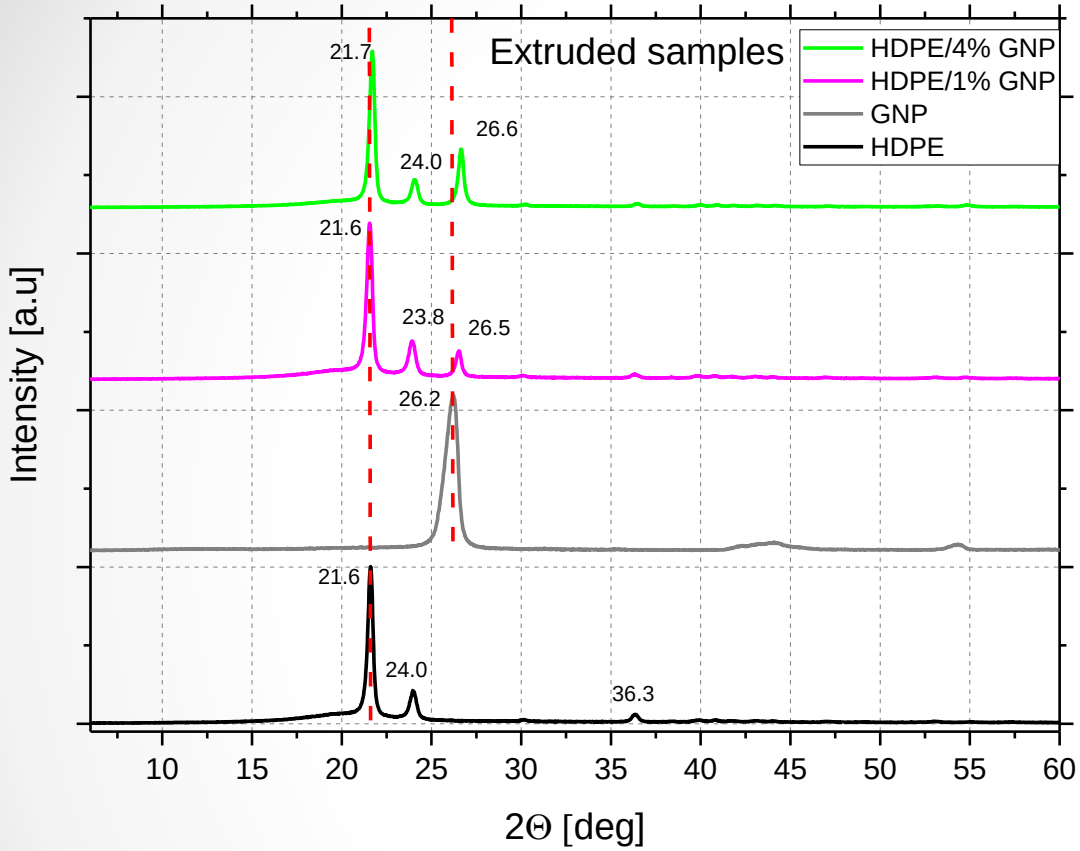
- ✓ Two GHz ranges:
- Vector network analyzer Micran R4M
  (12 – 18 GHz)

- Scalar network analyzer Elmika R2408R
  (26 – 37 GHz)

- ✓ Measurements at high frequency
  (0.2 – 1 THz)

Type of composite	Filler content [wt%]
Binary	0.5
	1
	2
	3
	4
Ternary	0.25 + 0.25
	0.5 + 0.5
	1 + 1
	1.5 + 1.5
	2 + 2

XRD of binary nanocomposites



21.6° and 24.0°

⇩

(1 1 0) and (2 0 0) lattice planes of the HDPE crystals

Crystallinity

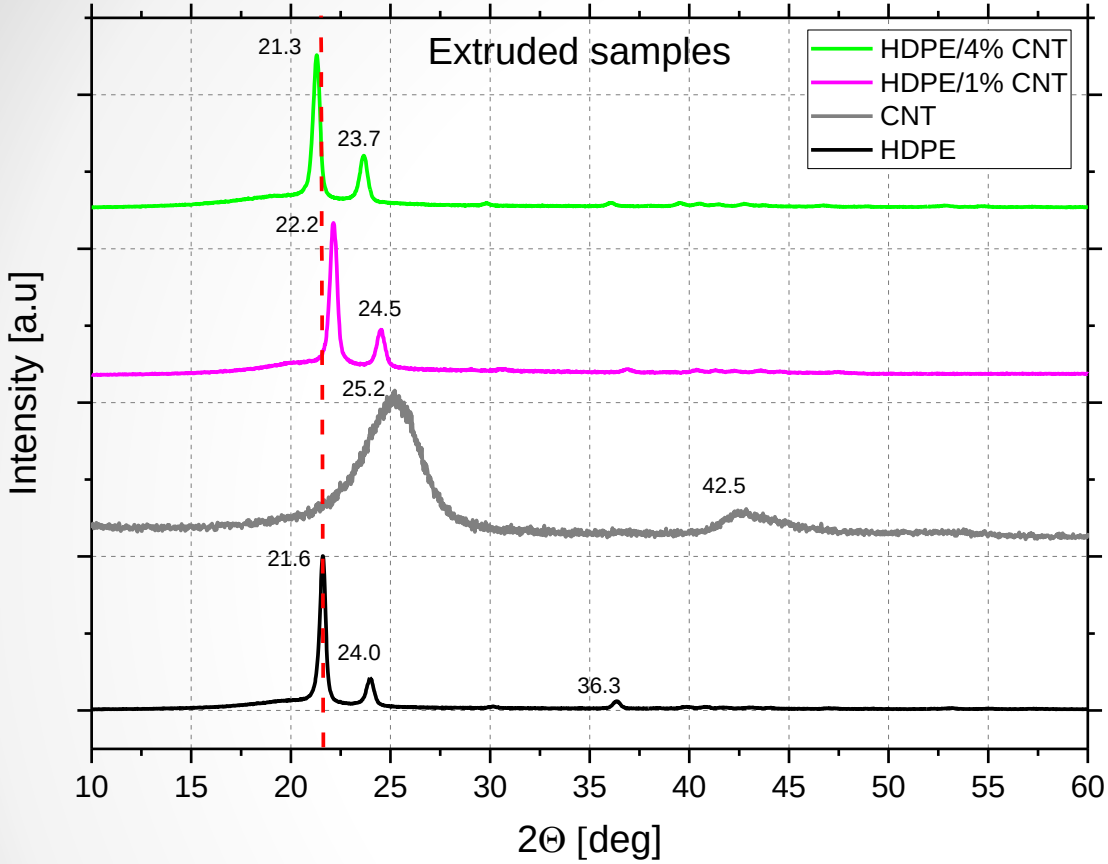
⇩

Nucleation effect

Extruded samples	Crystallinity [%]
Pure HDPE	25.7
HDPE/1wt% GNP	30.8
HDPE/4wt% GNP	28.9

[1] B.J. Kim, K.M. Bae, M.K. Seo, K.H. An, S.J. Park, Mater. Sci. Eng. A 528 (2011) 4953.

XRD of binary nanocomposites



Lack of MWCNT peaks

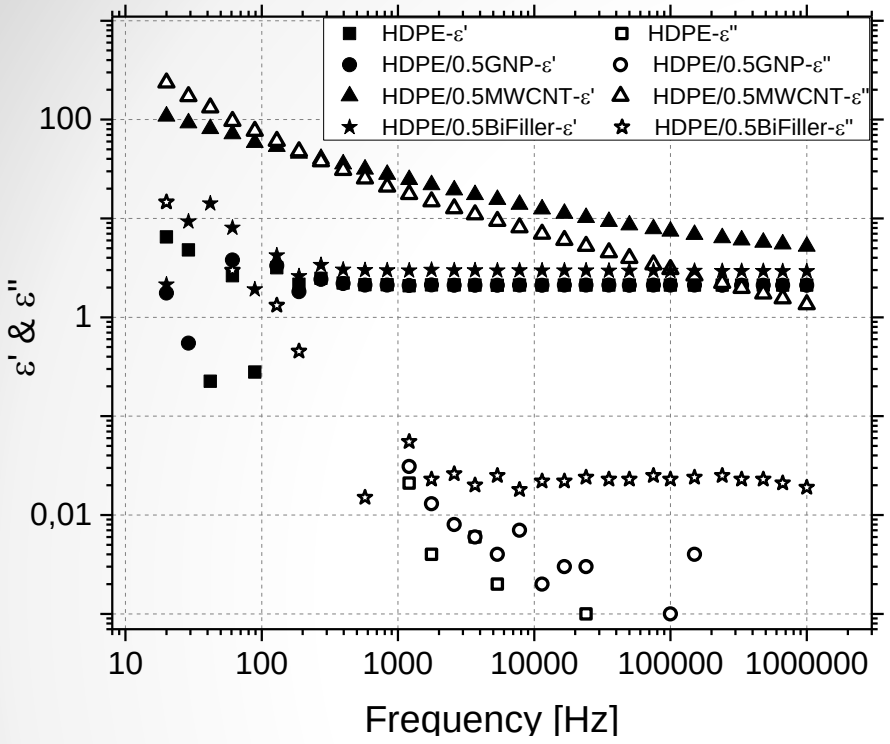
⇓

An efficient mix of the MWCNTs in HDPE

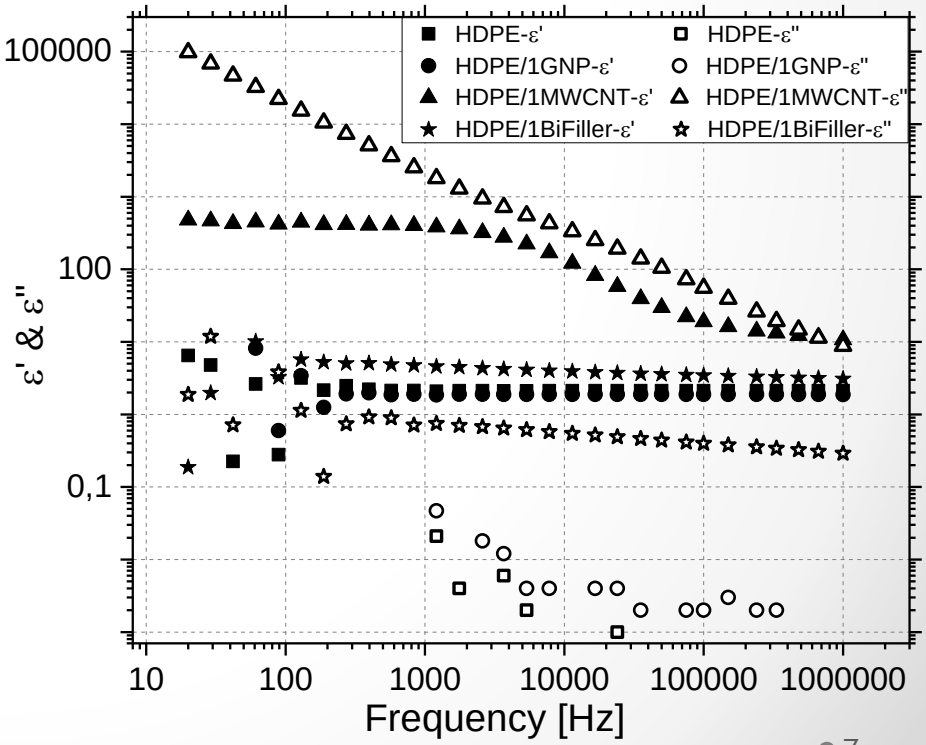
Extruded samples	Crystallinity [%]
Pure HDPE	25.7
HDPE/1wt% MWCNT	25.1
HDPE/4wt% MWCNT	29.0

[2] T. McNally, P. Potschke, P. Halley, M. Murphy, D. Martin, S. Bell, G.P. Brennan, D. Bein, P. Lemoine, J. Quinn, Polymer 46 (2005) 8222.

Low frequency

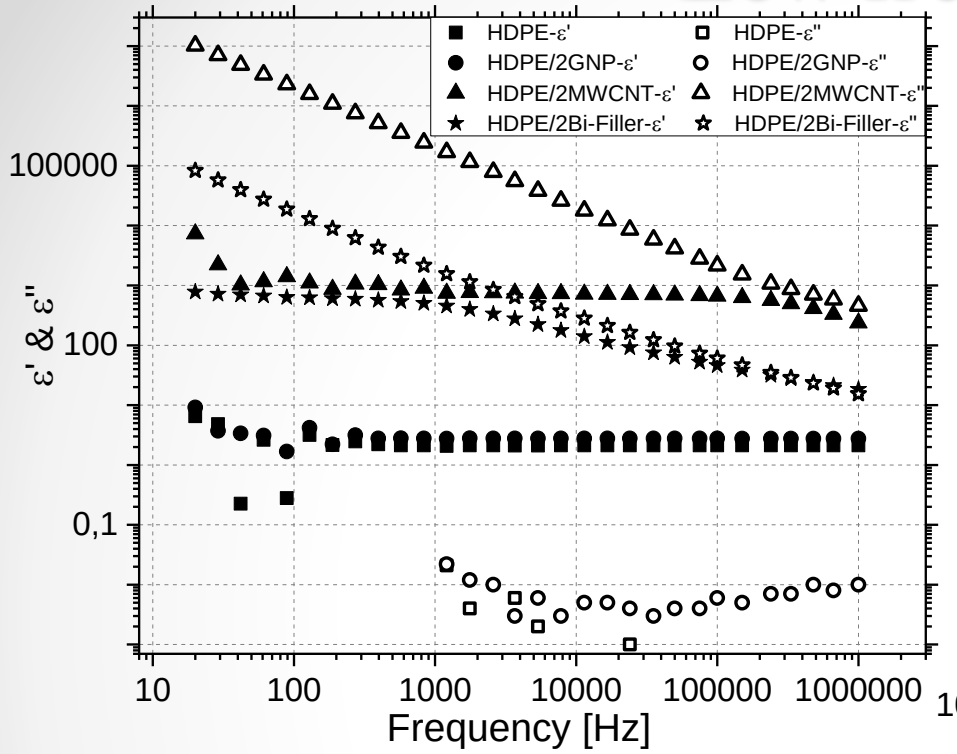


20 Hz – 1 MHz

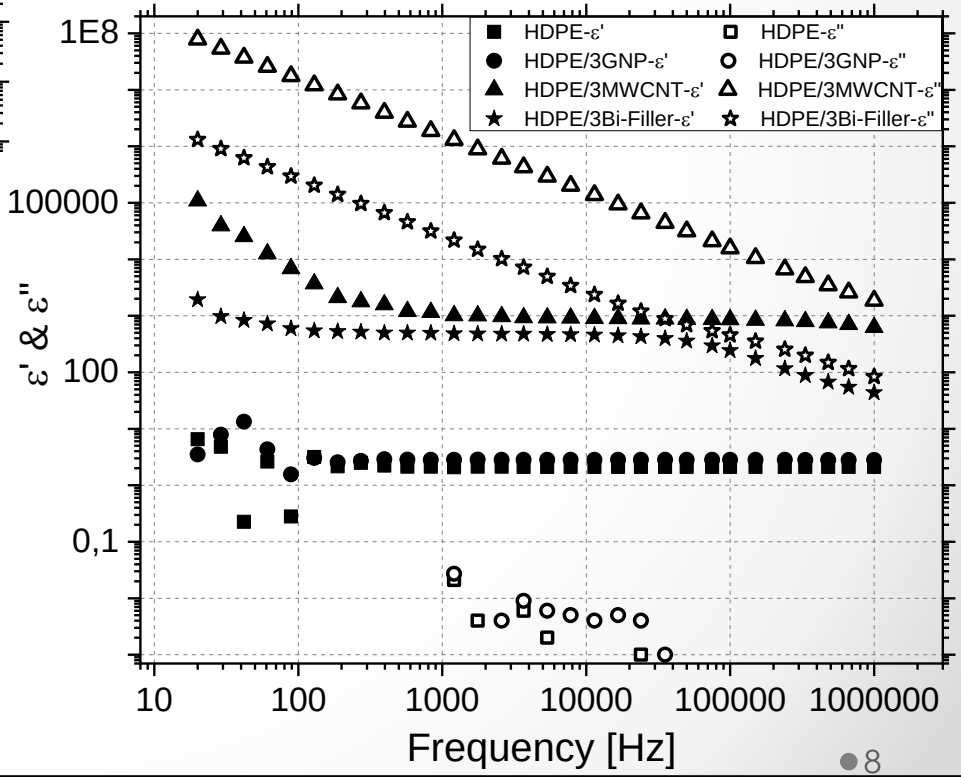


Not significant effect in GNP and Bi-Filler nanocomposites

Low frequency

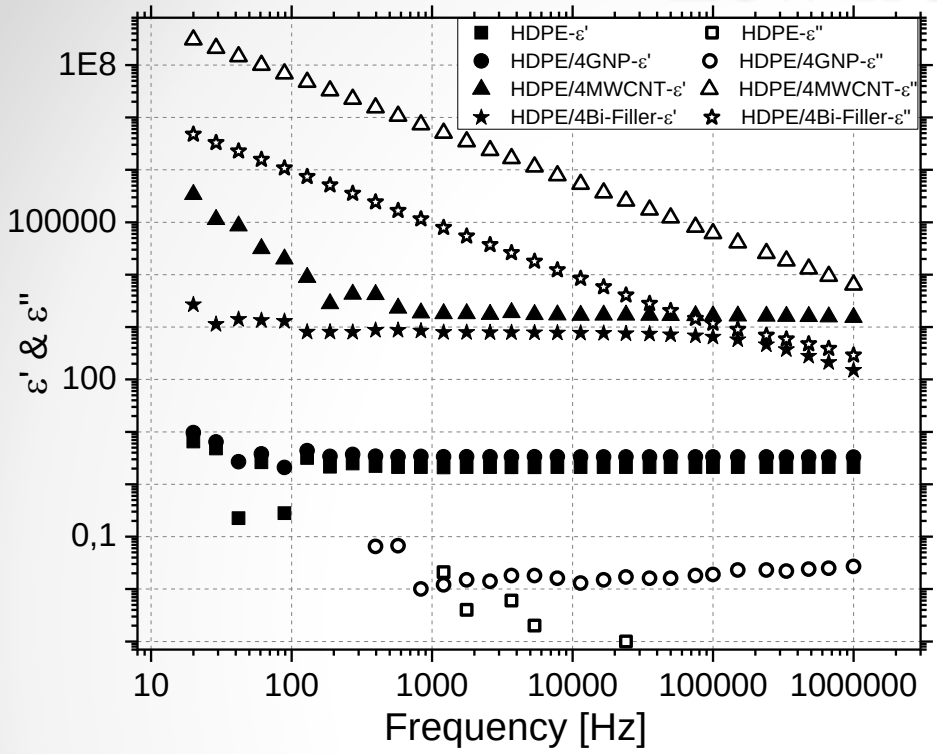


20 Hz – 1 MHz



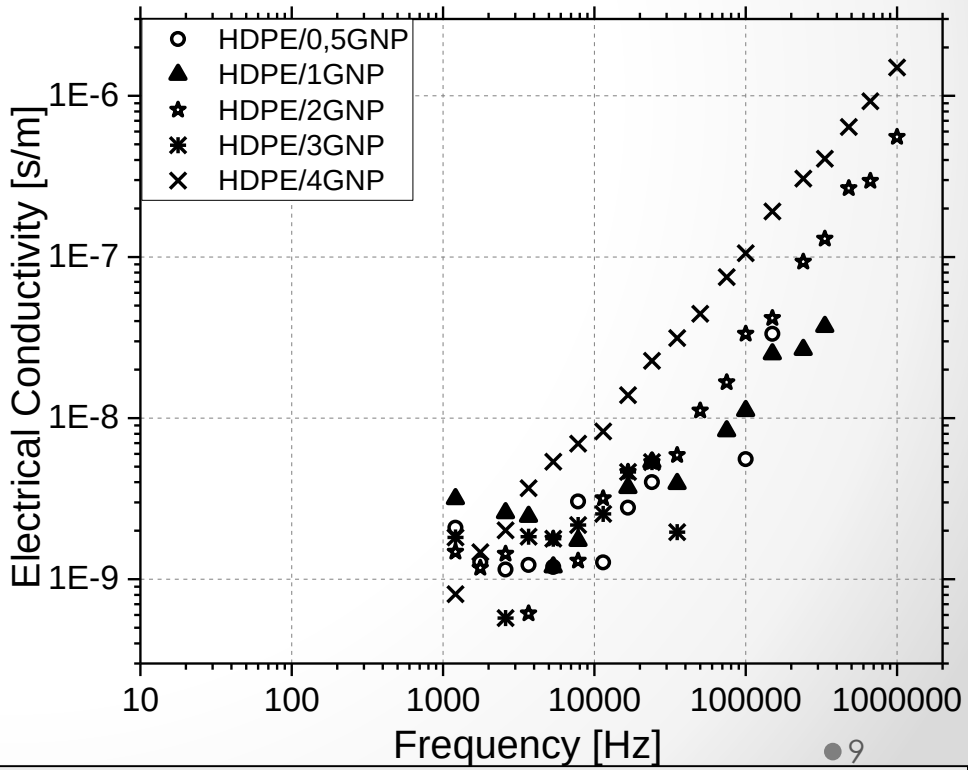
Enhanced dielectric permittivity in MWCNT and Bi-Filler composites

Low frequency



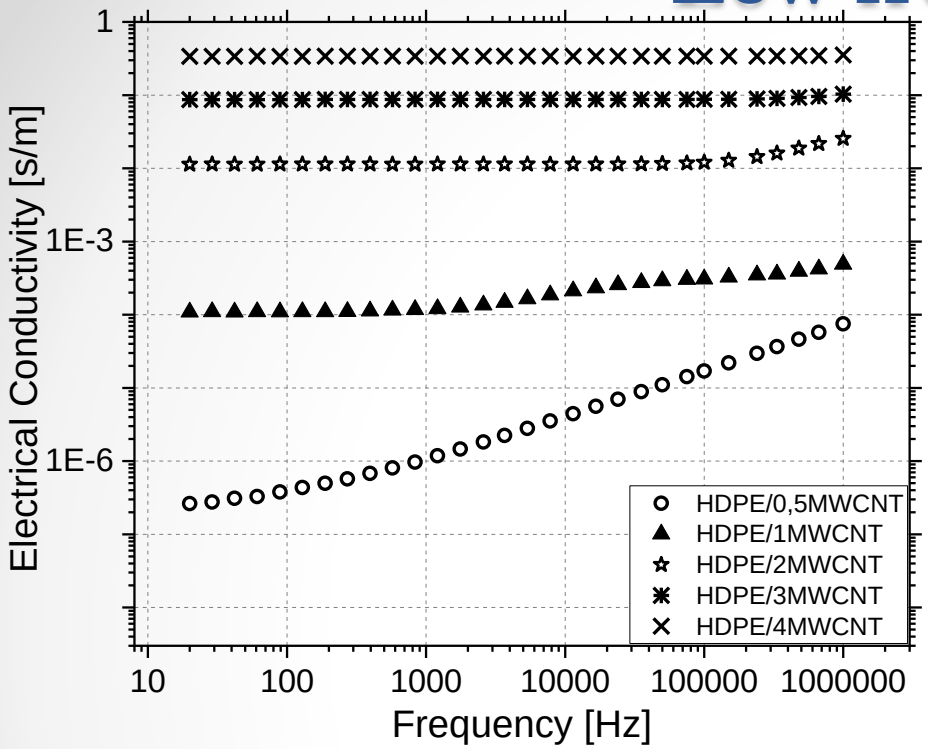
20 Hz – 1 MHz

Not conductive GNP composites



$$\sigma = 2\pi\varepsilon_0 \nu \varepsilon''$$

Low frequency

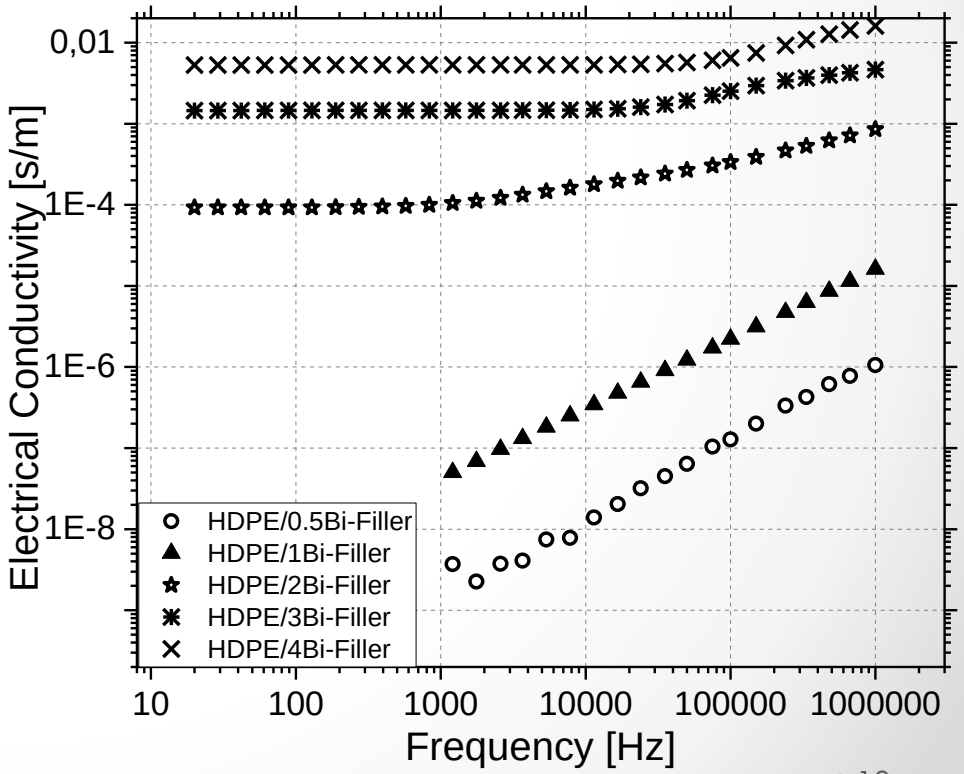


20 Hz – 1 MHz

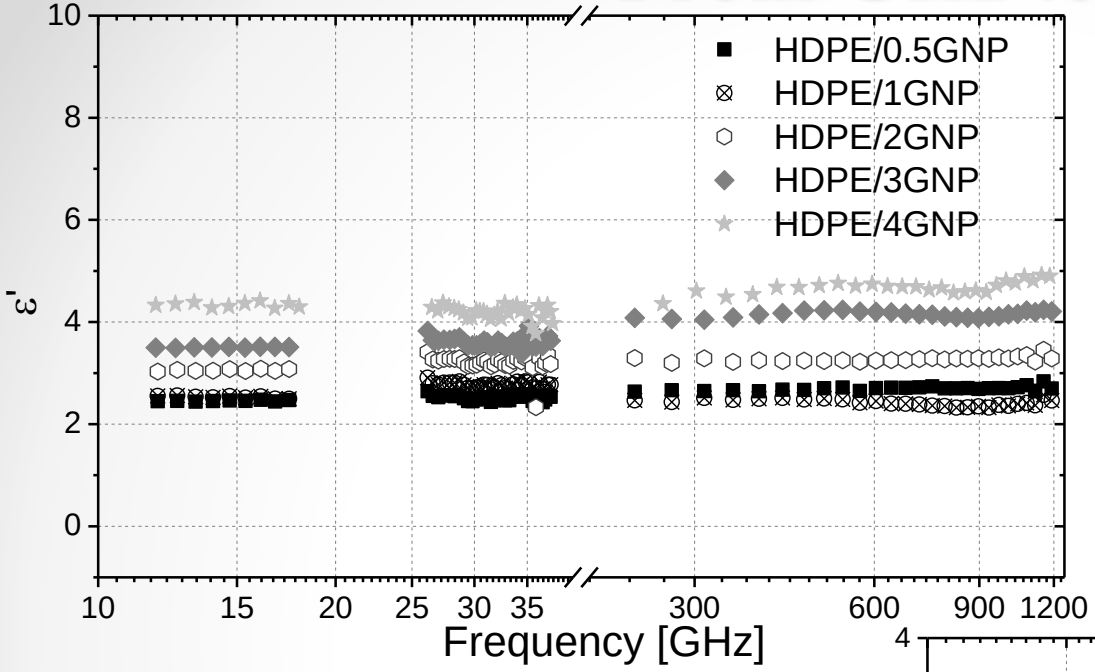
Percolation threshold:

- between 0.5 and 1wt% MWCNT
- 2wt% Bi-Filler

$$\sigma = 2\pi\varepsilon_0\nu\varepsilon''$$



From GHz to THz

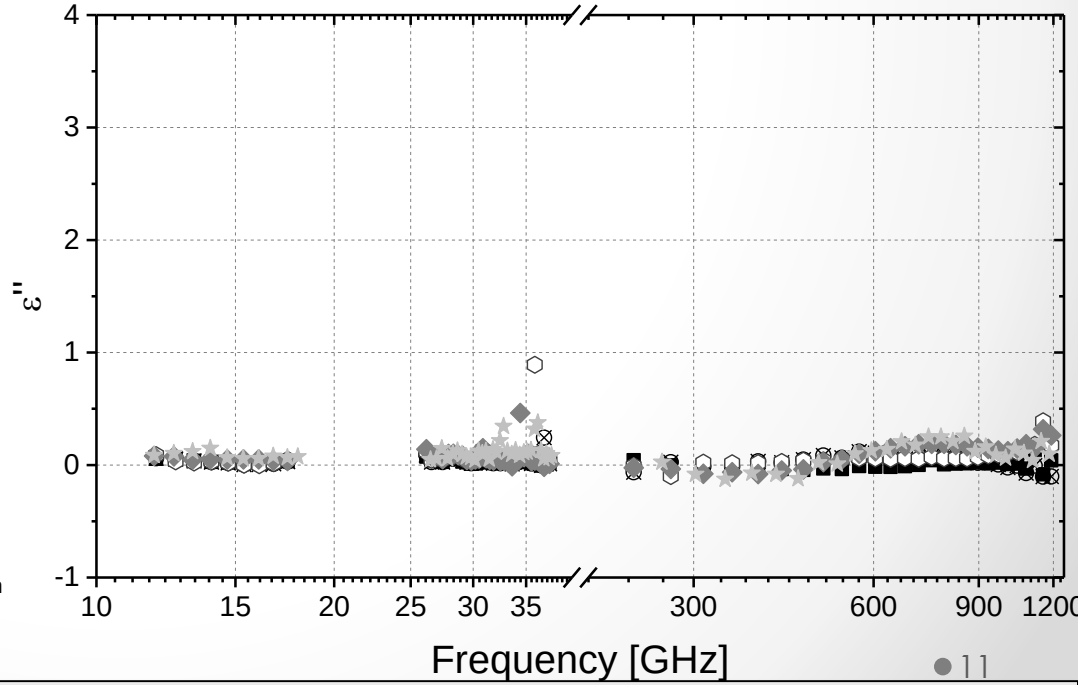


12 – 18 GHz

26 – 37 GHz

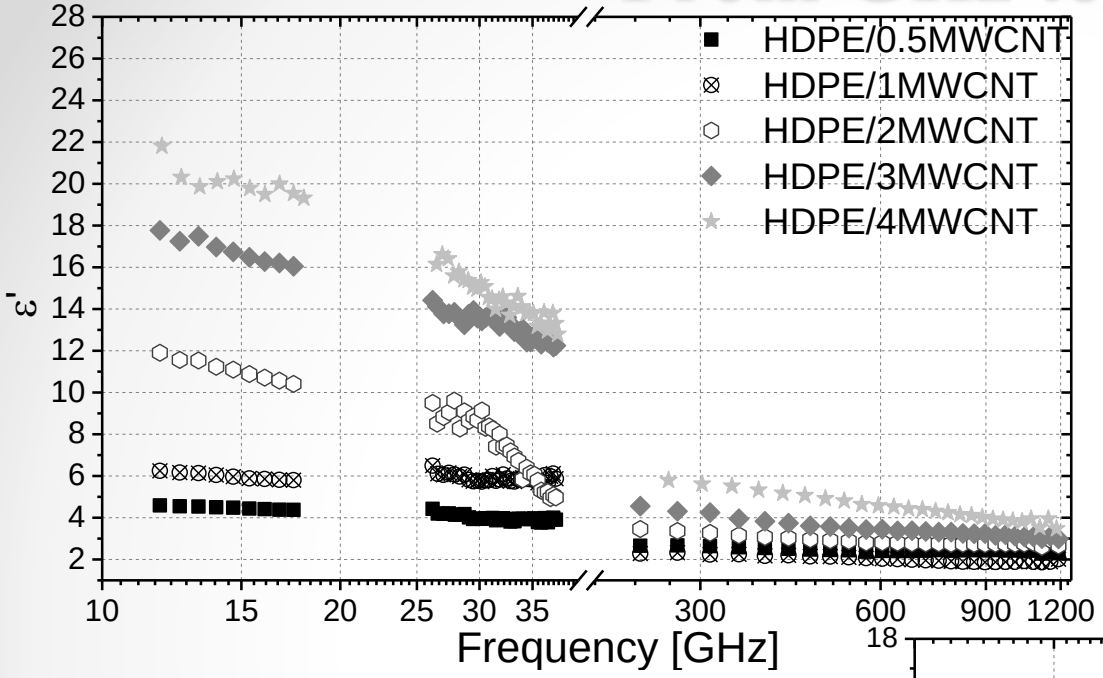
0.2 – 1 THz

Slight effect on the dielectric permittivity



[3] J. Backer-Jarvis, R.G. Geyer, P. D. Domich, en, IEEE Transactions on Instrumentation and Measurement, Oct. 1992, 41, 646-652.

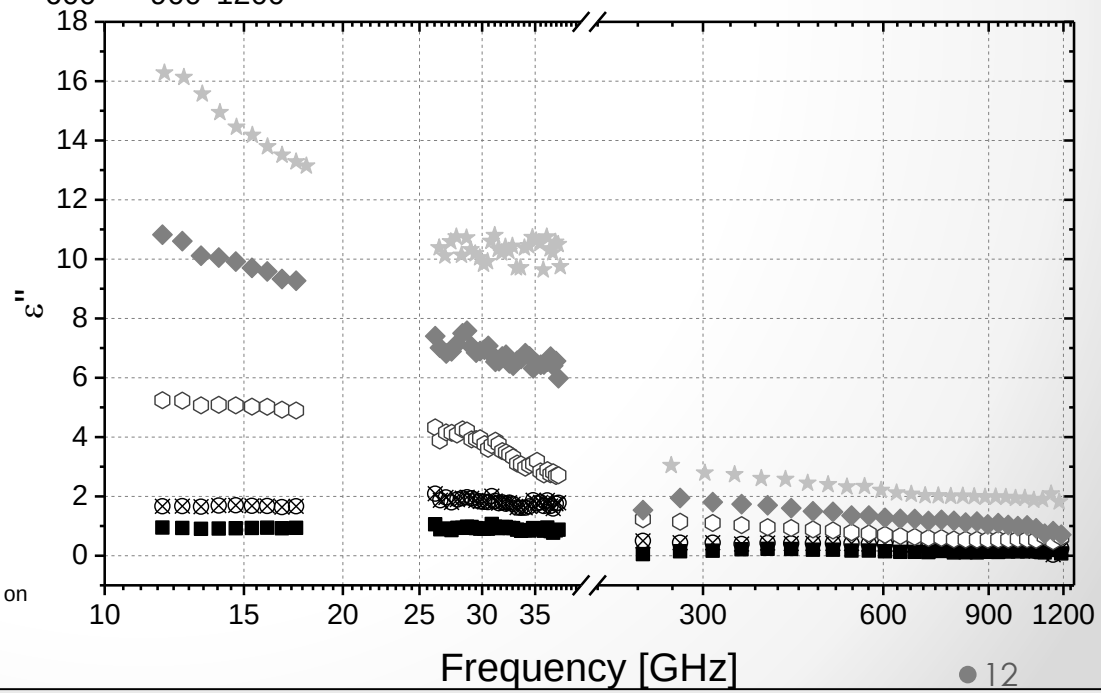
From GHz to THz



12 – 18 GHz

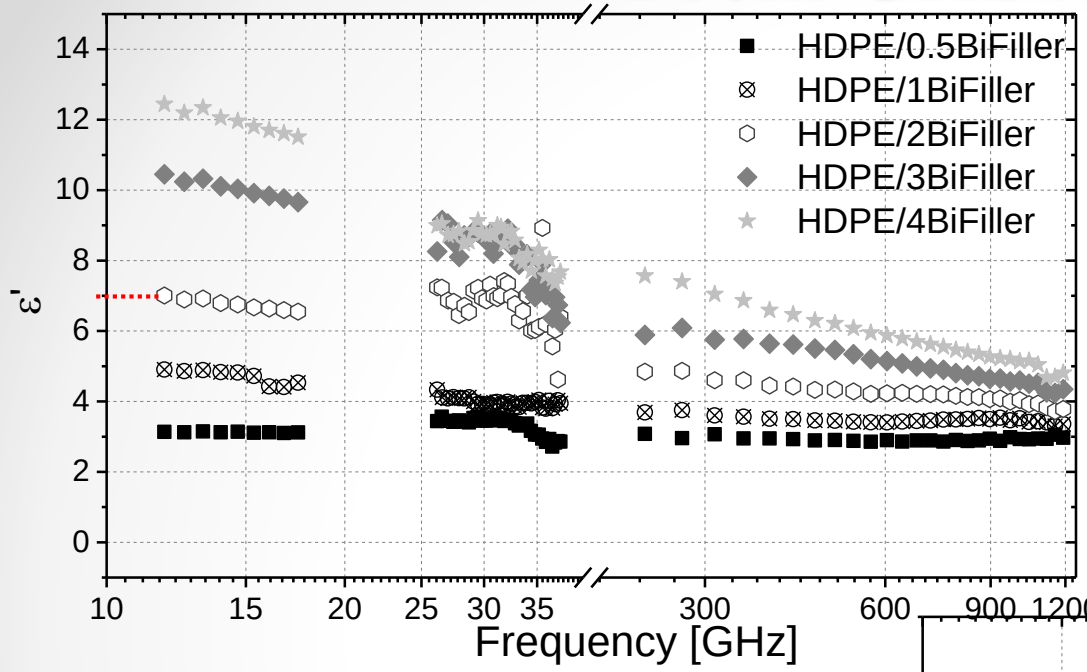
26 – 37 GHz

0.2 – 1 THz



[3] J. Backer-Jarvis, R.G. Geyer, P. D. Domich, en, IEEE Transactions on Instrumentation and Measurement, Oct. 1992, 41, 646-652.

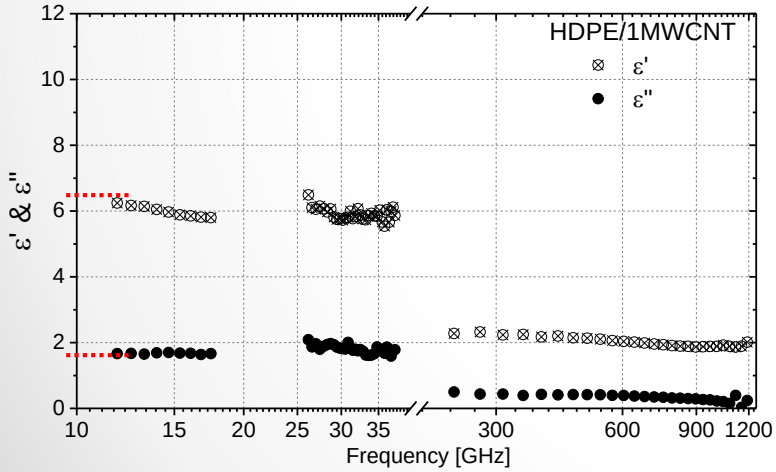
From GHz to THz

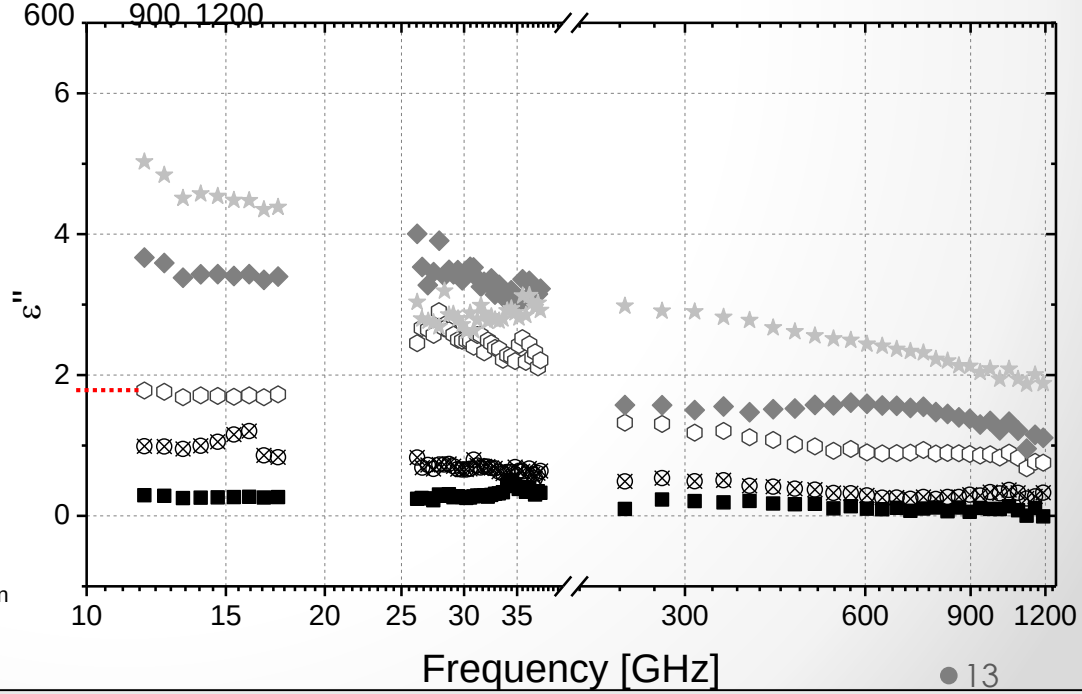


12 – 18 GHz

26 – 37 GHz

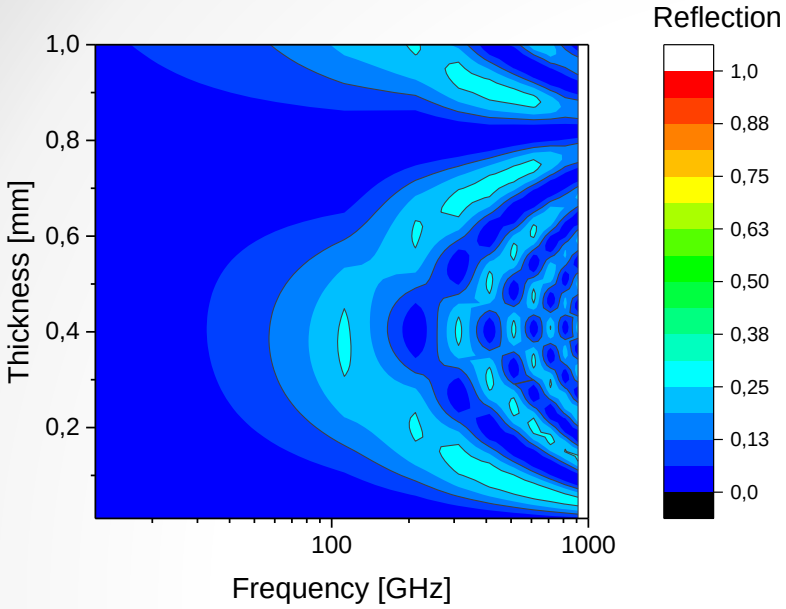
0.2 – 1 THz

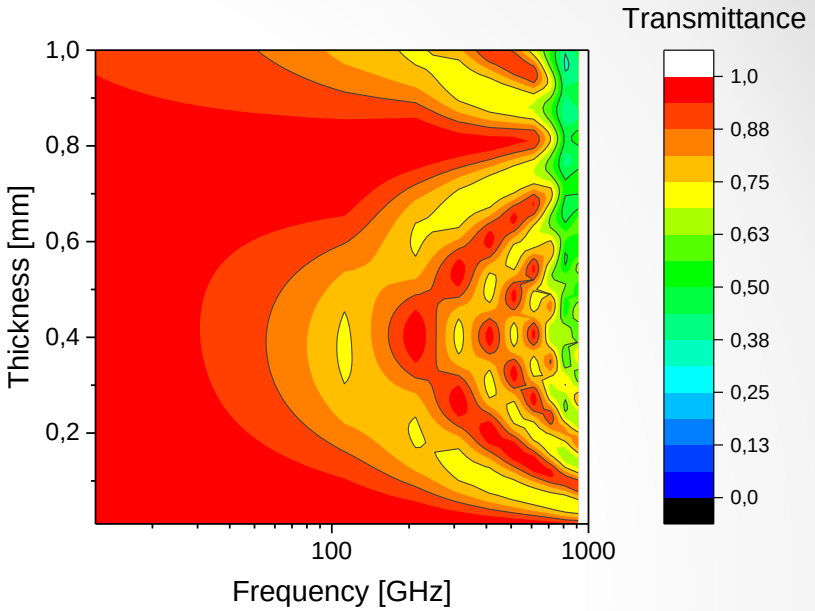


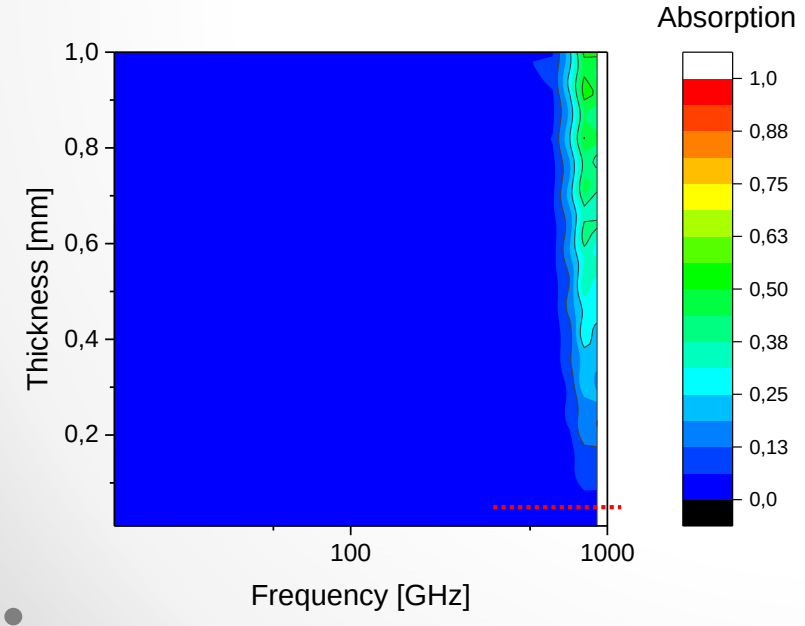


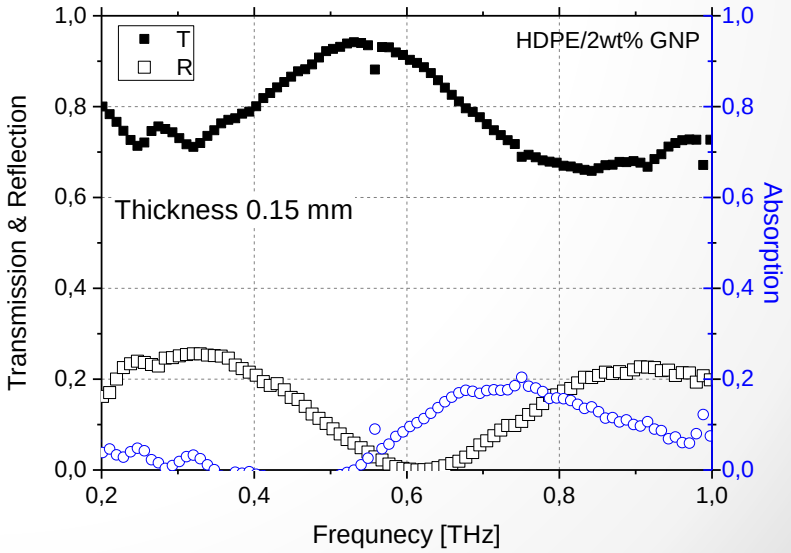
[3] J. Backer-Jarvis, R.G. Geyer, P. D. Domich, en, IEEE Transactions on Instrumentation and Measurement, Oct. 1992, 41, 646-652.

HDPE/2wt%GNP

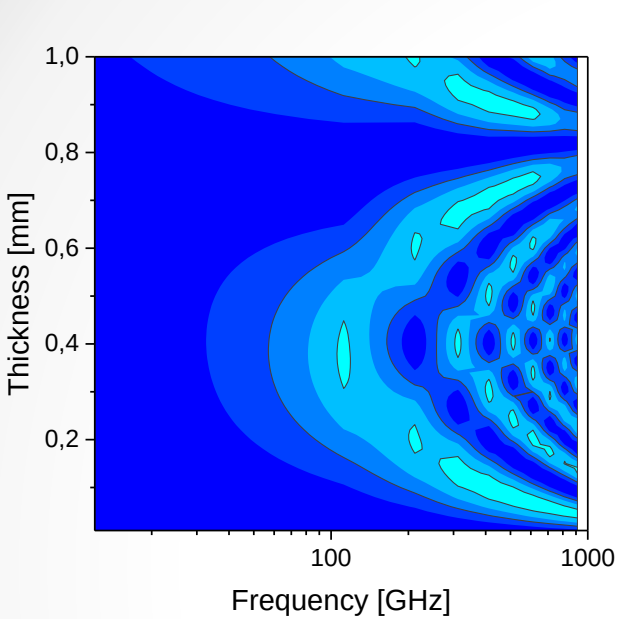

Reflection
Thickness [mm]
Frequency [GHz]
1,0
0,8
0,6
0,4
0,2
100
1000
1,0
0,88
0,75
0,63
0,50
0,38
0,25
0,13
0,0

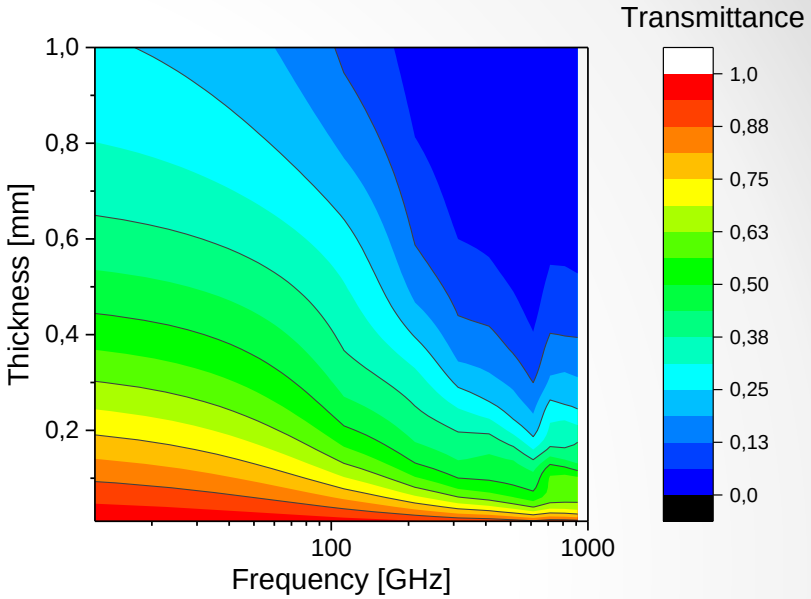

Transmittance
Thickness [mm]
Frequency [GHz]
1,0
0,8
0,6
0,4
0,2
100
1000
1,0
0,88
0,75
0,63
0,50
0,38
0,25
0,13
0,0

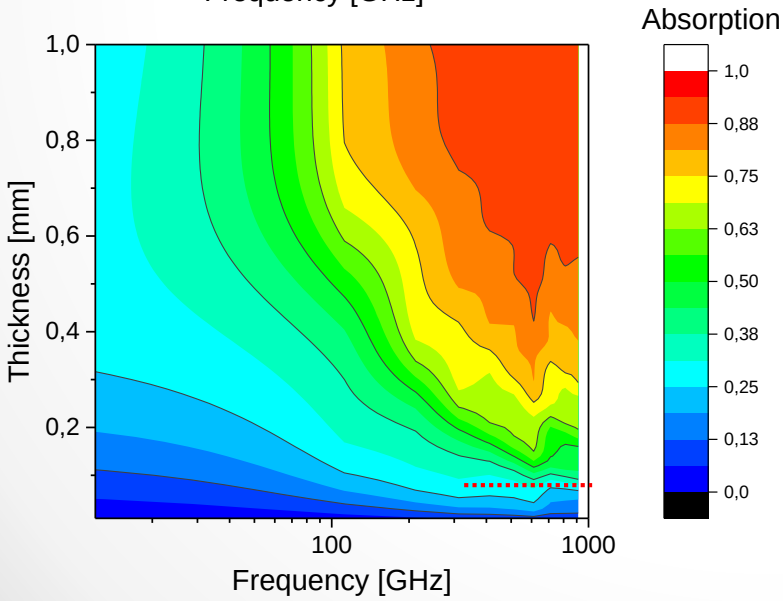

Absorption
Thickness [mm]
Frequency [GHz]
1,0
0,8
0,6
0,4
0,2
100
1000
1,0
0,88
0,75
0,63
0,50
0,38
0,25
0,13
0,0

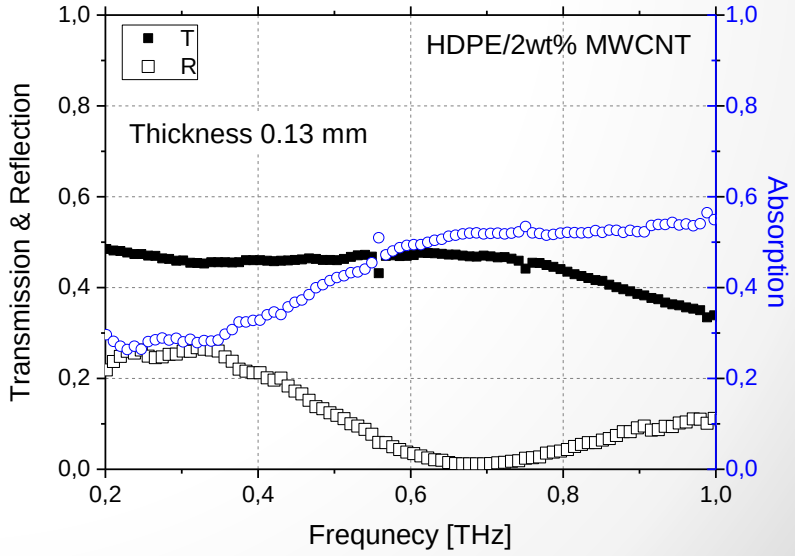

T
R
HDPE/2wt% GNP
Thickness 0.15 mm
Transmission & Reflection
Absorption
Frequnecy [THz]
1,0
0,8
0,6
0,4
0,2
0,0
0,2
0,4
0,6
0,8
1,0

HDPE/2wt%MWCNT

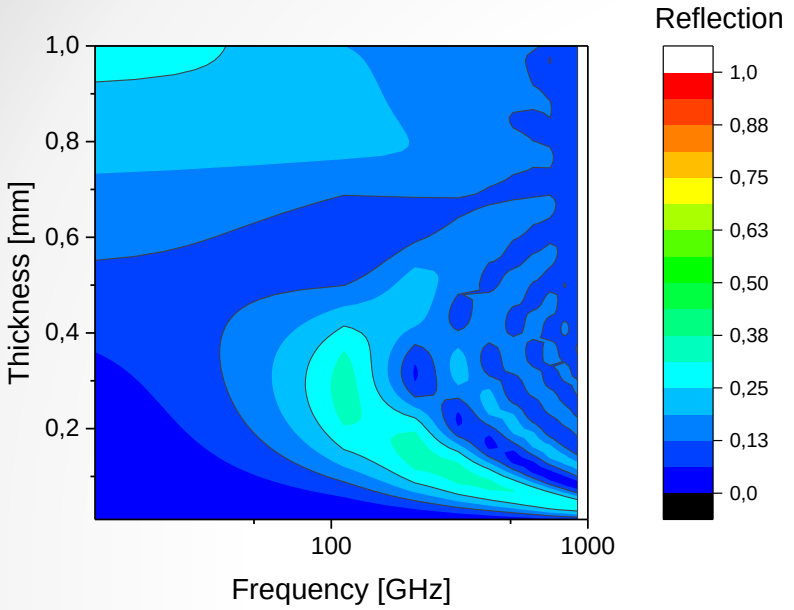


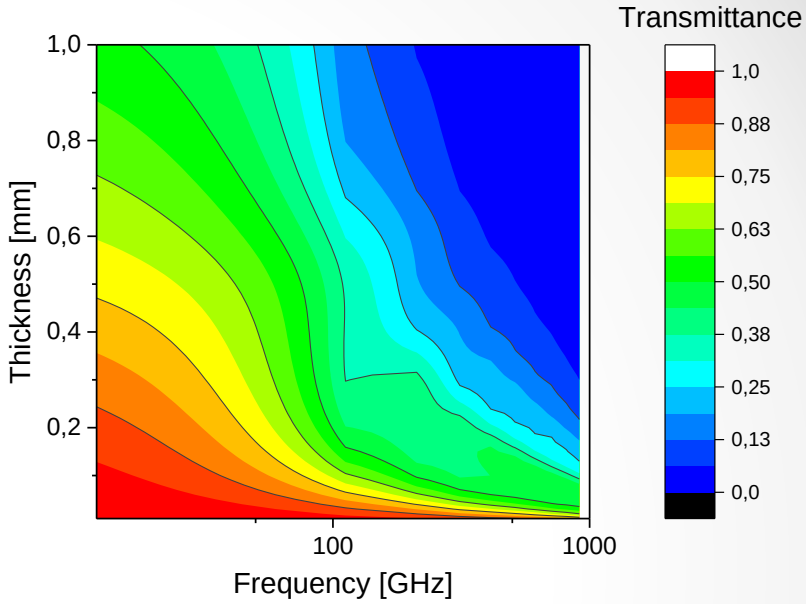


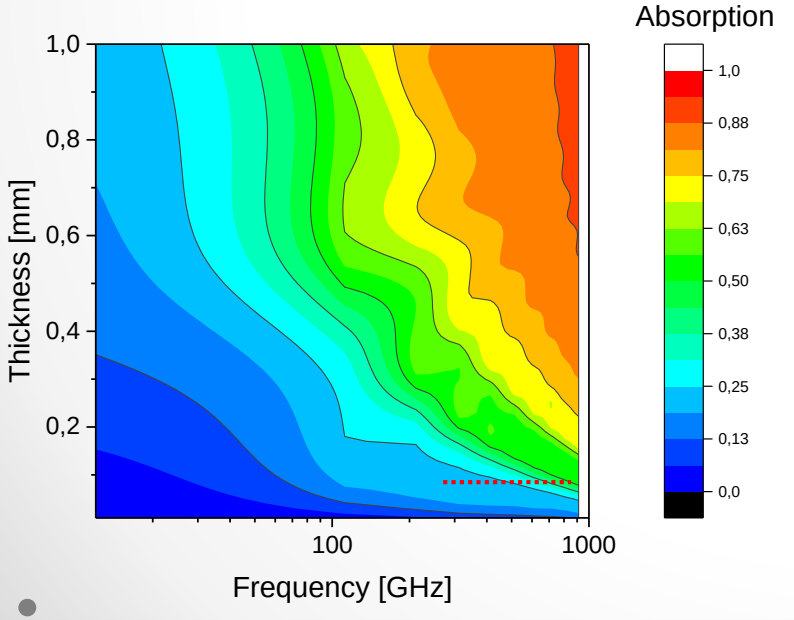


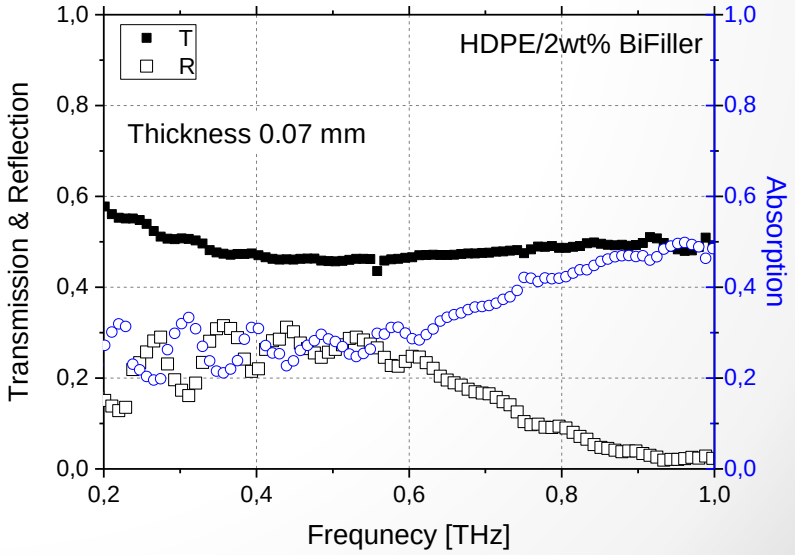


HDPE/2wt%Bi-Filler





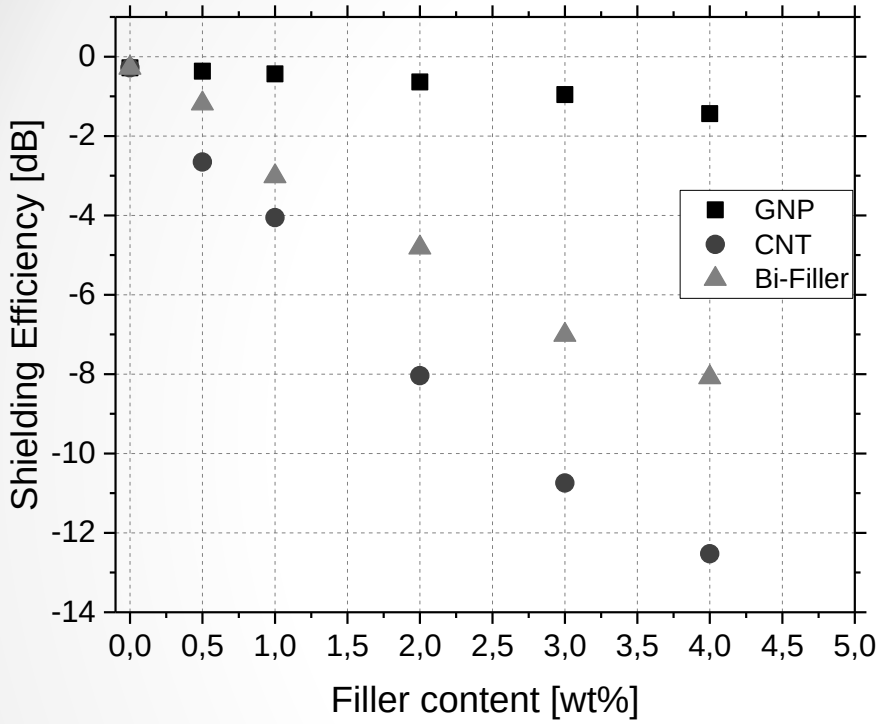




Shielding efficiency and Absorption

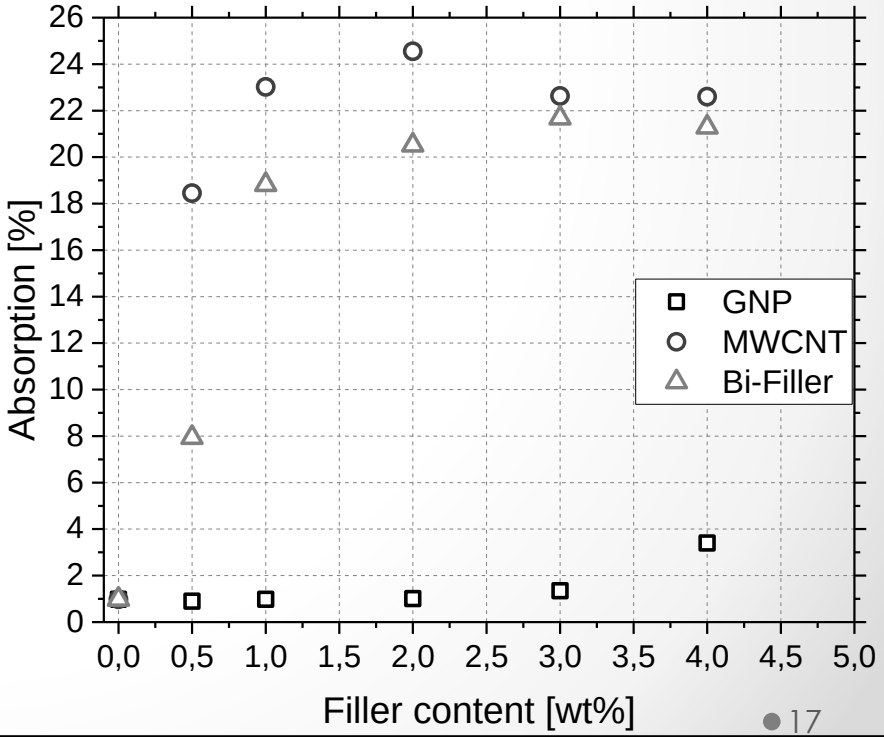
12 - 18 GHz

20Lg(S21lin)



Absorption at **14GHz**

$$A = [1 - T - R] * 100$$



Thickness ~1mm

Conclusion remarks

GNP composites

- Nucleation effect;
- Don't show significant effect on the dielectric permittivity;
- Not conductive;
- No dispersion at high frequency;
- Maximum absorption at 14GHz is ~4%;

MWCNT composites

- An efficient mix of CNTs in the polymer matrix;
- Conductivity percolation threshold between 0.5 and 1wt%;
- High dispersion at high frequency;
- ~90% absorption in THz for 2wt% filler with 1mm thickness;

Ternary composites

- Conductivity percolation threshold ~2wt%;
- ~80% absorption in THz for 2wt% Bi-filler system with 1mm thickness;
- Shielding efficiency for 4%Bi-Filler = 2%MWCNTs;

Acknowledgements: This research was supported by the H2020-MSCA-RISE-2016-734164 Graphene 3D and the H2020-SGA-FET-GRAPHENE-2017-785219 Graphene Core2. First author acknowledges the young scientists project № 17-184/05.09.2017 supported by the Bulgarian Academy of Sciences.