Barium Titanate or Carbon/Polydimethylsiloxane Nano/Micro-composites: Dielectric Response, Functional behavior and Energy Storage

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ABSTRACT

The scientific and technological impact of nanostructured materials is well established and appreciated nowadays, because of the improvement in electrical, thermomechanical properties etc. and the resulting potential for numerous applications. Nanodielectrics is considered as a group of smart materials, which includes polycrystalline semiconducting or insulating materials, with grain diameter at the nanoscale level and polymer composites incorporating nanoinclusions. The dielectric behaviour of elastomer nanocomposites can be tailored by simply controlling the type, size and amount of the nanofiller. In this work polydimethylsiloxane composites reinforced with

(1) microsize barium titanate ($BaTiO_3$),
(2) nanosize barium titanate ($BaTiO_3$),
(3) graphite nanoplatelets (GNP),
(4) carbon black (CB),
(5) multiwalled carbon nanotubes (MWCNTs)

were fabricated and studied, in terms of the type, size and amount of the filler content.

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INTRODUCTION

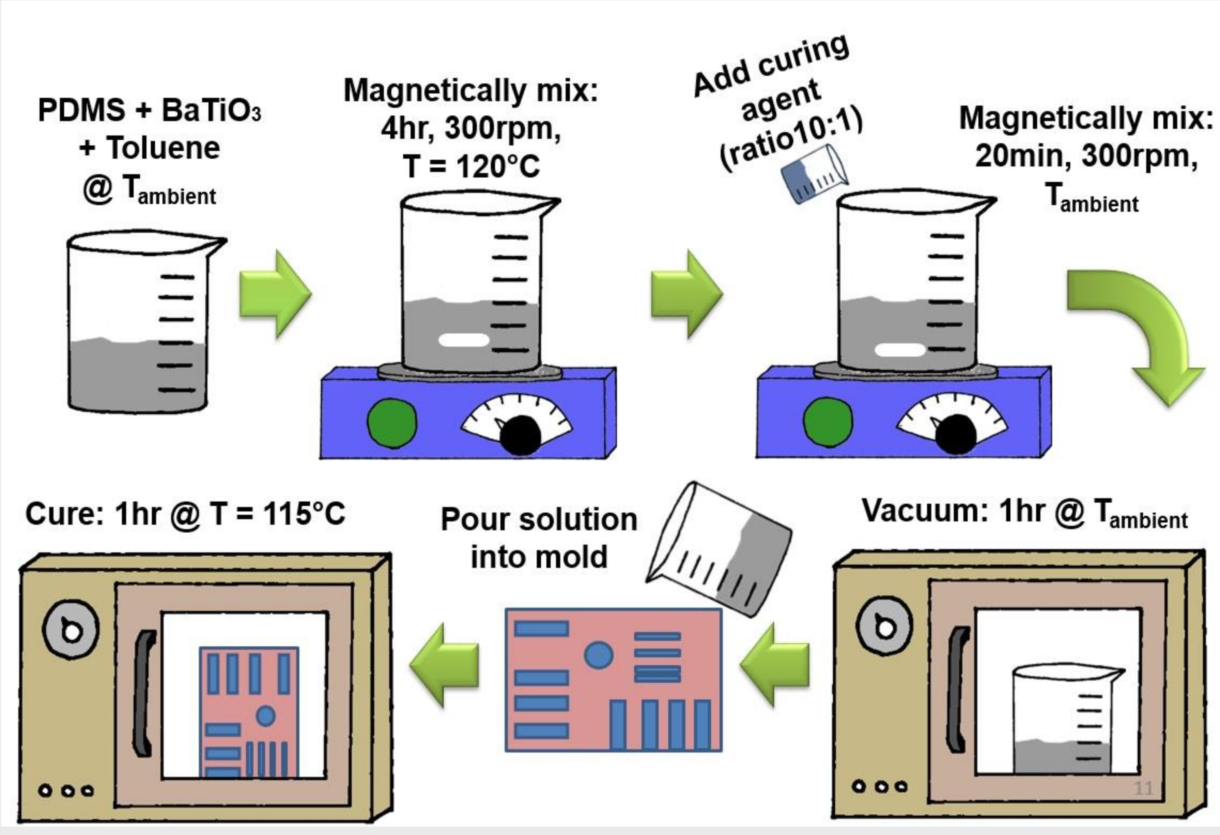
Composites are materials in which the micro/nano-sized dispersed phase in a suitable matrix can enhance some of the existing properties, as well as give rise to new ones. Elastomers micro/nano-composites are of great interest because the addition of filler improves electrical, mechanical and thermal response and can also modify other properties. Polydimethylsiloxane (PDMS) elastomer is an electrorestrictive polymer having excellent electrical, elastic, mechanical and thermal properties [1 -3]. The composites derived from PDMS elastomer can be used in various applications including actuation, sensing, artificial muscles, biocompatibility and microfluidics, exhibiting also good environmental stability. Elastomer matrix composites incorporating both ceramic and carbon nanoinclusions receive enhanced scientific and technological interest, because of their advanced performance.

In this study, various nanoparticles are embedded in an elastomer matrix. The employed fillers are micro- and nano- $BaTiO_3$ particles, graphite nanoplatelets (GNP), nano- carbon black (CB) and multiwalled carbon nanotubes (MWCNTs) for each type of filler a series of composites is prepared varying the ceramic content.

METHODS & MATERIALS

Composite specimens were prepared by employing commercially available materials. In particular, polydimethylsiloxane (PDMS) belongs to a group of polymeric organic silicon compounds that are commonly referred to as silicones. The chemical formula for PDMS is $CH_3[Si(CH_3)_2O]nSi(CH_3)_3$ and was provided by Dow Corning.

Morphological characterization was performed via Scanning Electron Microscopy (SEM),
Dielectric measurements were conducted via Broadband Dielectric Spectroscopy (BDS) in the frequency range from 10^{-1} Hz to 10^6 Hz. Temperature was varied between 30^{o}C and 200^{o}C at steps of 5 ^{o}C.
The preparation procedure is constituted by the following steps:



RESULTS & DISCUSSION

Morphological Characterization: SEM

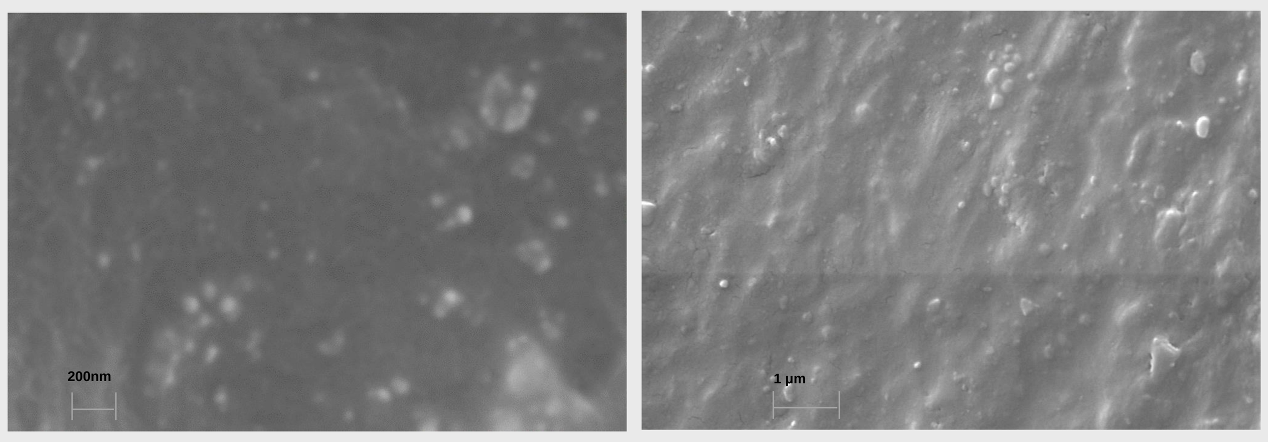


Figure 1. SEM images for the specimens with 1 phr nano $BaTiO_3$ / PDMS.

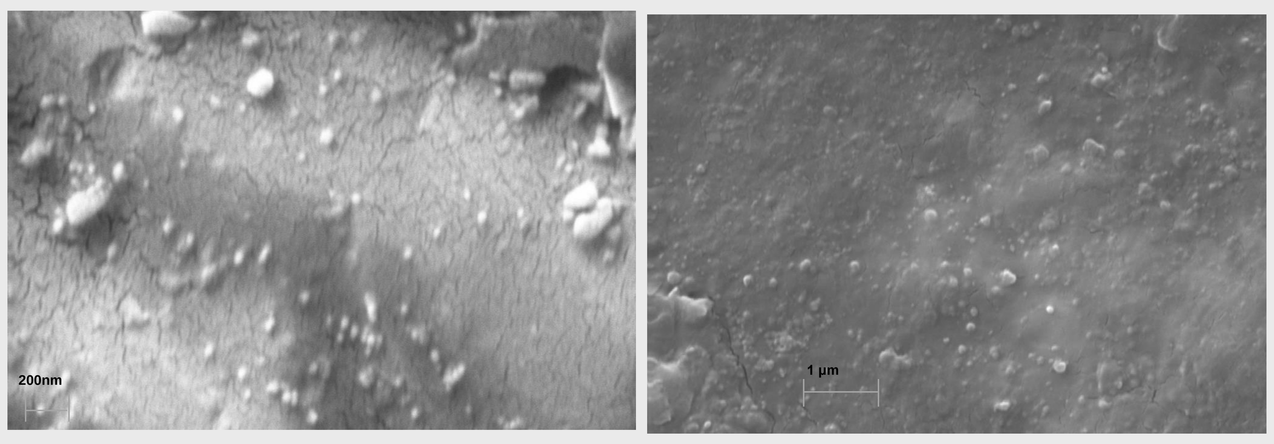


Figure 2. SEM images for the specimens with 1 phr micro $BaTiO_3$ / PDMS.

Dielectric Analysis: BDS

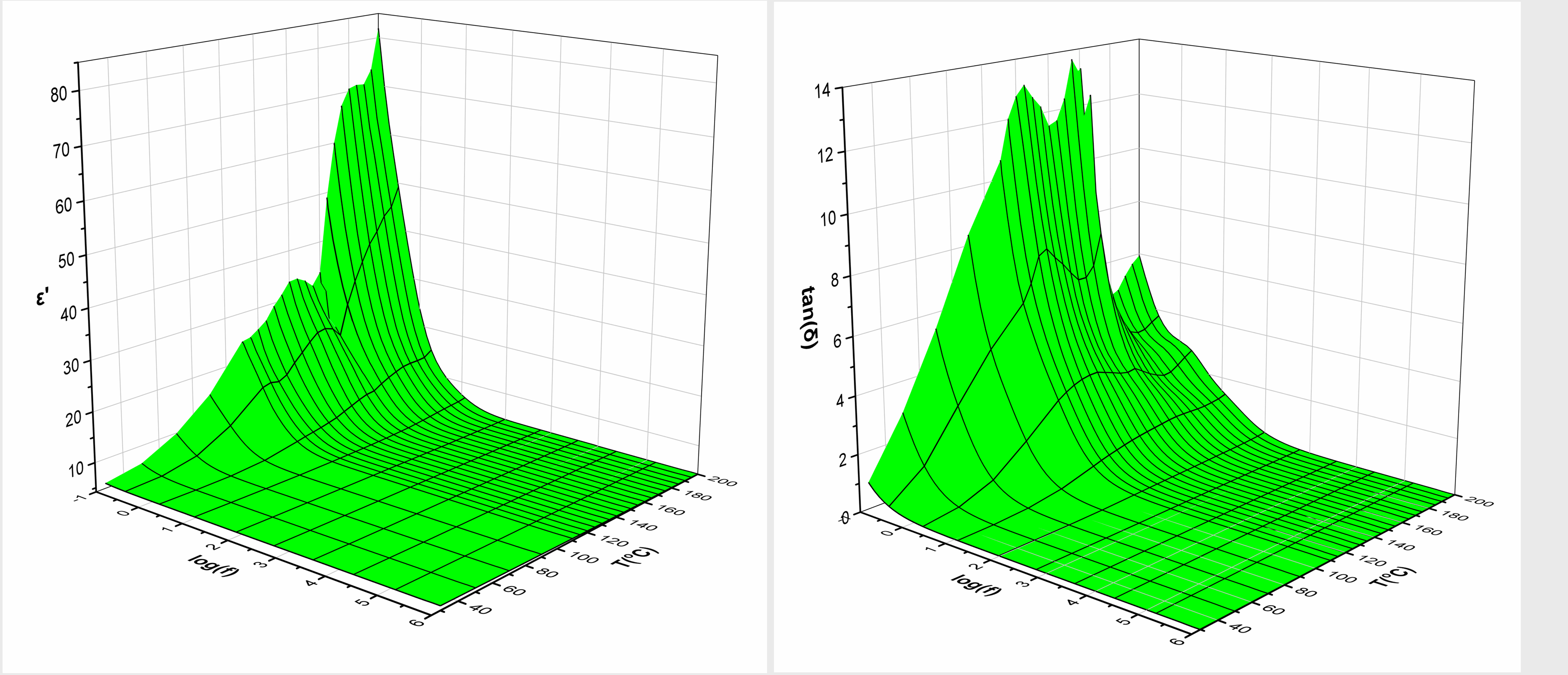


Figure 3. Dielectric spectra of the 1 phr $BaTiO_3$ nanocomposite as a function of temperature and frequency for the (a) real part of dielectric permittivity and (b) loss tangent.

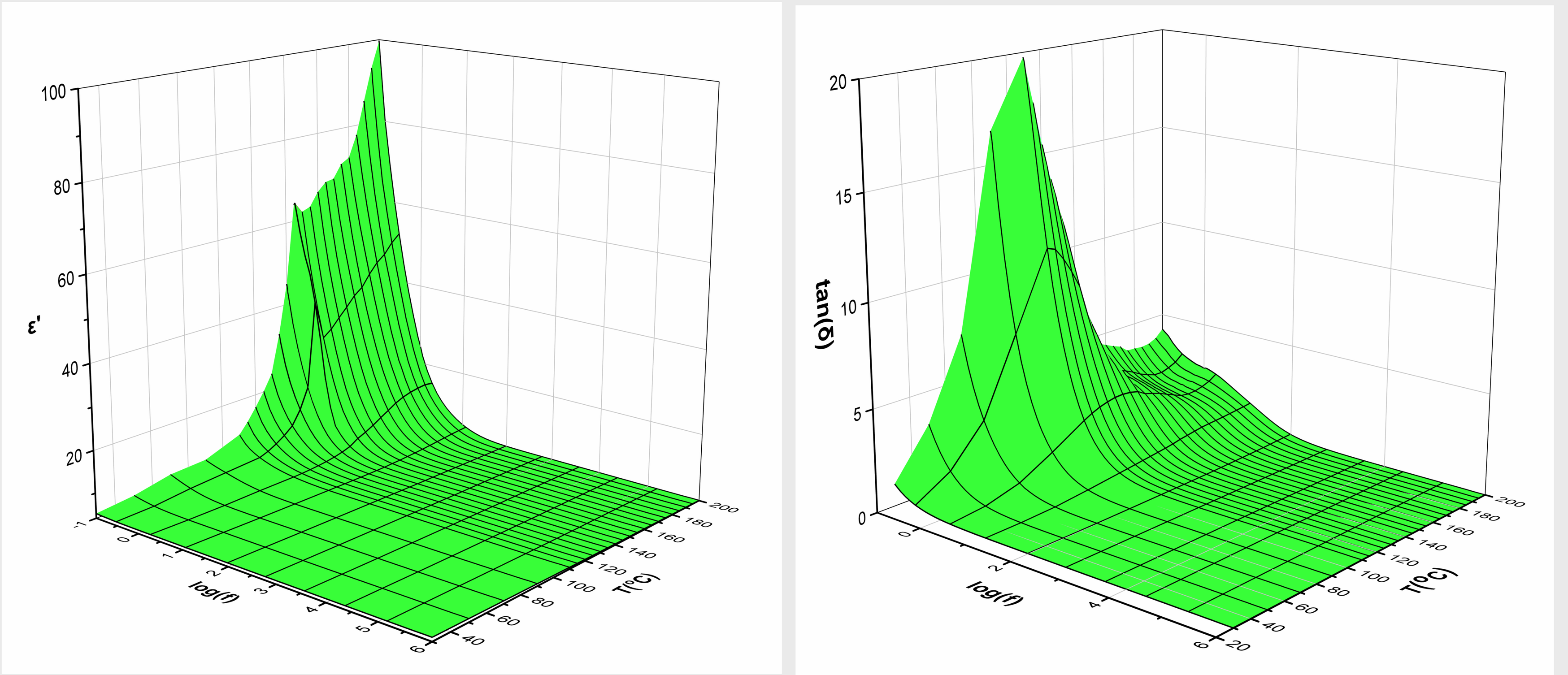


Figure 4. Dielectric spectra of the 1 phr $BaTiO_3$ microcomposite as a function of temperature and frequency for the (a) real part of dielectric permittivity and (b) loss tangent.

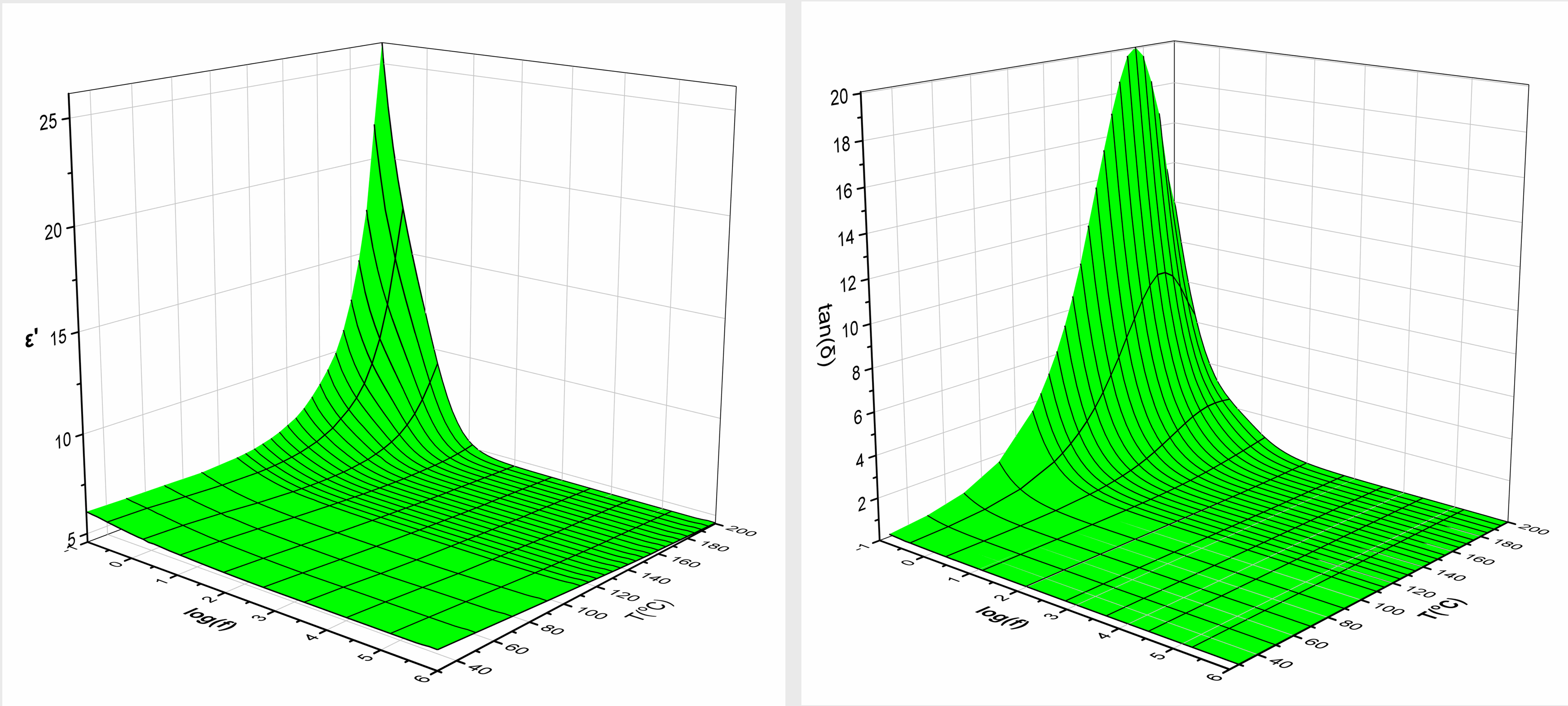


Figure 5. Dielectric spectra of the 1 phr MWCNTS nanocomposite as a function of temperature and frequency for the (a) real part of dielectric permittivity and (b) loss tangent.

$$U = \int E \cdot dD \Rightarrow U = \frac{1}{2}\varepsilon_0 \varepsilon' E^2$$

Energy Density

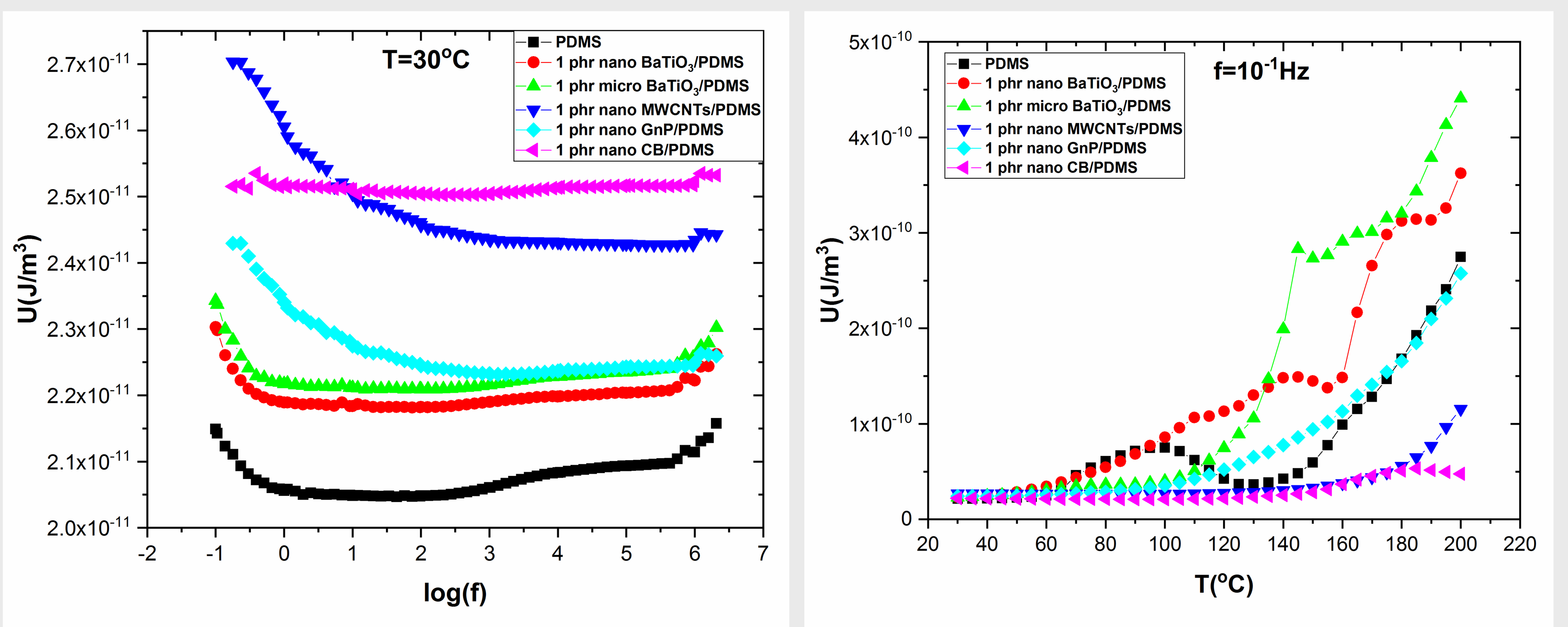


Figure 6. Energy density for all types of fillers a) left as a function of frequency at 30 ^{o}C and b) right as a function of temperature at f=0.1 Hz.

CONCLUSIONS

Dielectric spectra reveal the presence of two relaxation processes arising from the re-orientation of polar side groups of the polymer chains (β-mode) and the interfacial polarization, due to the accumulation of charges at the interfaces between crystalline, amorphous regions and filler. Moreover it is evident that ε' acquires higher values as the filler content and temperature increase. Finally energy density exhibit similar behaviour with ε'.

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