RIGA TECHNICAL UNIVERSITY

August 9-12, 2010
Riga, LATVIA

inter-academia

The 9th International Conference on Global Research and Education

Inter-Academia 2010

DIGEST

Prospective polymer/nanostructured carbon composites for application in multifunctional sensors

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Summary
Recent achievements of our scientific group in design, processing and investigation of polymer-nanostructured carbon composites (PNCC) as prospective materials for non-rigid mechanical (pressure, strain) indicators, chemical vapour indicators, humidity sensors and polymeric thermistors have been presented. Complex "conductive AFM" (Fig.1), SEM, FTIR ATR, dielectric spectroscopy measurements as well as mechano-electrical, chemo-electrical, thermo-mechanical and thermo-electrical properties were studied to understand the mechanisms of the multifunctional sensing and to improve the sensing parameters.

Introduction
Non-rigid multifunctional sensing materials attract attention of scientists and engineers because of potential possibility to incorporate them in different solid and nonsolid systems for specific parameter control [1, 2]. Our early works [2] proved that polymer composites filled with highly structured carbon black (HSCB) (mean diameter of primary particles 30 nm) show brilliant strain sensing properties. The uncommon fact that electrical resistance of certain polyisoprene/HSCB composites rises reversibly by whatever deformation (tension, compression, bend or shear) has been observed. This has been used to elaborate composite material for organic solvent vapour (OSV) sensors which function due to the swelling of polymer matrix in OSV and simultaneous electrical resistance change. The general aim of our scientific group is to optimize the sensing properties of previously elaborated PNCC as well as to develop new advanced non-rigid composites for multifunctional sensing.

The concept of the design
Experience with electro-active materials like ferroelectrics suggests that maximum sensitivity of material to any influence is observed in the vicinity of phase transitions. The percolation transition in PNCC could be imagined as specific phase transition from electrically insulating state to electrically conductive state. Thus, the maximum sensitivity of PNCC materials to external thermodynamic forces (ETF) should be expected near the percolation threshold of electric conductivity. The reversibility of material reaction to ETF should be achieved by positioning highly structured carbon nanoparticles in the grid by curing hyper-elastic polymer matrix.

Results and discussion
To implement the general aim different dispersion methods of nanostructured carbon(NC) were developed and tested: roll mixing,

chloroform solution mechanical mixing and chloroform dispersion mixing with ultrasound (US). NC such as "Degussa Printex XE2" HSCB as well as Multi Wall Carbon Nanotubes (MWCNT) "Aldrich 636835" was used as filler. The obtained raw rubber preparations were vulcanized under pressure using hot steel mould.

A lot of interesting effects have been found.

1. The electrical conductivity of PNCC rises with vulcanization time that means the conductive carbon nanoparticle channel (Fig. 1) grid in PNCC forms just during vulcanization phase. By means of SEM, dielectric spectroscopy and FTIR ATR investigations four processes that affect the formation of percolation structure of HSCB in PNCC during vulcanization phase have been stated.

2. The PNCC prepared by chloroform dispersion mixing with ultrasound showed noticeably lower value of percolation threshold. The optimum vulcanization parameters (temperature, pressure and time) for strain indicators as well as for organic solvent vapours indicators were found.

3. Positive piezoresistance effect for PNCC with "Degussa Printex XE2" has been found. Both positive and negative piezoresistance effect was found for PNCC with MWCNT.

4. Operational all-hyperelastic PNCC pressure indicator (without any rigid elements) has been made.

5. Repeatable electrical resistance change of PNCC in ambience of different organic solvent vapours has been shown.

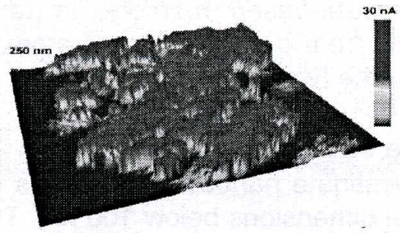

Fig. 1. Map of electroconductive carbon channel section (red color) on the surface of polyisoprene/higly structrued carbon nanoparticle composite obtained by "conductive AFM". 10 phr of Printex XE2. Relaxed state. T = 294K. Scale (250 nm x 250 nm)

Conclusion

PNCC with concentration of NC slightly above percolation threshold demonstrates prospective multifunctional sensing properties.

Acknowledgements

Author is thankful for collaboration in implementation of the concept to V.Teteris, J.Zavickis, G.Sakale, K.Ozols, V.Tupureina, J.Zicans, B.Polyakovs and R.Orlovs.

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