Enhanced actuation strain of PDMS based loudspeaker membrane by using core-shell structured CNT-SiO_2 nano-inclusions

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Abstract:
Dielectric elastomers (DEs) are flexible active materials capable of large deformations when activated by high voltage. They consist of a thin elastomeric membrane covered on each side by flexible and stretchable soft electrodes. When a high voltage (~1kV) is applied, the membrane is compressed and its surface area increases by up to 100% [1]. Because of this strong electromechanical conversion, associated to their high energy density, lightness and ability to work over a broad frequency range, they are considered as promising materials in different mechatronic applications[2], such as soft robotics[3] or fluidic pumps[4] and energy harvesting systems[5] just to name a few. On this regard, DEs have been considered also as promising materials for acoustic applications, such as loudspeakers [6]. Several prototypes have been developed and tested by several research groups, and models have been proposed to estimate their performance [7,8].

Previous studies described the electro-elastoacoustic interactions occurring in a DE membrane with the help of an electromechanical model solved numerically using finite elements. The frequency response was well predicted in a broad frequency range. Moreover, the relation between the electrode shape and the dynamical and acoustical behavior of membranes was described for the first time with the perspective to control selectively the contribution of eigenmodes to the radiated sound [9].

Although several progresses have been made in the field in these recent years, still a high actuating electric field (~10V/μm) is needed to induce large mechanical deformation of DEs, thus limiting their practical applications[10]. The major challenge in this field is to achieve a high actuation stress under a low applied electric field. A new approach based on the use of polymers loaded with conductive nano-inclusions is the subject of growing interest in scientific research. Indeed, the presence of nanoparticles leads to an increase in the dielectric constant of the material, altering their electrostriction coefficient, which is linked to the actuation deformation of the composite according to the Maxwell stress equation.

DE nanocomposites, are generally made up of random dispersions of particles without any structural optimization. In this study, we propose to manufacture and formulate isotropic self-assembled networks of core-shell nano-inclusions composed of conductive carbon nanotubes (CNT) coated by a few nanometers of SiO_2 passivation layer uniformly dispersed in flexible polymer elastic matrix (PDMS) without compromising breakdown strength (E_b) and elasticity (Y) of membrane assuring high actuation strain under a low driving electric field.

According to Maxwell stress equation $S_{Maxwell}=\varepsilon_0\beta E^2$, with $\beta= \varepsilon_r Y$ a substantial increase of the electromechanical sensitivity (β) obtained by a slight improvement of the

dielectric constant of DEs nanocomposite keeping a reasonable elastic modulus represents a safe and reliable solution to reduce the driving electric field of dielectric elastomer loudspeakers. The improvement of the electromechanical couplings in these novel elastomeric dielectric nanocomposites, following the optimizations electrodes shaping studied by Garnel *et al.* will be validated by the integration of these membranes in loudspeakers prototypes. Based on actual measurements of the tensile-dielectric properties of nanofabricated nanocomposites, we aim for improvements beyond the state of the art by obtaining high actuation stress at halved applied electric field.

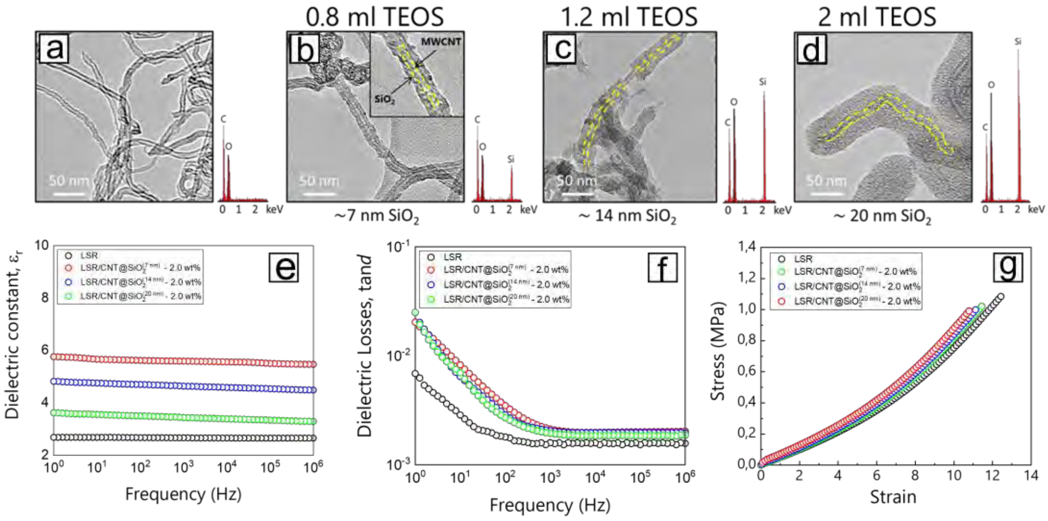

Fig. 1 – TEM/EDS images of the CNT-SiO2 prepared by sol-gel method: (a) Pristine carbon nanotubes, (b) 7 nm of SiO_2 passivation shell, (c) 14 nm of SiO_2 passivation shell, (b) 20 nm of SiO_2 passivation shell. Dielectric-tensile properties of nanofabricated nanocomposites: (e) frequency dependence of dielectric constant, (f) frequency dependence of dielectric losses and (g) Tensile stress-strain curves of the nanofabricated nanocomposites.

Keywords: Dielectric elastomers (DEs), Loudspeakers, Core-Shell nanocomposites, electromechanical sensitivity, Dielectric properties.

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