Fabrication of functionally graded ceramic- polymer dielectrics via freeze casting for RF applications

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Most of traditional antenna design approaches rely on surface metallization and use of homogeneous material layers where antenna performance is improved through design of metallic surfaces of the antenna only. In order to achieve a well performing antenna design that is both conformable and small in size, in addition to the full design freedom offered by topology optimization studies, the capability to fabricate resulting novel material designs varying in three dimensions made of high dielectric, low loss and conformable dielectric constituents plays an important role. One approach towards delivering conformability while controlling the variation of permittivity would be to adjust the micro porosity of a polymer-ceramic material substrate. This well-known concept of porosity controlled permittivity has been applied to producing full dense ceramics with desired permittivity in the past. Freeze casting is a well-known method in the materials science community that allows creation of micro channels in ceramic-polymer composites by freezing water molecules inside of the structure and then evaporating them suddenly. The freezing temperature and freezing duration are the known two factors controlling the porosity distribution of the ceramic substrate which in its standard form is succeeded with a sintering process where the polymer constituent is ultimately eliminated. It is important that the freezing process is conducted under a controlled framework to allow for a fully sintered dense ceramic substrate. Motivated by these findings, it is shown for the first time in this study, that this process can be used to create locally controlled pores in various sizes and orientations in an intact dielectric substrate that is deformable. Made with aqueous based polymer-ceramic slurries by controlling the freezing temperature of each material grid dictated by a mosaic antenna substrate design, it holds the potential of locally controlling the permittivity at the desired locations of the design and allows the fabrication of functionally graded material substrates for novel RF applications. To demonstrate the feasibility of this new process, a cooling device is designed and fabricated for functionally graded material substrates to control porosity, hence to deliver a spatially varying dielectric constant. More specifically, in order to control the temperature variation of a dielectric substrate within a freeze casting process of a single substrate layer, a PD controlled cooling device is designed and produced. With the help of this device, cooling temperature value and hence porosity in two dimensions of the dielectric substrate is easily adjustable to the desired point. Furthermore, it is possible to control the cooling down time for the freeze casting process. The cooler device will employ -as a proof of concept- two different heat sinks and, therefore, allows for the cooling down process of the antenna substrate to two different temperature values concurrently. With the help of this technique, it is aimed to deliver mainly two different dielectric properties within the same substrate. The same concept, however, can be adapted to a multi-gridded device with the help of multiple cooling heat sinks. Therefore, the resulting final substrate represents a functionally graded material and has the potential to be adopted for various antenna applications with possibly smaller multi-material gridded architecture in the future.