STUDY OF THE NONLINEAR PHENOMENA IN CERAMIC DIELECTRIC COMPOSITE USED IN COMPACT PFLs

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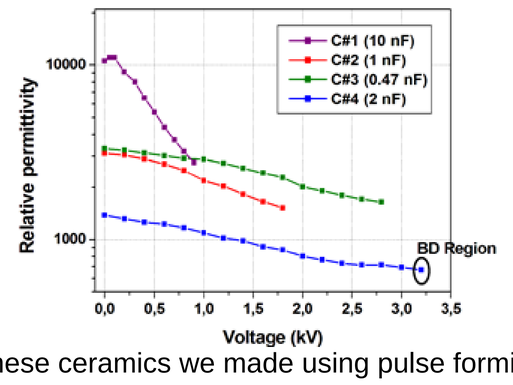
I. INTRODUCTION

There is a growing interest in the development of dielectric materials of high voltage breakdown strength used in compact pulse forming lines (PFLs) to drive high power microwave (HPM) sources and pulsed lasers. Therefore, much attention has been paid to polymer-ceramic composites, where normally the ceramic powders with high dielectric constant are dispersed in a polymer matrix of high breakdown strength (BDS). Therefore, we have tested composite samples made of barium titanate (BT) as the ceramic powder and epoxy or polymethyl-methacrylate (PMMA) as the matrix polymer. Because of the polymer mixture, we have measured higher BDS compared to the pure ceramics of the order of 2.55 MV/cm for the epoxy-barium titanate composite (with ε= 40) and 420 kV/cm for the PMMA-barium titanate composite (with ε=25). However, as pointed by [1] the use of barium titanate in the PFL dielectric can distort the pulse waveform generated on the load as BT is highly nonlinear, i.e. not leading to a rectangular output pulse as desired. To circumvent that this paper addresses this issue by proposing the manufacturing of the polymer-ceramic composite based on PZT (lead-zirconium-titanate) ceramics of weak nonlinearity for use in PFLs.

II. BT AND PZT CERAMICS

- Generally, barium titanate is used as the main component in high voltage ceramic capacitors because of their its high breakdown strength. However, this material is highly nonlinear and dopants are required in the composition of ceramic capacitors, where stability of capacitance with voltage is required in linear applications. Normally, ceramic capacitors of higher capacitance C above 2 nF are highly nonlinear (NL) and have strong nonlinearity as shown by C#1. For capacitors of C less than 1 nF, their nonlinearity because of the dopants used in the capacitor composition. The weak nonlinearity behavior is illustrated by C#3.

- PZTs are piezoelectric ceramics used as sensors in industrial applications. Like ceramic capacitors of low capacitance, they have weak NL as shown by C#4 independent on their value of capacitance. For our applications for operation as ceramic capacitors in our tests, PZT ceramics were de-poled during the fabrication process.

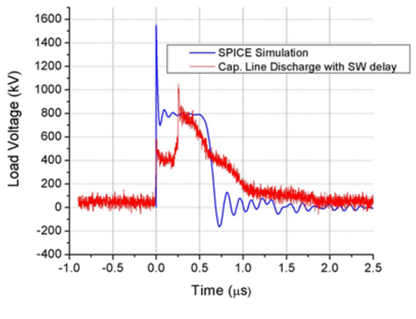


- NL testing of these ceramics we made using pulse forming networks (PFNs):

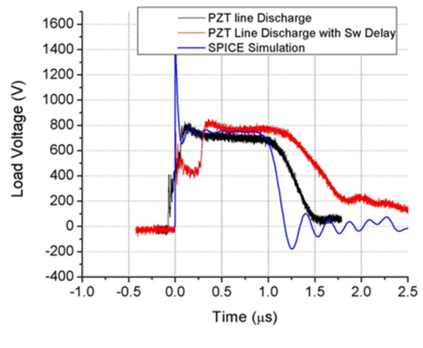
BT Capacitor PFN in air

PZT PFN immersed in oil

L=1 µH, C=1 nF, 10 sections



L=1 µH, C=3 nF, 10 sections

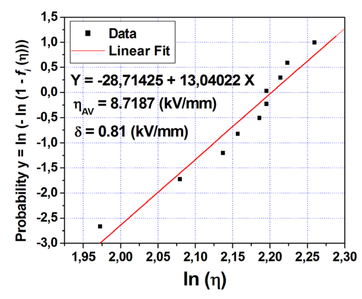


- From the NL testing, we can see that the BT ceramics used in the composition of ceramic capacitors has strong NL while as PZT ceramics present weak NL. Thus, BT is useful for nonlinear applications as for instance to generate RF and to achieve pulse sharpening using nonlinear transmission lines (NLTLs). On the other hand, PZT is suitable for working in linear applications for generating rectangular flat pulses from pulse forming lines (PFLs).

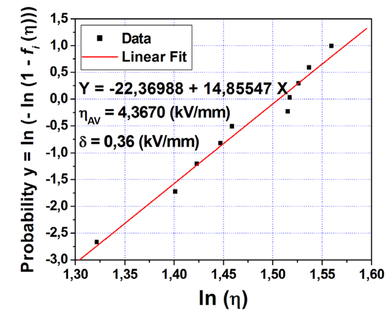
- Another important characteristic of BT and PZT ceramics is their high breakdown (BD) voltage since the energy stored in dielectrics is proportional to the square of the voltage applied ($W = \varepsilon_0 \varepsilon E^2/2$).

- Weibull (WB) plots below show that the BD strength of the BT (87 KV/cm) is approximately the double of the PZT (43 kV/cm).

BT-WB Plot



PZT-WB Plot



III. POLYMER-CERAMIC COMPOSITES

- The idea of using a ceramic-polymer composite is to increase the BD strength of the ceramic by means of a mixture of the ceramic in powder dispersed into the polymer matrix.

- Although ε obtained for the composite is very low compared to the pure ceramics (tens versus thousands), the increase of the BD strength still gives a high gain for the stored energy because of its dependence with the square of the applied voltage.

Epoxy/BT sample composite

PMMA/BT sample composite

- BD tests using WB plots proved that epoxy was more effective than PPMMA for the sintering process of the composite as the BD strength obtained for the former was of about 2.55 MV/cm whereas for the latter was only 0.420 MV/cm.

IV. DISCUSSION

- Polymer-ceramic composite has been developed for use in high-energy storage systems because of their high BD strength(BDS). Other reason is they still have a high ε of tens compared to a pure polymer (2 to 3). The combination of ε and BDS of the composites makes them ideal for use in compact storage systems as for instance in PFLs.

- However, in linear applications as in rectangular pulse generation, the use of the BT for making the composite dielectric of the compact PFL has revealed to be unsuitable because of the pulse deformation at the line output due to the BT strong nonlinearity.

- In the literature is reported the use of a polymer composite based on strontium titanate (SrTiO3) for PFL applications as this type of ceramics presents on the contrary weak nonlinearity.

- Another important contribution of this work is to propose a new a polymer composite using in its composition the PZT ceramic of weak nonlinearity for compact PFL applications. The challenge will be the material sintering process for its dispersion into the plastic matrix of epoxy, which is more suitable polymer to achieve a higher BD strength.

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