Journal of Electrostatics 71 (2013) 422–428

Contents lists available at SciVerse ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Analysis of the Pulsed Electro-acoustic signal treatment recorded on electron beam irradiated dielectrics

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ARTICLE INFO

Article history:
Received 31 August 2012
Received in revised form
30 October 2012
Accepted 27 November 2012
Available online 20 December 2012

Keywords:
Electrostatic discharge
Electron beam
Dielectrics
Pulsed electro-acoustic
Deconvolution process

ABSTRACT

To study the space charge distribution in the bulk of dielectric materials irradiated by an electron beam the Pulse Electro Acoustic (PEA) method has been selected. However this method offers a limited resolution and doesn't allow the detection of injected charges when they are too close to the surface. Actually, it is difficult to separate the negative injected charges a few micrometers below the surface from positive induced surface charges. In this work, we focus our attention on the deconvolution process that is commonly used to recover the space charge distribution. The aim is to determine the more appropriate resolution factor that appears in the treatment software. A link between the resolution factor and the cutting frequency of the Gaussian filter that is introduced in the deconvolution process to get rid of the high frequency noise is established. Then, the relation between the spreading factor of the surface charge and the resolution factor introduced in the calculation is analyzed. From experimental data it is shown that the choice of the resolution factor can be of mayor importance in order to obtain an accurate space charge distribution especially at the interface.

1. Introduction

Dielectric materials are frequently used for satellite applications especially because they offer good thermal properties. In space they are in contact with a flow of various charged particles such as electrons and protons. Due to their dielectric nature, these materials bring into consideration the charging effect that can lead to Electrostatic Discharge (ESD) phenomena. To get a better control on ESD, it is necessary to determine the charge's location and estimate their quantity during irradiation and the way they relax with time. This work takes only under consideration the electrons effects that can be trapped on a non-uniform way depending on materials nature and their exposure. To study these materials in the laboratory and anticipate ESD phenomena, an irradiation chamber called 'MATSPACE' has been built [1,2]. In order to characterize space charge distribution post-irradiation, the Pulse Electro Acoustic (PEA) technique is used. Several results obtained on material irradiated by an electron beam have already been published [3,4]. In our case, the classic PEA device in air is used. However, it is difficult to detect properly the charge position when they are injected near the surface because they cannot be distinguished from the positive induced charges on the surface. In this paper, the signal treatment technique is analyzed and the importance of the resolution factor choice that appears in the software will be discussed on experimental data. A link between the resolution factor and the cut of frequency of the Gaussian filter introduced in the deconvolution process and between the resolution factor and the space charge profile spreading will be established.

2. Experimental set-up

2.1. Irradiation chamber: MATSPACE

The irradiation device called 'MATSPACE' is made of a vacuum chamber (about 10^{-6} mbar) and a thermionic electron gun that can produce electrons up to 100 keV (Fig. 1). The source delivers electrons in the vertical direction toward the sample holder which is located perpendicularly to the beam. The spreading of the beam is realized by an electromagnetic lens. The irradiation can be considered to be homogeneous on the sample holder in an area of about 10 cm diameter.

2.2. Pulse Electro Acoustic system

The Pulse Electro Acoustic (PEA) method is currently used to measure the space charge distribution in solid dielectric materials.

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0304-3886/$ – see front matter
http://dx.doi.org/10.1016/j.elstat.2012.11.039

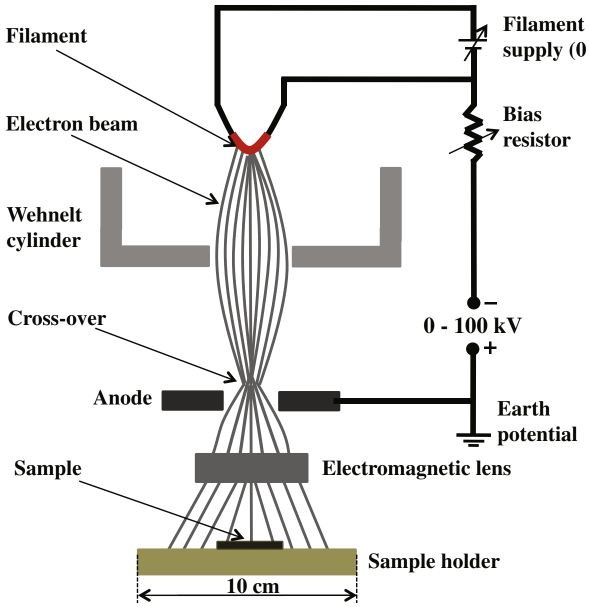

Fig. 1. Thermionic electron gun and sample holder arrangement in the irradiation chamber 'MATSPACE'.

It has been first developed in the eighties [5] to study dielectrics used in electrical engineering domain. Since, it has then been adapted to investigate various domain such as materials used in space environment [6,7].

2.2.1. Device description

In the classical set-up the studied sample is located between two sets of electrodes (Fig. 2a). The sample thickness that can be studied should be located in the range [50 μm–1 mm]. From the upper electrode a polarization voltage and a pulsed probe voltage $v_p(t)$ can be applied. The probe voltage is delivered by a pulse generator (50–400 V, 400 Hz), in our case the signal width is of about 5 ns. The semi-conducting layer between the upper-electrode and the sample ensures the acoustic impedance adaptation and prevents interface signal reflection.

A thick metallic lower electrode is used to delay the signal. Below the plate a Poly-Vinylidene Fluoride (PVDF 9 μm thick) transducer transforms the acoustic wave in electric signal. The output signal $v_S(t)$ is visualized on a digital storage oscilloscope connected to a computer where the data are recorded and mathematically treated.

2.2.2. PEA signal production

In the present case, a dielectric film of thickness d is considered. A charge density distribution $\rho(x)$ is present in the bulk and two induced surface charge densities σ_1 and σ_2, are respectively located at $x = 0$ and $x = \mathrm{d}$ (Fig. 2b). When the pulsed voltage is applied across the sample, it creates a variation of the electrical field $e_p(t)$ and excites the volume charges $\rho(x)$, and the surface charges σ_1 and σ_2. The acoustic waves generated from these sources propagate in the sample. A part of them transit through the lower electrode and reach the piezoelectric transducer at different delay times corresponding to their origins in the sample. The piezo-transducer transforms the received acoustic waves into electrical signals, which can then be digitally processed and used for evaluating the internal charge distribution. The space charge distribution density can be recovered by a deconvolution treatment that will be described in the following section.

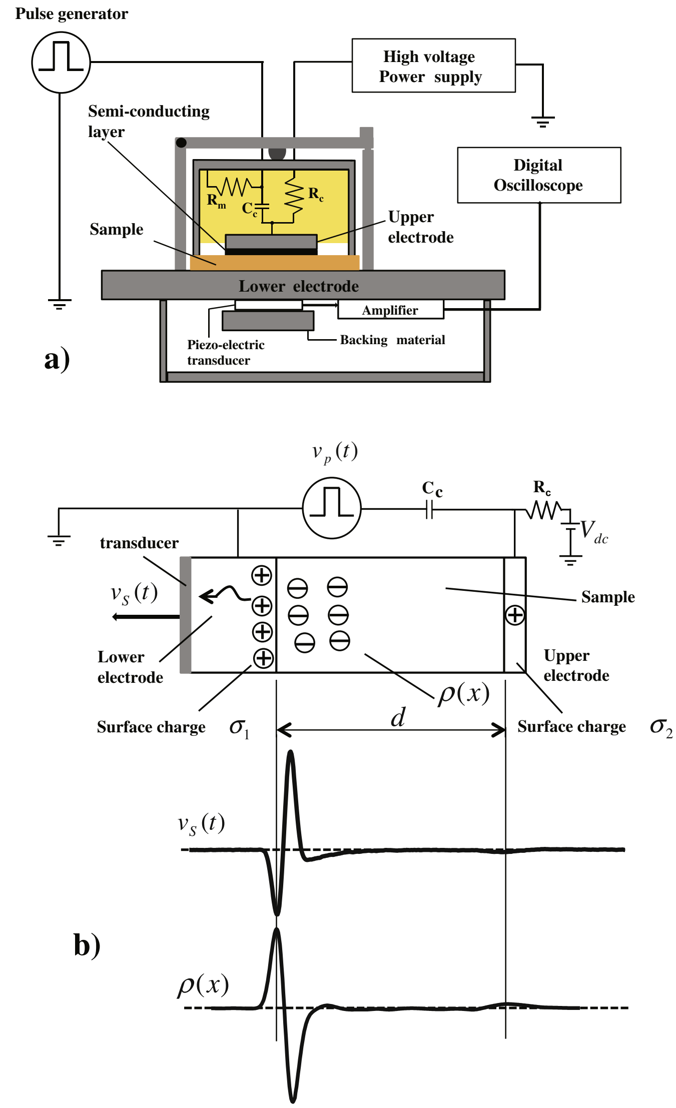

Fig. 2. a) Classical PEA set-up, b) Schematic diagram of the PEA signal formation on a sample containing negatives charges in the bulk and positives induced charges on both surfaces.

3. PEA signal treatment analysis

3.1. Signal processing

The obtained voltage signal $v_S(t)$ is described as a convolution of the impulse response of the system $h_{PEA}(t)$ and the charge distribution $\rho(t)$ [8], $t = x/v_{sa}$ where v_{sa} is the acoustic velocity in the sample:

$$v_S(t) = \rho(t) * h_{PEA}(t) \quad (1)$$

In the frequency domain, this equation is also expressed in a convolution form:

$$V_s(f) = R(f) \cdot H_{PEA}(f) \quad (2)$$

Where $V_s(f)$, $R_s(f)$, $H_{PEA}(f)$ are the Fourier transforms of $v_S(t)$, $\rho(t)$ and $h_{PEA}(t)$ respectively. $H_{PEA}(f)$ needs to be identified in order to obtain $R(f)$ through a deconvolution technique. The transfer function is obtained by mean of a reference signal that gives access to the system impulse response. This reference signal is recorded on a raw