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Electrostatic testing of ESD-protective clothing for electronics industry

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Abstract. Current standard test methods do not adequately evaluate the performance of modern electrostatic discharge (ESD) protective garments used to protect ESD sensitive devices during handling in electronics industry. A new European research project – ESTAT-Garments – aims to supply the standards body IEC TC101 with a means to assess the effectiveness of ESD garments and to develop appropriate test methods.

This paper reviews the requirements for ESD garment test and presents results of measurements of charge transferred and peak ESD current in direct electrostatic discharges obtained from charged fabrics. Results obtained using triboelectrification and direct contact charging methods showed no significant differences. Fabrics could be placed in the following order of increasing charge and peak current corresponding to decreasing surface resistance: carbon core fibre, carbon surface conducting fibre and stainless steel conductive fibre.

1. Introduction

The evolution of electronics has been made possible by continual reduction of the size of semiconductor devices. Unfortunately, this size reduction leads to inherent increase in sensitivity of the components to electrostatic discharge (ESD) damage. Investigations performed in different parts of the world, see e.g. [1] have shown that about 30-50 % of all failures in electronic products detected during manufacturing can be attributed to some kind of electrical overstress, of which ESD is the most important type.

ESD events are highly variable. The waveform characteristics – rise time, peak current, and duration – are strongly influenced by the electrical characteristics, geometry and dimensions of the materials in the discharge circuit, the level of initial charge, and the speed of approach of the contacting “electrodes” [2]. The practical need for assessment of ESD sensitivity of components using standardised electrostatic discharges has led to the development of three ESD models. Human Body Model (HBM) simulates an ESD from a charged human body to a device. Machine Model (MM) simulates an ESD from a charged, floating metal object to a device. Charged Device Model (CDM) simulates the discharge of charge accumulated on the device itself, to a grounded conductive object. All these models are based on a capacitor charged to a certain ESD voltage, which is discharged into the device to simulate the ESD event. Sensitivity of electronic components is given as an ESD withstand voltage, defined as the largest ESD test capacitor voltage that the device can stand without damage. [3]

Device manufacturers commonly include on-chip protection networks in IC designs, which can often withstand ESD in the kV-range. On the other hand, effective on-chip protection is not always possible and many discrete components are in the range of 100 - 150 V according to the standard HBM ESD test [3,4]. The number of ultrasensitive devices with ESD withstand voltages below 100 V is increasing, including special rf-devices, flat panel displays, and magnetoresistive (MR) recording heads.

It is necessary to take ESD protective measures in the manufacturing environment in order to protect ESD sensitive devices (ESDS) against damage [3,5]. In this study we concentrate on the risk of ESD due to charged clothing of the manufacturing operators. Electrostatic charges typically accumulate when the operator is moving, by triboelectric effects (rubbing or separation of two different materials). Specially designed ESD garments are worn over the ordinary clothing of the operator to protect ESDS from accumulated charge on the underlying clothes. These garments should provide shielding against any surface voltages or voltage transients (ESD) arising from underlying garments. In some cases the ESD garments also play other important roles such as protecting the electronics from dust particles originating at the operator (cleanroom clothing).

Current ESD garment test standards [5,6] are mainly based on research performed in the 1980's for homogeneous materials. They do not allow a proper characterisation of the modern heterogenous material garment performance [7,8]. Since then the electronics industry has demanded increasing performance, and at the same time there has been much progress in the textile industry. The ESD garments in use today are made of composite fabrics where a grid or stripes of conductive threads are present inside a matrix of cotton, polyester or mixtures of these materials. The conductive threads are often composite (core conductive fibres, sandwich type fibres etc.). The garment conductive fibres should be grounded or electrically connected to the operator's body, but in many real factories we have observed that this grounding is not achieved. In this case the ESD garment is free to acquire a voltage and become itself the source of ESD.

A European research project ”Protective clothing for use in the manufacturing of electrostatic sensitive devices” (ESTAT-Garments) commenced in early 2002. The main goals of the three-year project are to supply the International Electrotechnical Commission Technical Committee TC101 with a basis to qualify the effectiveness of clothing used in safe handling of ESD sensitive devices, and to develop appropriate test methods for the characterisation of ESD protective garments. The project partners – VTT (FIN), University of Genova (I), SP (S), Centexbel (B), STFI (D), Nokia (FIN), Celestica (I) - consist of experts of electrostatics, electrostatic measurements, textile technology and electronics manufacturers (end-users of the garments). To achieve the main goals, the project aims to understand the electrophysical processes leading to ESD damage to sensitive devices from garment materials.

2. Requirements for electrostatic testing of ESD garments

Standard test methods for ESD fabrics and garments are mainly resistive or measure the charge decay time of the material [5,6]. A good state-of-the-art review of the subject is given in ref. [8]. Current standard test methods do not satisfactory qualify the effectiveness of novel ESD-protective garments and ignore potentially important factors such as:

* triboelectric propensity of the fabric,
* the effect on performance of grounding the conductive garment elements,
* the risks introduced by unearthed conductive fibres as a possible source of ESD,
* possible ESD risk arising from charged insulating areas of a heterogeneous fabric,
* the possible penetration of electrostatic fields from underlying normal clothing through the fabric,
* the influence of grounded operator wearing the garment on the protective performance of the garment

The use of resistive measurements with core conductive fibre fabrics leads to the rejection of a fabric or garment, simply because the measuring electrode makes contact only with the non-conducting surface of the fibres. The charge decay test [5] emphasises the influence of the insulating base fabric on the material performance. To overcome this problem, it has been proposed that one should also measure the capacitance experienced by charge on the surface of the material [9] or the electrostatic shielding factor of the material [10].

Verification of all these factors could require a long list of measurements to evaluate the garment fabric and the garment as worn (system measurement) [11]. The ESTAT-Garments project includes basic research to evaluate the importance of such factors.

An ideal ESD garment might never be realised due to contradictory requirements: 1) low resistance for fast dissipation of charge and to prevent field-induced damage, 2) high resistance to slow down the charge decay and limit the energy transferred in a direct discharge, 3) total suppression of electrostatic fields from charge under, and on, an ESD garment surface, and 4) an anti-static material that does not generate a charge when contact is made to any other material [8]. A good understanding of the electrophysical processes is required to achieve proper compromises. Evaluation of the garment should ideally be done in a single, simple test. That, unfortunately, may not be a realistic target.

3. Assessing the risk of damage to electronics with reference to garments

For many components, ESD damage is related to the energy or peak power of the ESD dissipated within the device. These are related to the peak discharge current, which depends on the ESD voltage and the characteristics of the ESD source, and the impedance of the discharge circuit. For voltage sensitive components the critical parameter is electric field strength inside a device, which is proportional to charge. Hence, ESD peak current, charge transferred, and device charging have been suggested to be key parameters in assessing ESD risk [13]. A new way for the assessment of ESD threats to electronic components has been proposed, based on the use of current and charge thresholds derived from the component HBM and CDM withstand voltages, respectively. ESD garments may therefore be evaluated by measuring discharge currents from charged garments (direct discharge) and device charging due to induction or triboelectrification (CDM ESD).

A ESD failure caused by charged operator or charged clothing can potentially happen in at least three different ways: by a direct discharge to a device, by a discharge from a charged device, and by radiation, i.e. by an induced EMI (electromagnetic interference) pulse due to ESD. In the ESTAT Garments studies these risks will be evaluated and either justified or excluded. This paper, however, only considers direct ESD from the garment material as a source of ESD risk. Direct discharges from the clothing of the operator, from unearthed conducting threads of the garment, or from insulating surfaces of the garment fabric are related to improperly worn, ungrounded or defective, or poorly designed ESD garments, respectively. In the remainder of this paper we focus on studies of direct ESD discharges obtained from fabrics used for manufacturing ESD protective garments

4. The experimental arrangement

In the following experiments we have used two types of passive ESD probe to measure the discharge currents from a number of different discharge events [13]. One probe (SP probe) was developed at SP in Sweden. The other probe (JS probe) has been developed and described by Smallwood and Hearn [14,15]. Both probes have been found to give similar results.

Approximately 24cm x 24cm samples of the protective fabrics were fastened in a conducting frame and placed 5cm from a large ground plane (Figure 1). An electrostatic field meter mounted in the centre of this ground plane enabled measurement of the average potential of the system test fabric and its supporting frame.

We have included in this study protective fabrics with three different kinds of conducting threads, namely: Core-conducting carbon fibre (CC), Surface-conducting carbon fibre (SC) and Stainless steel fibre (SS). The conducting threads are woven into the main fabric in a square of 10mm and 5mm dimensions. We refer to the different fabrics as CC10, SC10, SS10, CC05, SC05 and SS05, where the “10” in SS10 stands for the 10 mm square and 05 for the 5mm square, and the letter code (SS etc) defined above.

The major part of these fabrics consists of polyester or cotton-polyester fibres. In these tests we have not observed any performance difference between these base materials.

All the test fabrics were preconditioned to 23 degrees Celsius and 12% RH for at least 72 hours before the measurements were made under the same conditions. Samples were charged by triboelectrification or by direct charging via the metal frame. Tribocharging was achieved by rubbing with a 5cm diameter Teflon disc until the average potential reached a given value (typical 1000V). The test fabric would be left for a minute to rest before it was discharged via one of the ESD probes.

Direct charging could only be used on conducting parts of the fabrics. In this case a voltage was applied to the sample support frame for two minutes before the power supply was disconnected. The sample was subsequently discharged through an ESD probe.

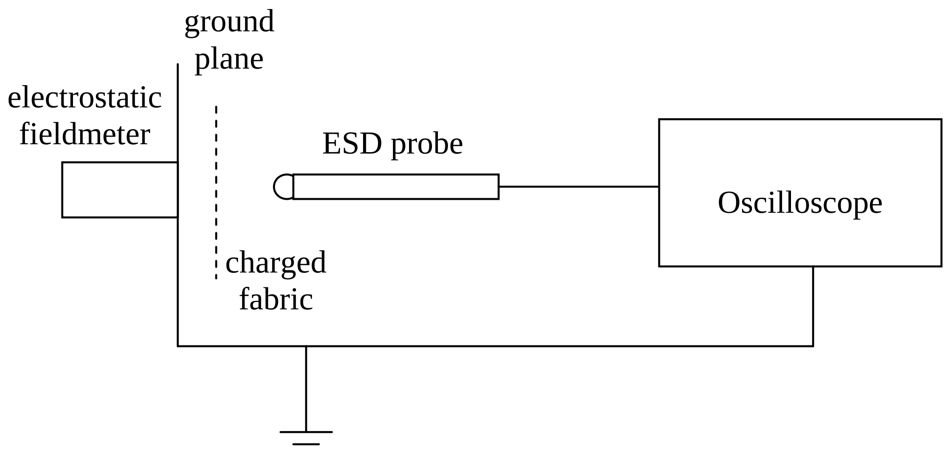

Figure 1. Experimental arrangement for measurement of ESD from charged fabric surfaces.

5. Experimental results

Figure 2 shows examples of the discharge waveforms obtained from a direct charged sample, and a triboelectrically charged sample, indicated measured with the SP-probe. The fabric used in this experiment was the core-conducting CC05. The discharge waveforms are similar in amplitude and in shape. There is an apparent voltage offset in the case of the direct charging waveform, due to measurement instrument effects. This was taken into account in the measured values given below.

Five discharges were made for each charging case with the sample average potential, and charging potential, fixed at 1000V. The average peak current was 0.33 mA for direct charging, and 0.27 mA for tribocharging. The average charge transferred in the discharges was 36pC for direct charging and 31pC for tribocharging. Direct charging and tribocharging appear to give the approximately the same discharge currents and charge transfer for given experimental conditions. Similar tests made for the fabrics with surface conducting carbon fibre and stainless steel fibres indicated that this holds for all the other fabrics tested.

Comparing the different fabrics requires a large number of measurements. Average charge transfer and average peak currents were calculated from approximately six discharge events. The direct charging method and the SP probe were used in these experiments. Figure 3 shows the average peak discharge current, and charge transferred in the discharge as a function of the charging voltage, for the fabrics SC05 and SC10.

While there is some variation in the relationship between the results SC05 and SC10 results, charge transfer and peak current increased rapidly with charging voltage for both fabrics. The SC05 fabric gave higher charge transfer but lower peak current than SC10 at most voltages. The charge transferred and peak current also appear to increase with charging potential for the CC05 and CC10 fabrics and for the SS10 fabric (Figures 4 and 5)

Figure 4 shows the results for CC05 and CC10 fabrics. Below the charging potential of 700V no discharges were obtained. It is unclear whether the measurement system was not sufficiently sensitive to measure the discharges, or there were no significant discharges below this threshold. As the conductive fibres have a buried conductive core, it is possible that a threshold voltage must be exceeded before charge can be transferred to, or from, the conducting fibre core. It is not clear from these results whether there are significant differences between the charge transfer and peak current for the two grid sizes for this fabric.

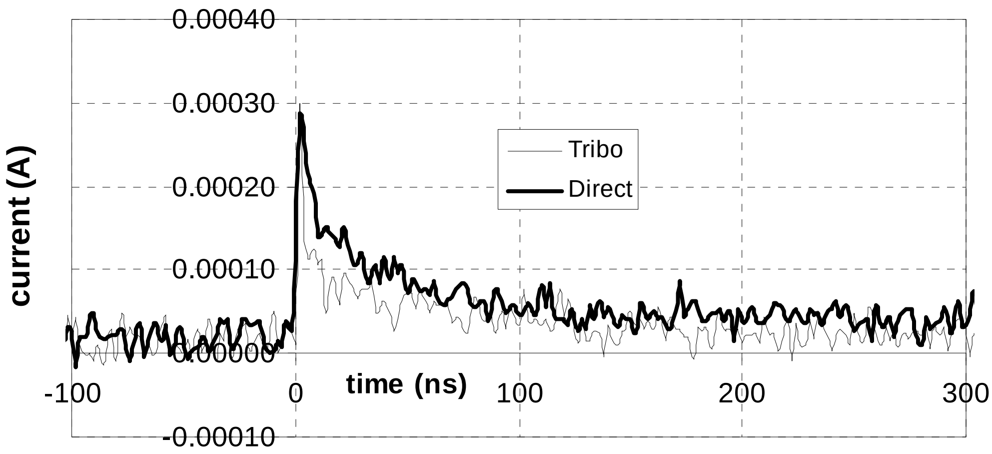

Figure 2. Discharges obtained after direct charging and tribocharging CC05 fabric.

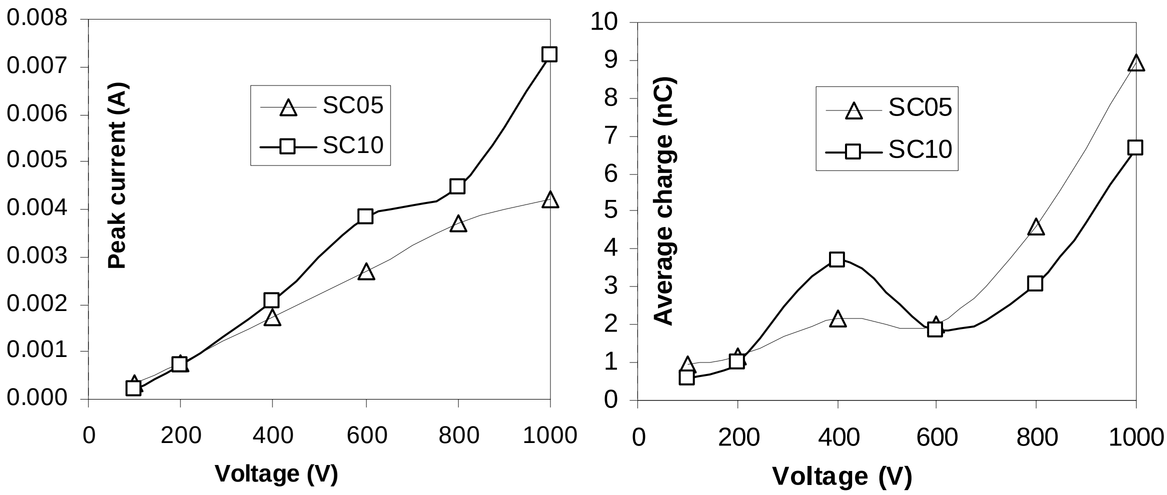

Figure 3. a) Average peak discharge current and b) average charge from a discharge as function of the charging voltage for the SC05 and SC10 fabrics.

The peak current and the charge transferred in a discharge event increased with the charging potential for all of the fabrics CC05, CC10, SC05, SC10 and SS10. If we compare the amount of charge and the peak current between the different fabrics for a given charging potential, we find the following order of the fabrics for decreasing peak current and charge: SS10, SC10 and CC10. This corresponds to increasing surface resistances of these fabrics (SS10 has the lowest value).

Examples of discharges taken from the conducting threads of fabrics charged to 2 kV are given in Figure 6. Figure 6a represents an ESD from stainless steel threads, and Figure 6b from surface conducting carbon fibre threads. Peak ESD current from surface conducting carbon threads is about one hundredth of the peak current from stainless steel threads. ESD peak current from core conductive carbon threads (not shown) is slightly smaller than that from surface conducting threads.

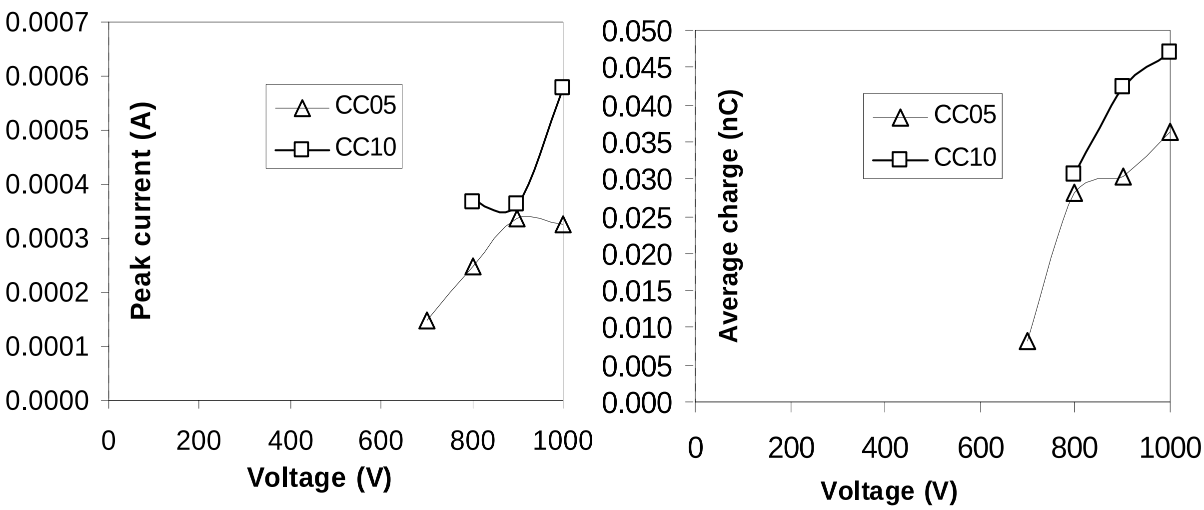

Figure 4. a) Peak current and b) average charge transferred in discharge events from CC05 and CC10 fabrics as function of the charging potential.

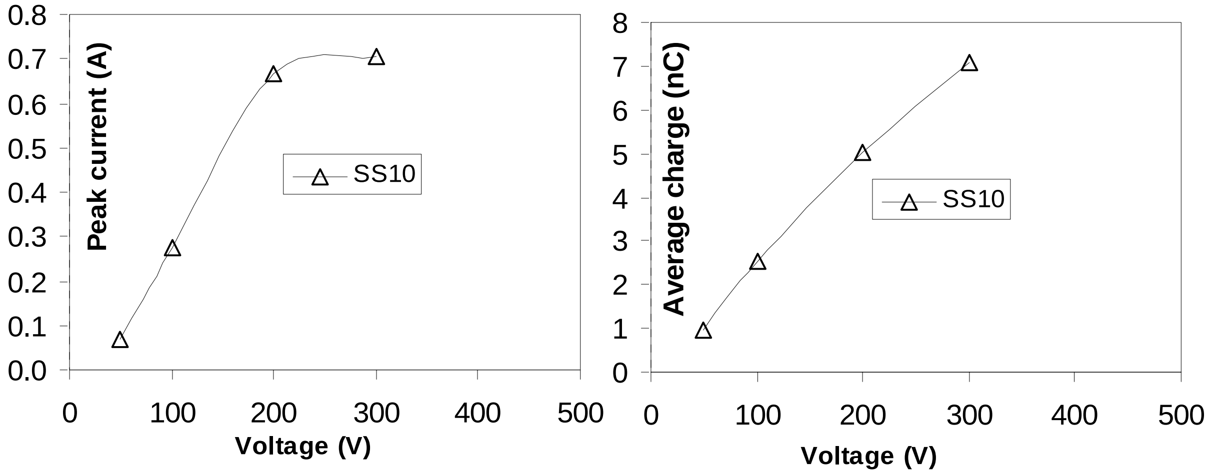

Figure 5. a) Average peak current and b) charge transferred in a discharge event as function of the charging potential for SS10 fabric

According to [13] the 13 A discharge current of the stainless steel thread would be expected to represent a threat for devices with HBM withstand below 20 kV and the 0.12 A current of Fig. 2b a risk for devices with HBM withstand below 200 V. No discharges were obtained from the insulating material between the threads at this charging level.

In order to be able to measure direct discharges from the insulating parts of the ESD protective fabrics, fabrics have to be charged by triboelectrification (or by ion deposition) up to several kV. Such high charging level is quite unlike in practice for ESD garment, on the contrary to normal clothing where surface potential of several kV is easily achieved. It seems that direct discharges from insulating surfaces of the garment fabric are not a significant ESD risk. Charged, unearthed conducting threads, however, form a risk for ESD damage of devices: unearthed stainless steel threads may be a risk for all ESDS and carbon fibre threads at least for Class 0 devices with HBM ESD withstand voltages below 250 V.

In Figure 6b the discharge from SC fibres continued at a lower level for a significant time duration after the initial peak. It is possible that this is due to charge draining from the wider area of linked conductive fibres through the sample over a period of time.

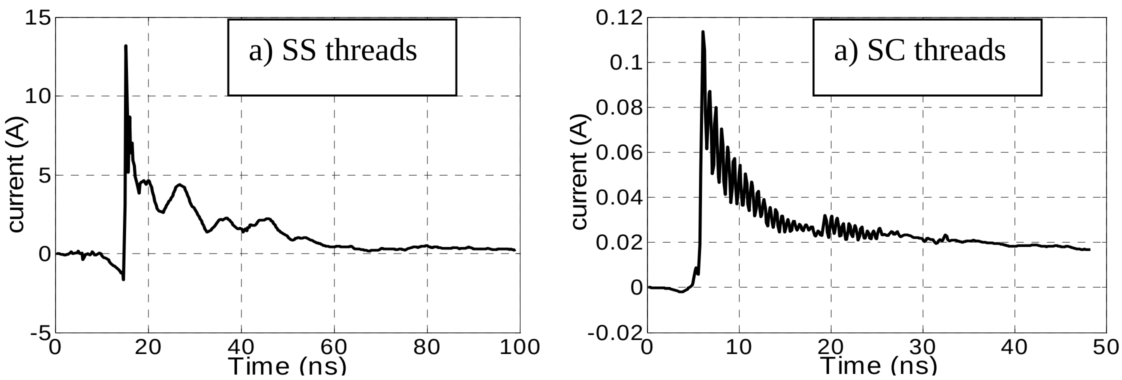

Figure 6. ESD current waveforms from fabrics charged to 2 kV: a) fabric with SS threads, b) fabric with SC fibre threads. Only the initial part of the discharge curve is shown.

6. Conclusions

A European research project ”Protective clothing for use in the manufacturing of electrostatic sensitive devices (ESTAT-Garments)” is in progress, aimed at giving a basis to qualify the effectiveness of clothing used for the ESD-safe handling of ESD sensitive devices (ESDS) and to develop appropriate test methods for the characterisation of such ESD protective garments.

Measurements have been made of direct ESD from fabric samples which have stainless steel, surface conducting carbon, or carbon core fibres as conducting elements. Peak current and charge transferred in the ESD events have been measured to evaluate their significance as a possible ESD damage risk to sensitive electronic devices. No difference has been found between discharges from triboelectrically charged, and direct charged, fabrics. Both peak current and charge transferred in the discharge increased with the fabric surface voltage. Fabrics could be placed in the order of increasing charge and peak current at a given surface voltage: carbon core fibre, carbon surface conducting fibre and stainless steel conductive fibre, corresponding decreasing surface resistances of these fabrics.

Discharges from stainless steel fibres charged to 2kV were about a hundred times greater amplitude (13 A) than from surface conductive carbon fibres (0.12 A). This amplitude could represent a significant ESD risk to sensitive devices.

Acknowledgements

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