Low Voltage Contact Electrostatic Discharge Phenomena

Tetsuji Oda, Yuto Ono, Hiraku Miyasaka

***Abstract*— Recent electronic device operates at very low voltage which will be less than 1 V soon. At that low voltage there is no gas ionization because the individual molecule needs much energy, more than 15 eV at least for the gas ionization. By using a simple serial LCR circuit model, the equivalent contact resistance is estimated for the contact electrostatic discharge experiment. Moreover, the electrostatic discharge photo-emission is also observed if the charging voltage is more than 180 V which may be due to the ionization of molecules. There are some discharge current wave forms which should be dependent on the discharge modes (contact situation). Those can be analyzed and discussed.**

***Index Terms*—Electrostatic discharge, low voltage, current wave form, resistance**

I. Introduction

MANY researches on the electrostatic discharge (ESD) phenomena have been done and many anti-electrostatic discharge technologies have been developed, for reducing the firing or explosion by the ESD recently where the typical electrostatic induced voltage is more than several kV level. In general, the minimum ignition discharge energy is more than 10 μJ (18 μJ for hydrogen, for example). Practical explosion-ignition energy is mJ level in general. However, still some electrostatic disasters occur in various fields. Moreover, the electronic devices become smaller and smaller with the increase of the acquisition speed. The electronic signal charge is also very small for high speed devices indicating a small amount of charge can destroy those devices. Especially, GMR (giant magnetic resistance) head for magnetic memory is easily affected by the small electric current although the discharge energy is very small and thermal effects can be neglected. In this range, the induced electrostatic voltage is sometimes less than 10 volts [1]. At those low voltages, the electrostatic gas discharge does not occur (ionization energy must be more than 15 eV for nitrogen molecule) and sometimes those discharges are named as the contact electrostatic discharge as in this paper title. The precise small gap discharge control needs a very stable (vibration free) and nanometer-scale manipulator, but it is very difficult and the authors gave up to control the nanometer gap but focused on the contact discharge current waveform which is important for the damaging of magnetic materials. As the electrostatic charge storage, a very small capacitor (pF order) connected with the DC power supply through the high resistance is used. Some mechanical relays are tested as the contact electrostatic discharge switch. If the applied voltage to the capacitor is more than 20 V, there may be the gas discharge with gas molecule ionization but no ionization discharge occurs if the voltage is less than 10 V. In this case, the contact resistance and circuit response must be considered. This paper reports on those experimental results.

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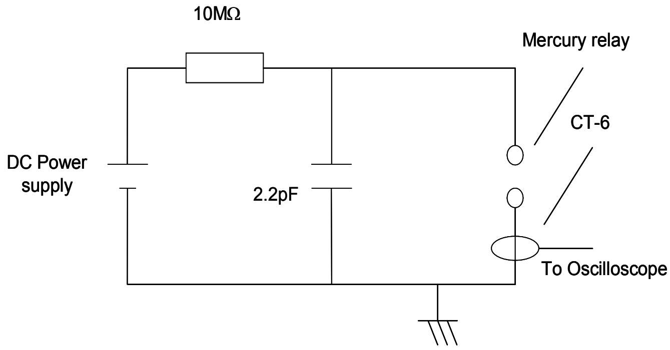


Fig. 1 Electrical circuit for low voltage ESD experiment.

II. Experimental

Figure 1 shows one experimental setup where a variable DC power supply (0 to 500V) is on the left and connected to the 2.2 pF capacitor through 10 M□ resistance. The both terminals of the capacitor are connected to the relay whose contact points are closed by the magnetic field (mostly generated by the magnetic coil). The CT current probe (TC-6 Tektronix; frequency range is less than 1.5 GHz) is connected with that earth line as shown in the figure and detected signal is observed by the digital oscilloscope (Tektronix DPO 7254; band width 2.5GHz). Several relays are tested. One is sealed-mercury-wet type reed relay (HFW-1A-12: by Okita Manufacturing Co.). The electric discharge-current-wave form is strongly dependent on the circuit and the relay contact point. The total length of the wire connecting the capacitor, relay and current transformer, is


Fig.2 A photo of mercury reed switch

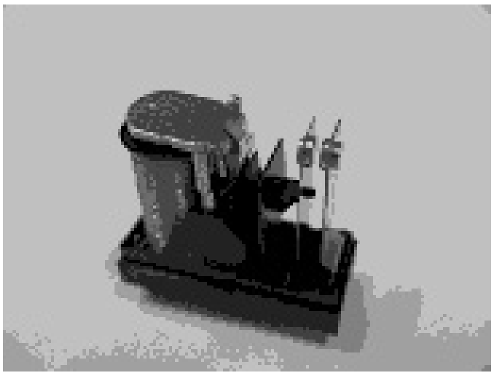


Fig.3 Photo of a large dry type relay which can be exposed in air.

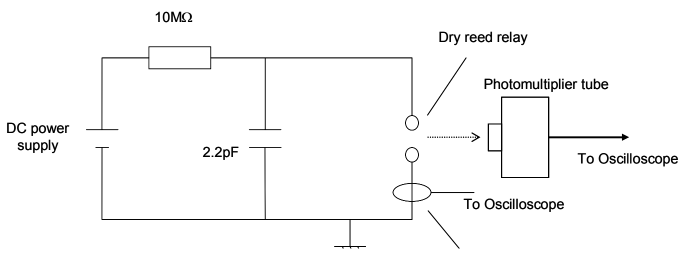


Fig.4 Optical emission measurement of low voltage ESD

about 5 cm which means that the wave flowing delay is 250 ps level which means about 4 GHz high frequency components can be generated by the circuit characteristics. The photo of the tested wet-type relay is shown in Fig.2 which contains switching coil inside. A glass sealed reed relay without switching coil is also examined. In the case of the discharge, the electrode surface property strongly affects the discharge-current-wave form. In order to investigate the surface contamination and corrosion, open dry type relay as shown in Fig.3 is also examined where the contact area of that relay is rather large and the separation gap is also long but the acquisition time is still pretty quicker than 100 ps which is less than the measuring limit.

If the high power discharge with the gas ionization occurs, the discharge photo-emission should be observed. To investigate that photoemission, photomultiplier tube is settled as shown in Fig.4 where the dry type relay is used but the reproducibility is not so good because of the shade.

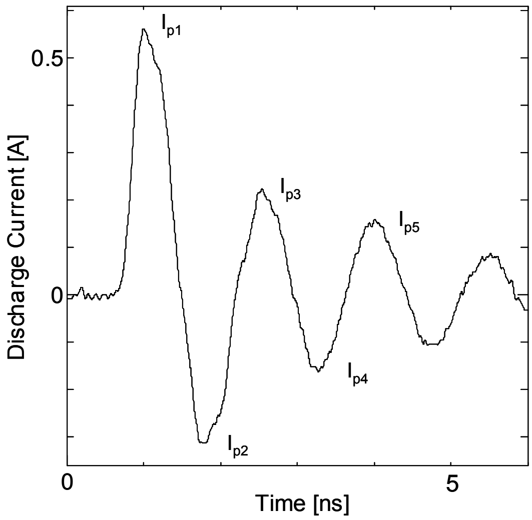
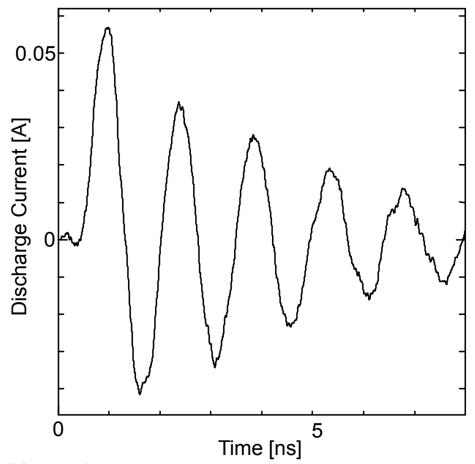


Fig.5 A discharge current waveform (50V)

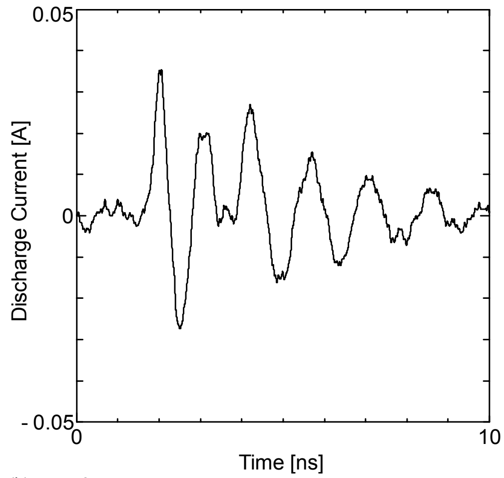
III. Results and Discussions

A Current wave form

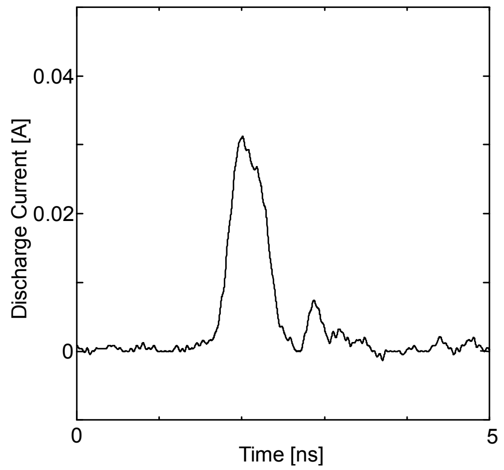
A typical discharge current observed by the CT is shown in Fig.5 where the charging voltages of the capacitance is 50 V and the contact switching relay is wet-type reed relay as shown in Fig.2. The oscillation frequency is about 700 MHz and the current peak is about 0.5 A. If the charging voltage increases from 50 to 100V, basic current-wave-form is the same but the damping factor becomes larger for the larger charging voltage. In this charging voltage, the discharge current is stable and photo-emission is detected. On the other hand, the discharge current-wave form for the low charging voltage, is not so stable and various forms are observed which are shown in Fig. 6 (a) – (c) where the open type dry relay was used and the capacitor charging voltage is 10 V. As the ionization energy of the nitrogen or oxygen molecular is more than 10 eV, the environmental gas molecule cannot be ionized by the ESD effect and the short circuit current should be caused by the tunnel current. The current-wave form is dependent on the short circuit and the tunneling resistance including the diffusion resistance of the electrode. The wave form of type 1 (shown in Fig.6 (a)) is most typical wave form and very similar with the normal current-wave form for high charging voltage as shown in Fig.5 where peak current is about 1/10 which is rather smaller than the estimated value from Fig. 5. Type 2 and type 3 suggested the unstability of the contact point. As this unstability is not observed for the wet-type relay,



(a) Type 1



(b) Type 2



(c) Type 3

Fig. 6 Current wave form at 10 V.

the relay contact surface is not so smooth and a large peak current degrades the contact area and the current flow is disturbed. The sharp rising time observed is about 200 ps which is already less than the measuring limit (about 280 ps because the digital oscilloscope rising time is 150 ps and the rising time of the CT is about 200 ps). Maybe the real rising time should be much sharp! That appearance probability is examined as shown in Fig. 7 where three types are compared with the charging voltage where the open switch was tested. In the case of wet-type switch, type 1 appears over 100 V but in this case, only type 1 is dominant even when V is more than 20

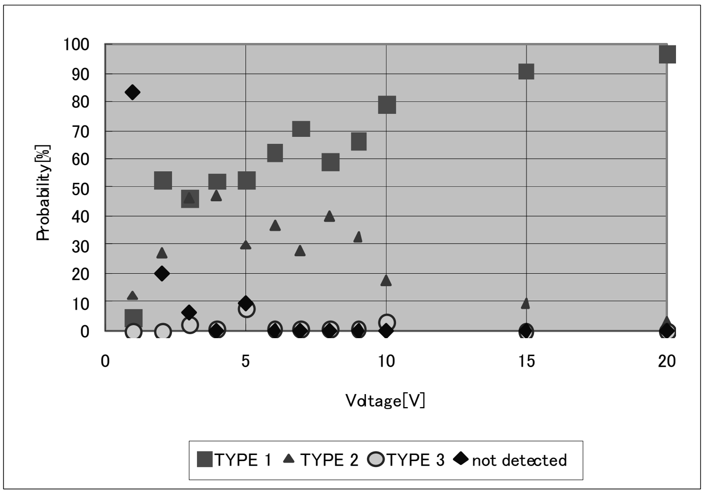


Fig.7 Appearance probability of three different current wave forms.

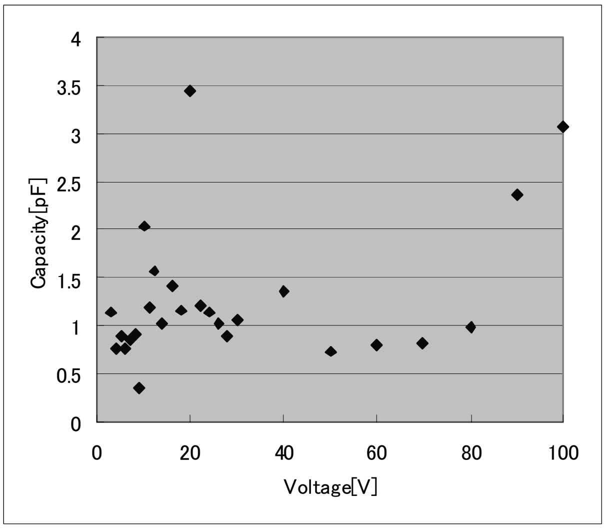


Fig.8 Total capacitance of the circuit.

V. Maybe types 2 and 3 means insufficient contact and contact may be cut during microseconds.

B Data analysis by a simple model

If we estimate the equivalent simple circuit of a serial LCR circuit, LCR value may be calculated from the experimental current-wave forms. The integration of total current I(t) should be equal to the total charge Q stored in the capacitor (Q=CV) and we can estimate the total capacitance from the C=Q/V where V is the charging voltage on C which includes the capacitance between switching electrodes and the stray capacitance. Those estimated capacitances are shown in Fig.8 where the inserted capacitance is 2.2 pF. If the charging voltage is less than 40 V, the capacitance is widely dispersed and from 40 to 80 V. At that, the estimated capacitance is lower than 2.2 pF suggesting that all charge stored in the capacitance is not yet released enough even in several microseconds. .In other word, type 1 suggests that all charge stored in the capacitance is released rapidly and only the current oscillation exist later but at other cases (types 2 and 3), the contact is insufficient and some charge still remains in the capacitance. In the case of the wet-type relay, the total capacitance is about 3.5 – 3.9 pF indicating the stray capacitance is about 1.2 – 1.7 pF for the wet-type relay but much smaller for the dry-type (open type) relay. From the simple circuit calculation of serial connection circuit of L, C and R, , current I(t) can be shown as

$$I(t) = \frac{V_0}{\omega L} e^{-\alpha t} \sin(\omega t) \qquad (1)$$

where

$$\alpha = \frac{R}{2L}, \omega = 2\pi f = \sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2} \qquad (2)$$

Frequency of the current vibration suggests us the inductance L and that damping factor tells us the series resistance R. The experimentally calculated inductance is very stable of 18 nH.

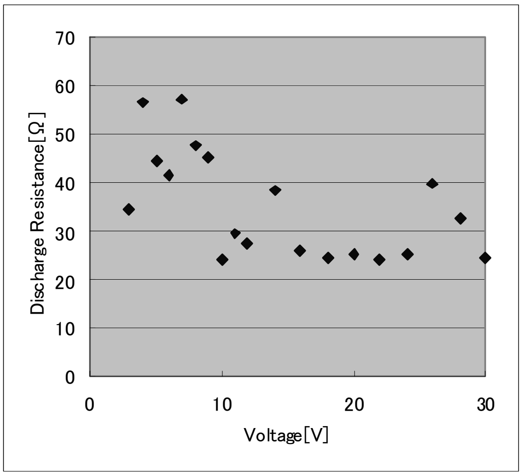


Fig. 9 (a) Resistance of the switching area
V is less than 30V.

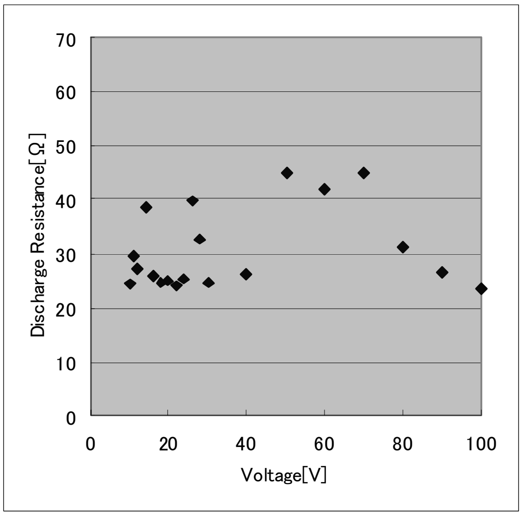


Fig.9 (b) Resistance of the switching area
V is less than 100V

On the other hand, the wire inductance can be theoretically calculated as

$$L = 2l\left[\log\left(\frac{4l}{d}\right) - \frac{3}{4}\right] [nH] \qquad (3)$$

where l is the wire length and d is the wire diameter. The observed value of 18 nH is roughly in good agreement with the

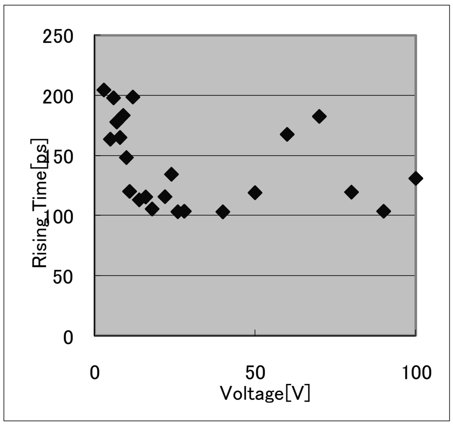


Fig.10 Peak current rising time versus charging voltage.

calculated value from the wire size. On the other hand, the resistance R is strongly dependent on the charging voltage and the relay itself. Those examples are shown in Figs. 9 (a) and (b). At less than 10V, no ionization occurs and the contact should be tunnel current mode. Maybe the electrode surface of the dry type relay is not so smooth and contacting area is so small that the spread resistance of the electrode materials limits the current. The surface corrosion also affects that high resistance. In the case of the charging from 10 V to 30 V, that resistance is rather stable and small suggesting the current flow stability for high current and high electric field, but not yet sure. At the charging voltage of more than 50 V, a small filament discharge may occurs causing some resistance. If the voltage is more than 200 V, the pretty stable discharge channel may be produced and the resistance should be small.

The first current peak rising time from 10 % to 90 % versus the charging voltage is also shown in Fig. 10. The rising time is very small of 100 ps, which is smaller than the theoretical measuring equipment limit, is observed during the charging voltage of 20 – 50V which is in good agreement of small resistance range as shown in Fig. 9. In this range, good tunneling contact can be made. At lower voltage charging, the equivalent resistance is large and the current rising time is also large indicating the resistance change with time. If the charging voltage is larger than 50 V, the gas ionization occurs which influences the rising time. As already described, 100 ps rising time is measuring system limit and real response should be much quick although we use mechanical switch. In the case of the wet-type switch, the serial resistance is very large when the charging voltage is large. That is maybe the gas discharge effect. The discharge occurs between a little bit long distance and their rather large resistance affects the large rising time.

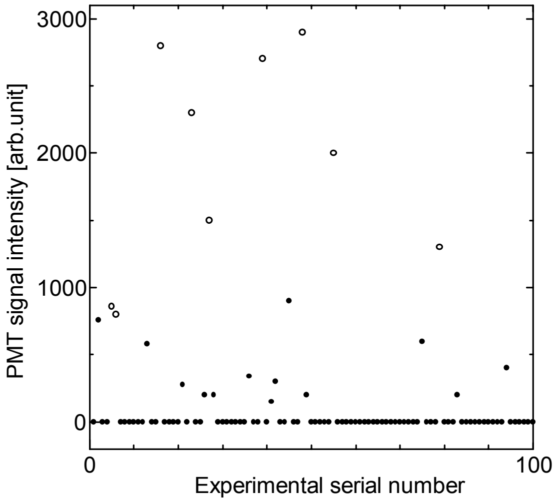


Fig.11 Optical output (photomultiplier output) intensity for repeated process where the charging voltage of the capacitor is 160 V.

C Photo-Emission

If the charging voltage is less than 100 V, no photo-emission of the discharge is observed. Still at higher charging voltage, the photo-emission is not so reproducible as shown in Fig. 11 where the charging voltage is 160 V. If the charging voltage is 200 V, that photo-emission signal intensity increases very much and the frequency (photo-irradiation probability) is also much large. The authors judge the photo-emission threshold charging voltage may be about 180 V in our experimental setup. However, the precise photo-emission mechanism is not yet understood and it is not easy to identify the difference of the discharge-current-wave form according with the photo-emission.

IV. Conclusions

As the low voltage electrostatic discharge simulation, the small capacitor of 2.2 pF is charged at low voltage from 1 V to 400 V. The mechanical switching relay shorts the both ends of the capacitor and the short current wave form is observed by the quick current probe and the digital oscilloscope. Theoretically the low voltage under 20 V cannot cause the gas molecule ionization and the gas discharge cannot be produced. Those current phenomena are observed and following results are obtained.

1. Reproducibility of the short circuit current waveform observed the high speed current transformer is not so good. Especially, under 10 V charging, a little bit complicated current wave forms were observed. The most typical discharge-current-waveform is the oscillating wave form with a sharp rising pulse current and successive damping oscillation. At the charging voltage of more than 20 V, all short current-wave form is that typical one. On the other hand, the shortening becomes complicated (superimposing of double switching or sudden disconnection).
2. Those phenomena can be explained that only the tunnel current at the local area can flow under 10 V. When the charging voltage of the capacitor is more than 20 V, the ionization of the gas molecules occurs and stable gas discharge can be seen which causes rather stable and low resistive switching performance.
3. When that charging voltage is not so high, less than 100 V, not all the charge stored in the capacitor can flow by the shortening action of the switch.
4. The rising time of the short current is smaller than the instrumental limit (about 160 ns) and only the smallest observed value is about 100 ps.

Acknowledgement

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[1] [1] Lydia Baril, Mark Nichols, and Albert Wallash, “Degradation of GMR and TMR Recording Heads Using Very-Short-Duration ESD Transitions,”IEEE Trans. Magn., vol. 38, no. 5, pp. 2283-2285,(2002)