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A novel technique to detect effects of electromagnetic interference by electrostatic discharge simulator to test parameters of tunneling magnetoresistive read heads

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Electrostatic discharge (ESD) has been a significant problem in the manufacturing processes of the magnetic recording head technologies for many years. Besides direct discharge damage, ESD can also generate electromagnetic interference (EMI) which could possibly cause failure in magnetic read heads. The aims of this work are to measure the EMI from ESD simulator based on the standard IEC 61000-4-2 and to investigate the effects of EMI on tunneling magnetoresistive (TMR) read heads. The discharge current and the EMI generated by ESD simulator are measured in the experiment. Also, the EMI is applied to the TMR read heads at various amplitudes and distances in order to evaluate the changes of read head parameters including the bit error rate, resistance, read back signal amplitude, and asymmetry parameter of the head. The results show that the discharge current waveform is consistent with the IEC standard current waveform. In addition, it is found that the EMI is insufficient to cause a permanent change of the read head parameters at distances above 2 cm indicating the minimal impact on the head performance. Further experiments are proposed to carry out more detailed studies of the EMI effects on head parameters in order to improve the methods to prevent the degradation of parameters which can be a latent failure in the magnetic read heads. *© 2015 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4914963]

I. INTRODUCTION

Electrostatic discharge (ESD) is an important issue in the manufacturing processes of data storage applications since it can cause the physical and magnetic failures in the magnetic recording heads especially, during the phase before inclusion in the hard disk drive (HDD) enclosure.[1,2] Also, ESD can generate electromagnetic interference (EMI) which is the term of describing a disturbance occurring in the electronic circuit as a result of electromagnetic field.[3] The EMI can be caused of the magnetic failures within the magnetic read heads, resulting in a decrease of the head reliabilities.[4,5] The IEC 61000-4-2 standard specifies the test system for evaluating the immunity performance of electrical and electronic devices when subjected to ESD, which can occur as a contact discharge mode or an air discharge mode.[6] This test standard can produce a higher current than other ESD models at the same charging voltage, resulting in a higher radiated EMI.

Nowadays, the tunneling magnetoresistive (TMR) sensor is extensively used as the magnetic read heads for HDD and has continuously received interest to improve the head performance due to its high magnetoresistance ratio, thin barrier, and low bias current.[7,8] The performance of the magnetic read head can be exemplary evaluated using read head parameters such as the bit error rate (BER), read head resistance (RES), read back signal amplitude (AMP), and asymmetry parameter (ASYM).[1,9] The BER is a parameter used for investigating the probability of errors in data storage devices, which is proportional to a ratio between an amount of the bits causing an error and the total bits detected by the read head.[10] The RES is the resistance of the magnetic read head. The AMP shows a strength of output signal from the read head while sensing the magnetic field from magnetic media whereas the ASYM is used for measuring the asymmetry between the positive and the negative signal from the head.[9] These parameters can be used to detect the magnetic degradation in the magnetoresistive read head, resulting from the ESD.[1,9,11]

The aims of this work are to measure the discharge current and the EMI generated by the ESD according to the standard IEC 61000-4-2. Furthermore, a novel technique to detect the effects of EMI on the TMR read heads is proposed by evaluating the change of BER, RES, AMP, and ASYM in the TMR read heads after being affected by EMI.

II. EXPERIMENT SETUP

A. Measurement methodology of discharge current and radiated EMI field from ESD

The experimental setup to measure the discharge current and the EMI amplitude is shown in Fig. 1. The ESD is

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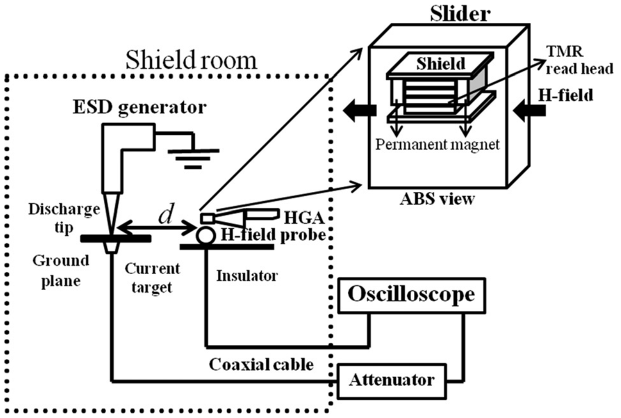

FIG. 1. Experiment setup.

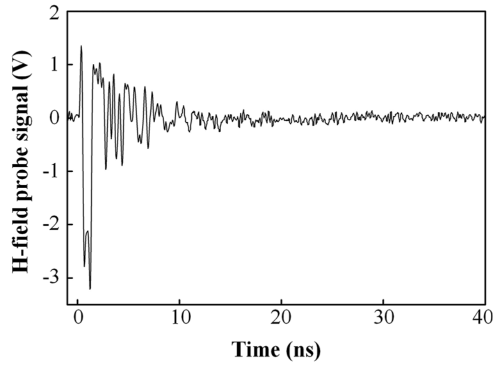

FIG. 2. The output signal from H-field probe, V, resulting from ESD with 8 kV charging voltage at 2 cm distance.

generated by the Thermo Scientific MiniZap ESD simulator resulting in the discharge current flowing through the current target attached to a ground plane. A contact discharge mode is only considered in the measurement, because this mode can be linearly reproduced in the test system while testing the electronic devices. The EMI radiated from ESD is measured by the magnetic field (H-field) probe model HP 11940A which has bandwidth of 30 MHz to 1 GHz, placed at distances, d, between 2 and 30 cm from the discharge point. An oscilloscope (Lecroy wavepro 7300A with 3 GHz bandwidth is used for measuring the signal from H-field probe and the discharge current attenuated by the attenuator. The voltage of the magnetic field probe, V, is given by $V = A \times (dB/dt)$ where A is the loop area of the probe and dB/dt is the rate of change of the magnetic field, B. Thus, the magnetic field, $H = B/\mu_0$, can be obtained by an integration of voltage signal.[12] While measuring the H-field, the TMR read heads are placed at the same distance with the H-field probe in order to investigate the effect of EMI on the head, described in **B**.

B. Test parameter evaluation in TMR read head

To evaluate the effects of EMI on the TMR read heads, the EMI radiated from ESD with a charging voltage of 2, 6, and 8 kV are applied to TMR read heads placed at various distances with the air bearing surface (ABS) facing the ESD. The EMI in terms of the H-field is mainly considered because H-field can affect the magnetization of magnetic layers inside the head. As illustrated in Fig. 1, the slider containing the TMR head is attached to head gimbal assembly (HGA) which is isolated from the ground by placing the HGA on an insulator. As can be seen in the magnified figure of a slider in Fig. 1, the TMR read head comprises several magnetic layers. The sensing layers of the TMR read head used for detecting the data bits consist of the pinned and free layers, which are the ferromagnetic layers, separated by the spacer. The magnetization of the ferromagnetic layers are aligned in the in-plane direction. Also, the magnetization of the free layer is biased by the permanent magnet and can be tilted during the operation by the magnetic field from the media disk while the magnetization of the pinned layer is held by the exchange bias field from an anti-ferromagnetic layer. The magnetization of the pinned layer is perpendicular to the ABS whereas the magnetization of free layer is parallel to the ABS. The H-field is applied perpendicularly to the magnetization of the pinned layer inside the heads because this direction could permanently tilt the magnetization of pinned layer, which could affect the BER, RES, AMP, and ASYM of the head. After applying the EMI to the heads, the BER, RES, AMP, and ASYM are measured by the spin stand tester and are compared with the values before applying the EMI field. These parameters are considered in the measurement because it can be changed by tilting the magnetization alignment of the sensing layers which can be affected by the external magnetic field.

III. RESULTS AND DISCUSSIONS

The magnetic field was reconstructed according to the procedure explained in the experiment setup part **A**. Figure 2 shows an example of the signal measured by the H-field probe for 8 kV charging voltage at a distance of 2 cm. Then, the H-field is obtained by $H = B/\mu_0$, where the magnetic field, B, is calculated by integrating dB/dt, as shown in Figure 3. Also, Fig. 3 illustrates a comparison of the waveform of the IEC standard current, the measured current, and the H-field generated by a 8 kV charging voltage at a distance of 2 cm from the discharge point. It is shown that the ESD current waveform measured in the experiment is consistent with the standard waveform. In addition, the H-field waveform is proportional to the discharge current as expected by Ampere's law.

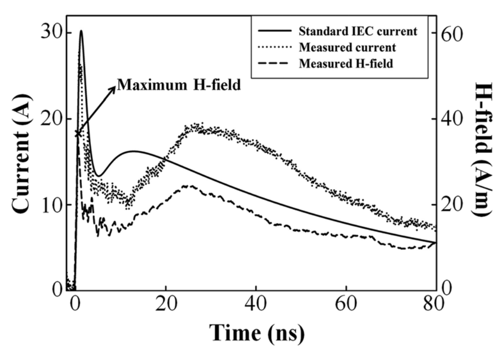

FIG. 3. Example of a comparison between the standard current, the measurement current, and the measured H-field with ESD charging voltage of 8 kV at distance of 2 cm.

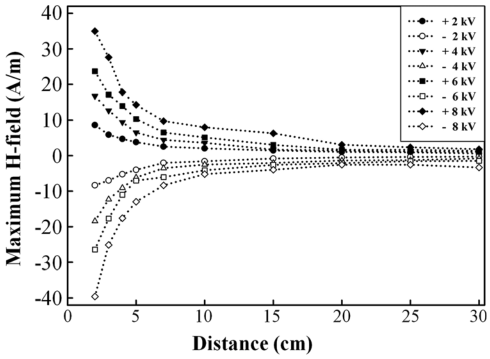

FIG. 4. The maximum magnitude of H-field with varying ESD charging voltages at various distances.

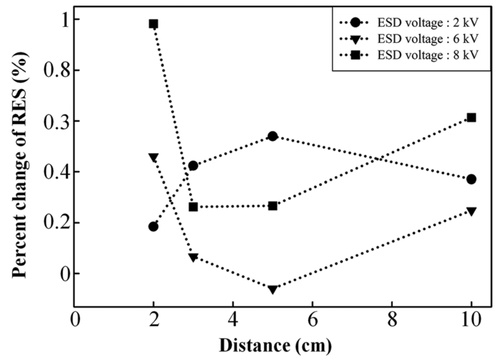

FIG. 6. The percent changes of the RES of TMR read heads at various distances for 2, 6, and 8 kV charging voltage.

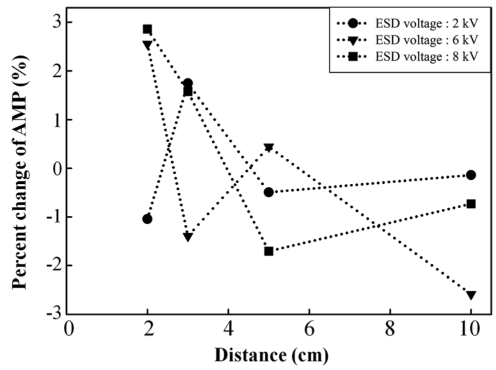

FIG. 7. The percent changes of the AMP of TMR read heads at various distances for 2, 6, and 8 kV charging voltage.

The peak magnitudes of H-field radiated from ESD with varying charging voltages at various distances are illustrated in Fig. 4. This figure shows that the symmetry of H-field between the positive and negative charging voltage is found in the measurement. Also, the result shows an immediate decrease of H-field with increasing distance when the distance is approximately lower than 10 cm after that, the H-field is slightly decreased with increasing distance. Normally, when the distance is varied, the magnitude of H-field is changed depending on the region where the H-field is measured. In the near-field region, the H-field is expected to be proportional to $1/d^2$ with increasing distance whereas in the far-field region, the H-field decreases by a factor of $1/d$ with increasing distance.[13] Therefore, the change of H-field observed in the measurement is consistent with the model.

For the investigation of EMI effects on the TMR read heads, the results of BER, RES, AMP, and ASYM were measured using a spin stand tester before and after the EMI with charging voltage of 2, 6, and 8 kV applied to the TMR read heads were presented in terms of the percent changes, shown in Figs. 5–8, respectively. For each data point, the percent changes of test parameters of three heads are averaged. It is found that BER, RES, AMP, and ASYM show little change with respect to their initial values. However, the results indicate that there is no clear trend in the changes of test parameters neither by increasing distances above 2 cm nor increasing charging voltages up to 8 kV. In order to clarify the changes of head parameters in Figs. 5–8, the head parameters are in addition measured twice without applying the EMI. It is found that the changes of the head parameters measured after applying EMI at various distances are within the variations found for the two tests of the same head without applying EMI. Therefore, the changes of test parameters in the experiment are within the tester variation. Then, it is concluded that there is no permanent effect on the BER, RES, AMP and ASYM by applying the EMI to the heads in the perpendicular direction to the magnetization of pinned layer. This is because the magnitude of EMI is much lower than the exchange bias field from anti-ferromagnetic layer which holds the magnetization of pinned layer and is insufficient to cause a permanent effect on the read head parameters by modification of the pinned layer. Additionally, the effects of EMI on the head parameters were investigated

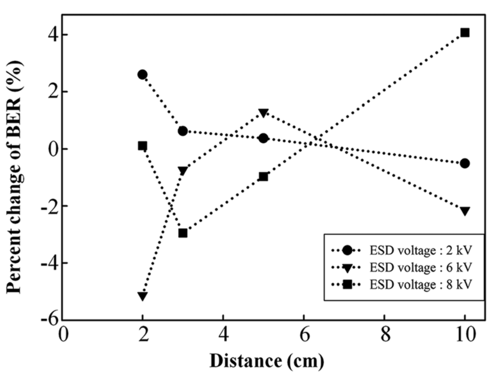

FIG. 5. The percent changes of the BER of TMR read heads at various distances for 2, 6, and 8 kV charging voltage.

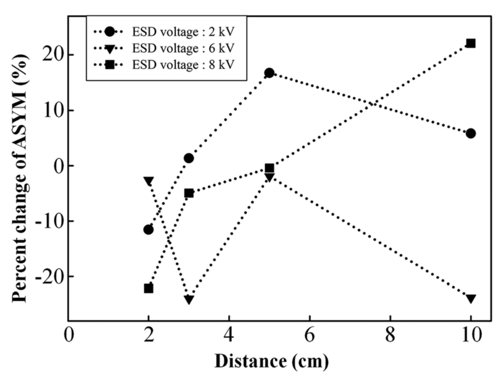

FIG. 8. The percent changes of the ASYM of TMR read heads at various distances for 2, 6, and 8 kV charging voltage.

only after the EMI was applied to the heads in this experiment. Thus, any temporary changes to the head that may affect the heads during the operation cannot be detected using this methodology.

Hence, the investigation of the effects of EMI on the BER, RES, AMP, and ASYM in case the heads are placed closer than 2 cm from the EMI source and the parameters are measured under operating conditions is suggested as possible future work. By decreasing the distance between the EMI source and the heads, the magnitude of EMI can rapidly increase due to the $1/d^2$ dependence in the near-field region. This will increase the probability of EMI effects on test parameters of the head because the EMI magnitude could be large enough to permanently modify the pinned layer. Also, the possibility of a change in the parameters can be increased by measuring these parameters while the indirect EMI field is applied to the heads because this EMI is the transient source of the electromagnetic field. In addition, measuring the head parameters during the read operation is also suggested for further study. In this condition, the magnetization of free layer is tilted following the stray field from a magnetic disk. Since the EMI is applied perpendicularly to the initial magnetization of free layer, it can either oppose or support the magnetization of free layer tilted by the stray field during the read operation, which can be a cause of the temporary change in the head parameters. However, the present magnetic read heads are generally operated with several terabits on the magnetic media then, the changes of BER, RES, AMP, and ASYM could play a significant role during operation. Thus, the BER, RES, AMP, and ASYM are the important factors which can indicate the latent failure of the head and should be minimized in order to maintain the performance of magnetic read heads for higher areal density.

IV. CONCLUSIONS

The EMI radiated by ESD standard IEC 61000-4-2 is experimentally evaluated. The discharge current waveform measured in the experiment verifies that the test system is in good agreement with the standard test procedure. A proportionality between the discharge current and the H-field waveform, as expected by the Ampere's law, is also shown in the measurement. In addition, the H-field radiated by ESD is measured by the H-field probe at various distances. The results indicate that the H-field is essentially inverse proportional to the distance squared in the near-field region whereas it is slightly decreased by increasing distance at the far-field length. Furthermore, the effects of EMI on the heads are investigated by an evaluation of the changes of read head parameters including the bit error rate, head resistance, read back signal amplitude, and asymmetry parameter after applying the EMI to the TMR read heads in the perpendicular direction to the magnetization of pinned layer. Additionally, future work is suggested to evaluate the effects of EMI on the head parameters while applying EMI at distances closer than 2 cm. Also, the EMI effects on read head parameters should be detected under the operating condition of the read processes. Hence, the magnitude of EMI is insufficient to play a permanent role on the head parameters which can imply the latent failure of the head before the magnetic failure occurs.

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