Note: This paper contains references to the first generation of D-CDM units produced by Integral Solutions Int'l. At the time of this writing this was the only version available. Since this writing a second generation unit has been released which more closely matches the desired manual discharge waveform described in this text, including the ~500ps pulse width requirement.

Degradation of GMR and TMR Recording Heads Using very short duration ESD Transients

LYDIA BARIL, MARK NICHOLS, ALBERT WALLASH

***Abstract*-- ESD testing results for GMR and TMR recording heads using a Direct Charged Device Model (D-CDM) tester are reported for the first time. The D-CDM is intended to replicate the ESD event produced by metal-to-metal contact discharge that occurs as a charged component discharges to another object at a different electrostatic potential. This discharge, through a very short path to ground, corresponds to an extremely fast (<1 ns-wide), high amplitude current transient.**

The D-CDM tester produces a transient by first charging the device itself and then grounding the device with a mercury relay. The ESD testing was done in-situ with a quasistatic (QST) tester on Giant MagnetoResistive (GMR) recording heads. Resistance, amplitude, asymmetry and transfer curves were recorded after each ESD event. D-CDM physical failure voltages are much lower (4 to 5 V) than the ones obtained with Human Body Model (25-30V). Magnetic failure threshold can be even lower. We also report some D-CDM damage on Tunneling MagnetoResistive (TMR) recording heads.

***Index Terms*— CDM, ESD, GMR, and TMR**

I. INTRODUCTION

With the increased application of automated handling of recording heads during Hard disk Drive production, the well-known Human Body Model (HBM) no longer reflects the reality of ESD failure mechanisms. Damage will most likely occur from metal contact rather than from bare fingers. The purpose of a D-CDM (Direct- Charge Device Model) tester is to approximate the metal-to-metal contact discharge event that occurs as a charged component discharges to a metal object at a different electrostatic potential. In other words, a tester should reproduce quite precisely the discharge waveform resulting from metal to metal contact discharge corresponding to the "worst case scenario ", i.e. the discharge through a very short path to ground, with little capacitance and inductance. In the IC industry, automatic CDM tester proved unsatisfactory as designs contains significant parasitic capacitance and inductance [1]-[3]. We will show that while the tester used in this study does display such effects too, they are minor and it still allows studies of the effect on state–of-the-art recording head design.

II. REVIEW OF THE D-CDM TESTER

The tester used here is a new ESD D-CDM module for electrostatic discharge sensitivity testing from Integral Solution International (ISI) and can be used in situ with the ISI QST tester. It is drastically different from the field induced Charge Device Model as its use is much simpler: Devices are directly charged and discharged through a mercury relay and QST parameters are automatically measured after each D-CDM discharge.

Figure 1 shows a typical discharge waveform for a capacitor replacing the flex circuit of a Head Gimbal Assembly (HGA) compared to a manual discharge waveform [4] for the same capacitor. In the ideal case the ISI tester should have similar discharge as manual discharge, but there is about a factor 2 difference in amplitude and width of the pulse *(see Note above)*. While the D-CDM tester is not ideal, it is still orders of magnitude faster than anything available on the market and the results are certainly closer to reality than the HBM, with 150 ns pulse width and much lower currents.

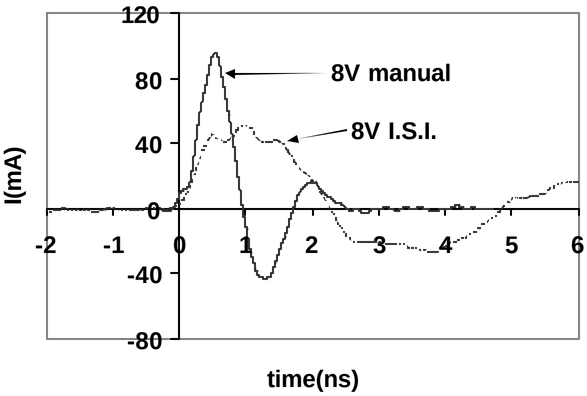

Fig. 1. Comparison between Manual discharge through a ½ in discharge wire to ground of a 5 pF capacitor charged with 8V and ISI automated tester discharge waveform under the same conditions. The ISI pulse is wider and has lower amplitude *(see Note above)*. Waveforms were measured using a 2GHz Lecroy DDA 260 oscilloscope and a Tektronix CT -6 current transformer

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III. RESULTS ON GMR HEADS

HGAs for 30Gbit/in^2 products were tested with the ISI D-CDM tester. The GMR stack as studied here consists of spin-valve read sensors with PtMn antiferromagnetic material and with synthetic pinned layers. The exact structures varied by vendor but all show very similar results. ESD D-CDM events were applied automatically to HGAs with increasing charging voltage. Resistance, amplitude, and other related QST parameters were recorded after each ESD event. QST curves were measured at 3.5mA bias current in the magnetic field range [-100 Oe; 100 Oe]. Figure 2 shows an example of amplitude degradation as a function of D-CDM charging voltage (V_DCDM). In this experiment no resistance change was seen before V_DCDM=5V but amplitude changes can be seen at much lower voltages. The transfer curve doesn't show any changes below 3.2V, but at V_DCDM= 3.2V, there is a 10 % amplitude increase. This 10% amplitude change corresponds to appearance of jumps in the transfer curve as shown on the figure. Transfer curve at VDCDM=0V and V_DCDM=3.2V are also shown figure 2 Sometimes an increase in hysteresis accompanies these jumps.

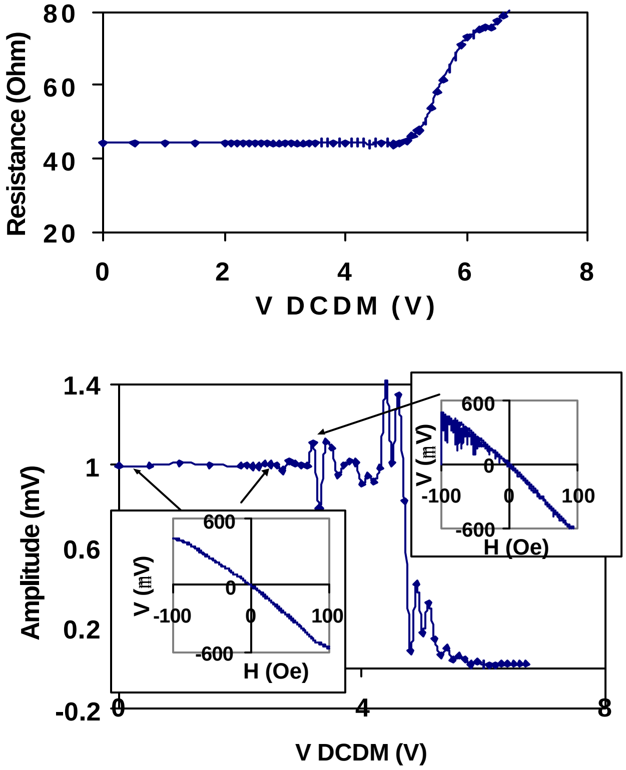

Fig. 2. Resistance and amplitude versus D-CDM voltage for a GMR head for 30Gbit/in2 product. Change in amplitude corresponds to increased noise.

IV. EFFECT OF POLARITY

Figure 3 shows amplitude versus V_DCDM for alternating positive and negative D-CDM events. In this experiment, there is no clear difference between the pulse polarities. Human Body Model studies on previous Head design [5], showed that during ESD testing, one polarity (the one with the field from the current "opposing " the pinned layer) was reversing the amplitude, and the other (helping the pinned layer) was not doing much damage until the onset of resistance change. In the present study, changes in amplitude do not necessarily correspond to a change of sign of the amplitude. Therefore we can conclude that de-pinning of the pinned layer might not be the only cause of amplitude change.

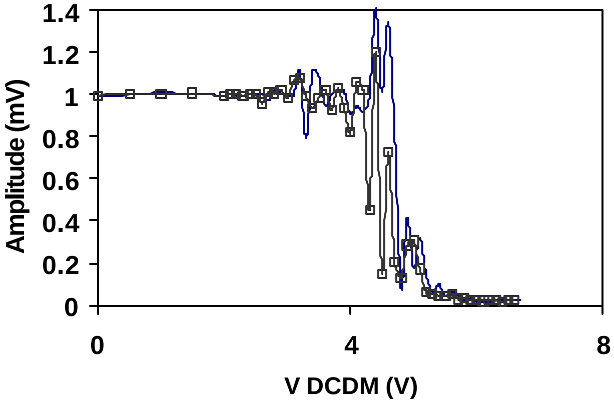

Fig. 3. Amplitude versus DCDM voltage for negative polarity (open squares) and for positive polarity (plain line) discharges applied to the same head.

V. COMPARISON WITH HBM

GMR Heads for 30Gbit/in2 products from four different vendors were tested at HBM and D-CDM for comparison. HGAs with similar resistances were chosen for HBM and D_CDM. Details for D_CDM are shown in figure 4: failure voltage for 2 % resistance increase and 10% amplitude change as function of resistance. As expected, and similarly to HMB, higher resistance correspond to lower failure voltage for the same vendor. However, magnetic failure voltage data doesn't show any clear trend. Table 1 and 2 report averages for both HBM and D_CDM. The first striking feature is the difference in level of failure voltage between HBM and D-CDM. Use of HBM testing for setting the voltage specifications will not prevent ESD damage by metal to metal contact. For both tests Vendor C remains the most ESD resistant. Vendor A, B and D seemed to have similar failure voltage at HBM but A and B are worse at D-CDM.

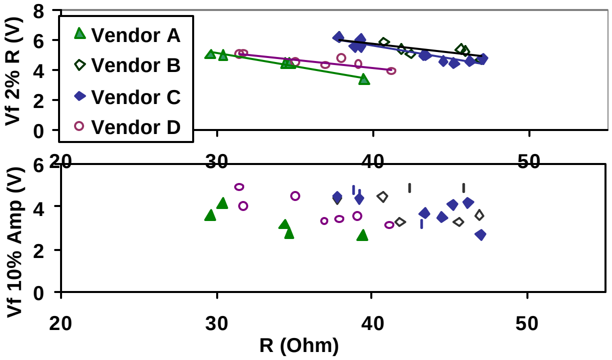

Fig. 4. Failure voltages for GMR Heads for 30Gbit /in2 products from

different vendors tested at D-CDM.

TABLE I
HBM RESULTS

average HBM	R(Ohm)	Vf2%R (V)	Vf10% Amp (V)
Vendor A	34.5	27.1	12
Vendor B	42	29.5	17.1
Vendor C	43.9	26.6	13
Vendor D	33.8	26.7	19.9

HBM Results. Average of 5 HGAs or more. The third column corresponds to the failure voltage for 2% Resistance increases, while the fourth to the failure voltage for 10% amplitude change.

TABLE II
DCDM RESULTS

average DCDM	R(Ohm)	Vf2%R (V)	Vf10% Amp (V)
Vendor A	33.7	4.5	3.3
Vendor B	43	5.4	4.1
Vendor C	42.5	5.2	4.0
Vendor D	36.2	4.6	3.8

D-CDM Results. Average of 5 HGAs or more from the same types of Heads as used for HBM above.

VI- TMR HEADS

Tunneling MagnetoResistive Heads for next generation product of approximately 0.2 µmx0.2 µm with a very thin Al_2O_3 insulator barrier (<1 nm) are studied with ISI D-CDM tester. Figure 4 shows sample data. Unlike GMR heads, the resistance decreases as TMR head fails. From 280 Ohm, the resistance starts to decrease slowly at 0.7 V, followed by a steep decrease at 0.9V to approximately 100 Ohm, and then a very slow decrease of resistance as V_DCDM is increased further. This behavior is different than large-scale TMR devices studied previously using HBM transients, which showed a very steep resistance drop to 0 at about 8 VHBM [6]. In reverse polarity, the steep drop in resistance occurs around 1.5V to 1.7V but behaves exactly the same way. This difference could come from the fact that the junction itself is asymmetrical [7]. As in GMR, magnetic changes also occur before any resistance change. In this particular case, it corresponds to an increase in both barkhausen jump and hysteresis in the QST transfer curve.

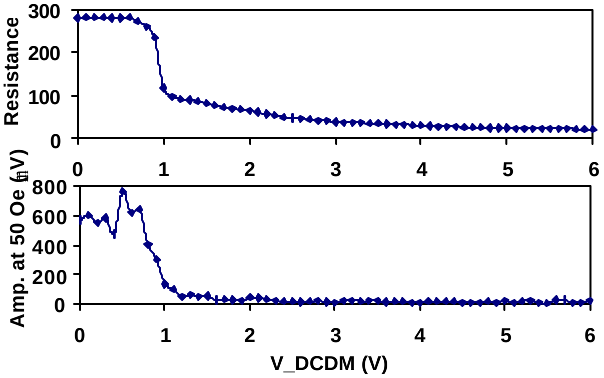

Fig. 5. Resistance and amplitude of TMR Head as a function of VDCDM

The value for failure is close to voltage breakdown reported in tunnel junction [8]. However a different mechanism is responsible for failure. Instead of applying a voltage across the TMR for quite a long time, as done in breakdown voltage studies, in our case, there is high current flowing through the junction for a very short time.

VI. DISCUSSION

Magnetic failure upon short ESD pulses occurs most often at much lower voltage than physical failure both for GMR and for TMR heads. This magnetic failure corresponds to increased hysteresis and barkhausen jumps, which are a serious concern for drive performance. Moreover, these magnetic failure voltages are unpredictable, as they do not follow a trend with resistance. Polarity studies showed that ESD pulses magnetic effects are not as simple as reversal of the pinned layer. Other possibilities include free and/or pinned layer instabilities. It is also possible that synthetic pinned layer contributes to a more confusing picture, although it is not yet clear exactly how. It remains to be shown which effects are due to new designs and which is due to D-CDM versus HBM. D-CDM transient, with its short pulse, high discharge current and its current undershoot (see figure 1) can give very different results [9].

VII. CONCLUSION

The D-CDM physical failure voltage for GMR (5V or less) and for TMR (1V or less) is very low. These values could drop by a factor 2 once the tester is optimized, as the current should double. Such low values are a real concern for production and testing lines. Of even greater concern are the magnetic instabilities developing at even lower voltage and that seem quite unpredictable.

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