Advances in Magneto Optical Static Event Detector Technology

Niels Jacksen (1), Lyle Nelsen (2), Donald Boehm (2). Tom Odom (3)
(1) ExMod Corporation, 830 Jury Court, San Jose Calif. 95112. Tel.: 408 998-5555, fax: 408 998-1414, e-mail: niels@uswest.net, (2) Novx Corporation, 830 Jury Court, San Jose Calif. 95112. Tel: 408 998-5555, fax: 408 998-1414, email: don@novxcorp.com, (3) VCD Technologies, 611 West Covina Blvd., San Dimas, CA 91773. Tel: 909 394-5292, fax: 909 394-5293

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ABSTRACT

Magneto-Optic Static Event Detectors, introduced at the 1998 EOS/ESD Symposium, have been demonstrated as a useful tool to detect low-level transients that damage Magnetoresistive (MR) and Giant Magnetoresistive (GMR) recording heads. Improvements in Magneto-Optic film characteristics, detector design, and wafer fabrication methods will result in enhanced sensitivity to those transients. Improvements in packaging and performance repeatability are described.

Introduction

Static Event Detectors (SEDs) are useful tools in the detection and control of ESD events during manufacturing, testing and end user handling of ESD sensitive devices. Magneto-Optic (MO) SED's have been recently developed(1) to provide a totally passive ESD detection capability. Although the MO detector's small size, wide operating temperature range and ability to reset and re-record Static Events are unique, improvements were needed in repeatability and sensitivity for many applications. A major application is in the magnetic recording head industry. Papers have been presented (2)(3)(4) demonstrating damage to MR and GMR heads due to ESD transients below the recording threshold of prototype MO SED's. This paper details the development and application of high sensitivity detectors, capable of detecting transients down to and below 5 volts.

MO detectors employ the Faraday effect(5), which rotates the polarization of a beam of light as it passes through a MO film. This effect, also known as Faraday Rotation, is exploited to detect and record an ESD event onto MO pixels. MO pixels are photo-lithographically delineated out of a thin film sheet of MO material using semiconductor wafer fabrication techniques. The ESD event will switch pixels that are subjected to a critical magnetic field which is determined by the magnetic and optical properties of the MO thin film. The magnetic field results from the ESD current transient in a conductor that is placed adjacent to or, in high sensitivity cases, directly over the MO pixel. The polarity and amplitude of the event can be determined by observing which pixels have been switched. A very high magnetic field will reset the pixel and make it available for re-use. High field strength permanent magnets are currently used as reset devices. There is no known limit to the number of times MO pixels can be reused without degradation to the MO properties of the detector. The detector has a built in fuse protection mechanism which is defined by the shape and composition of the metal stripe that is photo-delineated onto the MO SED wafer.

An ESD transient above the fuse level will melt the conductor thereby creating an open circuit. To increase sensitivity to low level ESD transients, the following design changes have been evaluated:

- The width of the sense line deposited onto the MO pixel has been reduced from 10um to 1.2um, resulting in an eight-fold reduction to the nominal 40 volt threshold of standard sensitivity detectors.
- MO pixels have been relocated to form a linear array. This improves the legibility of the amplitude labels photo-lithographically printed adjacent to the pixels. A linear configuration also facilitates a rapid ESD amplitude observation. The linear array also makes the device compatible with low cost automatic character recognition scanners that would dramatically lower the cost of observation in the production environment.
- Proprietary processes have been developed to move the sense line into the magneto-optic film, resulting in higher magnetic field strength at the Metal-MO pixel interface. This results in a 50% reduction in ESD threshold levels for the SED.
- Metallization composition has been modified to improve metal adhesion and compatibility with commercial high speed wirebond equipment.
- The magneto-optic properties of the thin film have been optimized to increase sensitivity to ESD transients.
- The detector architecture has been modified to allow for direct chip attach using solder bump flip chip technology.

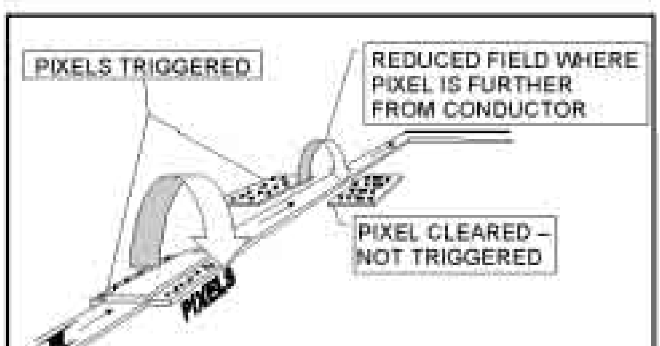

FIG. 1 – PRINCIPLES OF MAGNETO-OPTIC ESD DEVICE

A manufacturing development effort has also been initiated for continuous improvement in detector performance, repeatability and yield, thereby minimizing detector manufacturing costs.

Applications for high sensitivity MO SED's in the magnetic recording head industry are described.

Performance tests show improved sensitivity to Human Body Model (HBM), events. Additional characterization of both standard and high sensitivity SED's is needed to characterize performance changes resulting from:

a. Changes in ambient temperatures.

b. Changes in device performance due to adverse environmental conditions. Examples are:

   1. Loss of optical performance due to corrosion of the high reflectance layer caused by failure of the passivation layer.

   2. Degradation of fuse current by corrosion of the current carrying layer.

   On the flip chip device architecture, these two layers are one and the same.

Review of Magneto-Optic ESD Detector Technology

The Magneto-Optic (M-O) Static Event Detector described in this and previous papers(1) employs the Faraday Effect(5) to detect and optically record an ESD current transient onto a MO thin film detector. A strong magnetic field alters the thin film's magnetic state which rotates the degree of polarization of visible light passing through the film. A current pulse resulting from an ESD event will induce a magnetic field around the thin film conductor. If the field is of sufficient amplitude, it will then switch the magnetic state of the thin film from an altered state to a neutral state. This effect can be observed through a polarizing microscope. The critical field required to perform the switching function is equivalent to the collapse field in magnetic bubble memories. If the magnetic field is below the critical field amplitude, the thin film detector will remain in the altered state. The magnetic field strength at the thin film MO detector depends on the configuration of the conductor and its distance to the thin film detector. These factors are critical in determining the ESD sensitivity levels of the set of pixels delineated onto the detector. Figure 1 demonstrates the principle of operation of the detector. The magnetic field lines are shown surrounding the conductor. The altered optical states of the pixels are shown schematically as a shifting of the polarization vectors. Although polarization rotations are small, less than 10% in most cases, the rotation will produce a significant contrast, observable through the polarizing microscope. Figure 2 shows the details of Magneto-Optical light modulation (Faraday Effect).

Figures 3 and 4 show micrographs of a prototype high sensitivity SED. One pixel has been switched by an electro-static event.

These pixels exhibit three stable optical states: light rotated counterclockwise, neutral, and light rotated clockwise. The neutral state is often called the ‘striped’ state as regions of clockwise and counterclockwise domains are observed on a single pixel.

When the current in a conductor near a pixel reaches a critical level, the pixel will switch to its neutral (striped) state. In the photograph, the pixels of the ESD sensing die were originally all set to a common altered state. The ESD current induced the +A pixel to switch when the magnitude of the event exceeded the critical threshold level in that pixel. The switched pixels are seen as striped; the unswitched pixels are uniformly bright.

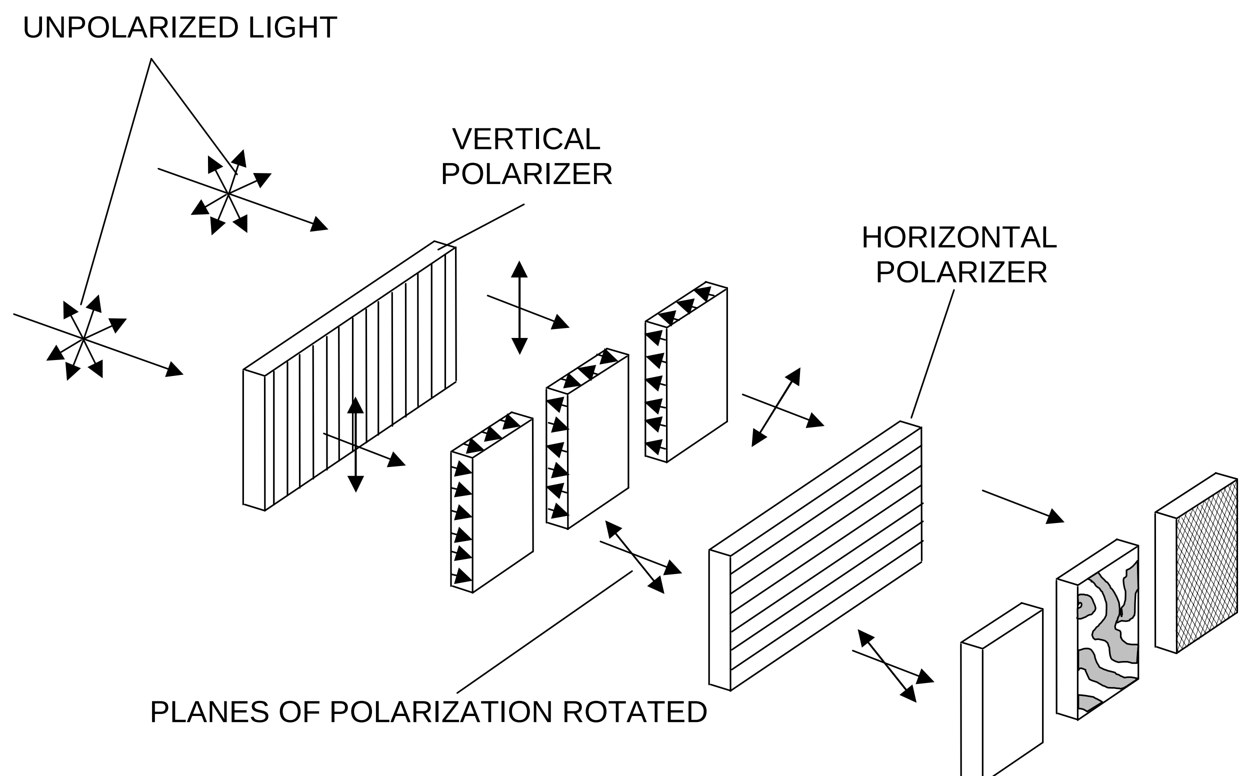

FIG 2 SCHEMATIC OF MAGNETO-OPTIC ESD DEVICE

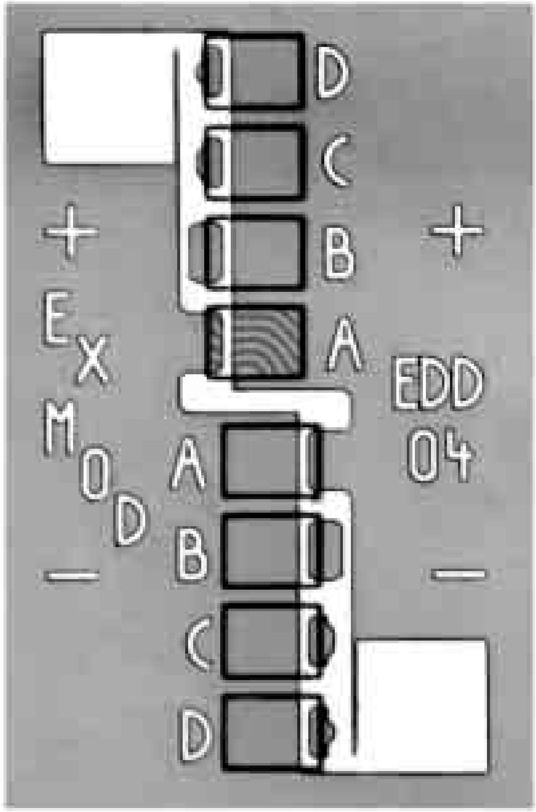

Figure 3. Photomicrograph of a High-Sensitivity M-O ESD Detector

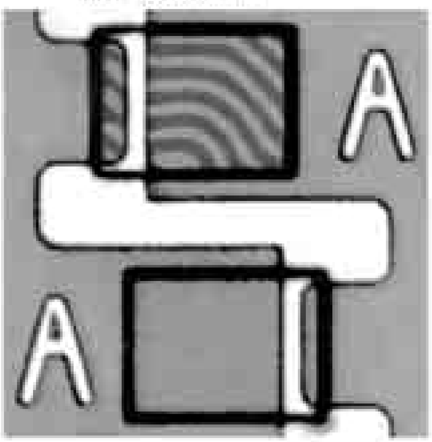

Figure 4. Detailed Neutral State of a ESD Detector

The contrast ratio between the bright and striped regions can be greater than 50:1. These switched detectors are easily reset externally, resulting in no degradation to future performance.

The performance definitions of the prototype ESD detectors are:

1. ESD current levels. These discrete levels can be related to ESD voltage transients using Ohm's law (V=IR) with R being the cumulative series resistance of the detector resistance and the input resistance of the ESD Simulator.
2. Polarity. If the conductor lines are placed adjacent to the pixel, the events are polarity sensitive. If they are placed over the center of the pixel, detection is polarity insensitive.
3. Fuse current level. In most cases, the fuse current should be as high as possible to maximize the number of times the detector can be reused.

Design of High Sensitivity MO ESD Detectors

MO detectors have been redesigned to achieve the low ESD transient detection levels known to degrade MR and GMR devices. Other devices, such as infrared detectors and unprotected field effect transistors[6][7], have similar ESD degradation thresholds.

High Sensitivity MO ESD Detector

Features of this high sensitivity detector are as follows:

Decrease in Sense Line width.

Sense line width is one of the critical parameters that determines the switching field of the MO pixel. The theoretical derivation of that relationship follows Maxwell's equations. In a magnetostatic simplification, the magnetic field is related to the current density. The strength of the magnetic field in a simple two dimensional conductor is

$$I = 2\pi r H \quad (5)$$

Where I is the current in the sense line, r is the radial distance from the conductor and H is the magnetic field strength in Amps/Meter.

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H_{coll} is defined as the collapse field needed to switch the MO pixel from the altered to the neutral state. Using typical values of H_{coll} as,

$$\mathbf{H_{coll} = 100Oe}$$
$$\mathbf{= 7.9\ e\ 3\ Amp/Meter}$$

Table I shows the calculated improvement in switching threshold between standard and high sensitivity design sense lines.

Table I Sensitivity vs Line Width

Sense Line width (μm)	ESD Threshold (mA)	HBM Voltage (1500 Ohm Load)
10	80	120
1.2	10	15

- **Linear pixel array.** The high sensitivity MO SED design consists of eight linear 70um X 70um pixels on 75um centers. Advantages of this configuration over the previous serpentine structure are:
  - o Improved visibility of switched pixels which enhances the speed and accuracy of manual ESD detection.
  - o Improved legibility of the HBM equivalent voltage level designators located adjacent to each MO pixel.
  - o Compatibility with computer controlled scanners containing character recognition software.
- **Conductor Redesign.** The Conductor stripe was redesigned to achieve higher fuse protection levels. The width of the present conductor, shown in Figure 3, does not change shape as it passes alongside or over the MO pixels. A high amplitude ESD transient will 'blow' the fuse at its weakest link, which is typically where it climbs up and down the side of the high sensitivity MO pixel. The new high sensitivity design necks down to the desired cross section only where it is needed, at the top of the MO pixel. The conductor cross section

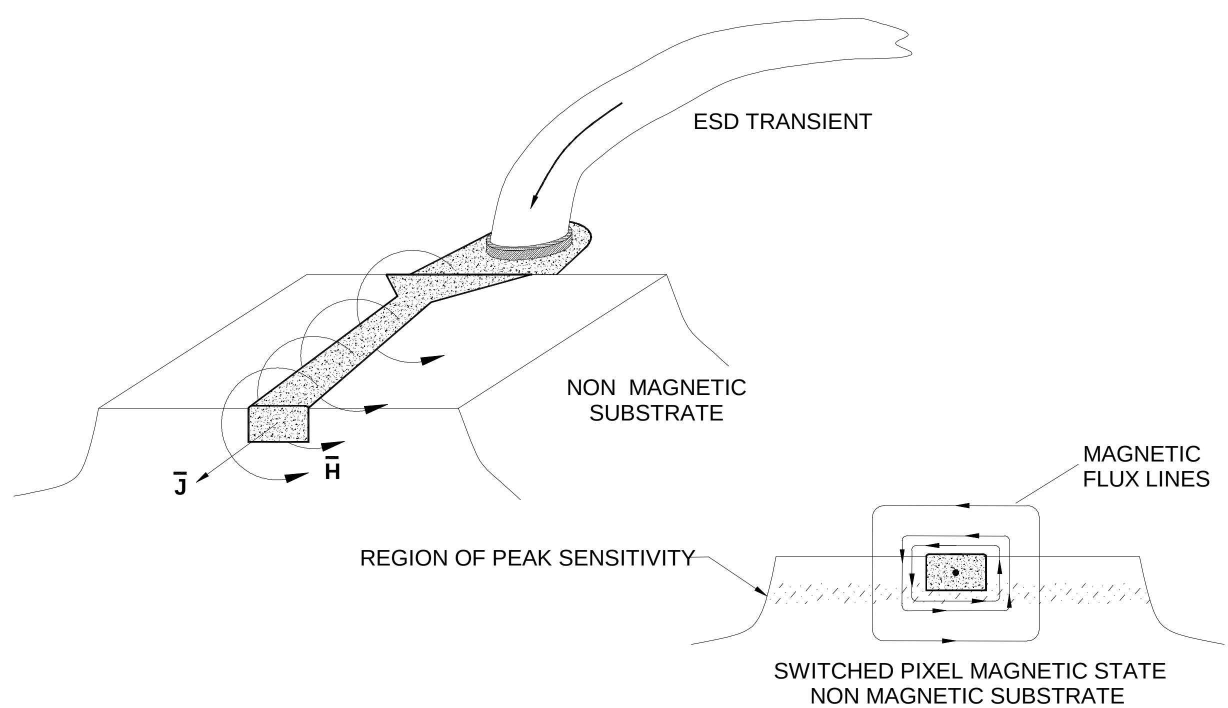

FIGURE 5 BURIED LINE CONDUCTOR

is much larger where it climbs up and down the side of the MO pixel. This design change substantially increases the fuse current, as compared to the old design.

- **Buried Sense Line.** Figure 5 is a schematic demonstrating a buried sense line MO SED. Proprietary processes have been developed to micro-machine a via for the MO thin film. The vias are then filled with conductor material, forming the sense line. Width and height of the line determines the magnetic field strength generated by the ESD transient. The magnetic field adjacent to the pixel for a fixed transient current is roughly doubled due to a 50% decrease in the equivalent distance from the center of the conductor to the MO material.

  Further increases in sensitivity can be accomplished using dipoles and thin film delineated windings. Micro machining techniques would then be required, substantially increasing the complexity and cost of the detector. Practical limits to this technology are, as yet undetermined.

- **Present Metallization Composition Improvements.** Aluminum was selected as the sense line material in the prototype MO SED's. Manufacturing characteristics of Aluminum are well known and Aluminum can be photo delineated to sub-micron dimensions using traditional Silicon VLSI manufacturing techniques. It is also an excellent reflector with >95% optical reflectance at visible wavelengths. This makes Aluminum an ideal candidate for the reflector material placed on the opposite side of the detector die. However, the use of Aluminum as the sense line material results in a number of issues;
  - Aluminum and Gold ultrasonic bonding have been difficult on the prototype MO SED's due to poor adhesion of Aluminum to MO substrates.
  - Because Aluminum has about 40% less conductivity compared to Gold, and has a relatively low melting point, it is an inferior choice as a sense line, compared to Gold.

  An alternative thin film stack, Ti-Cu/Au is being developed for use on the MO SED. A thin, 300 Angstrom thick, Titanium layer is used to improve adhesion to the substrate. The top layer consists of a Cu/Au alloy. These alloys are used in the magnetic head industry for low cost wirebonding of semiconductor components.

- **MO Properties.** The MO properties of the thin film have been optimized to increase sensitivity to ESD transients. The critical switching fields are determined by the composition of the garnets that are deposited on top of the non-magnetic substrate. Improvement in consistency of the MO stoichiometry will improve wafer-to-wafer switching uniformity.

- **New Package-less Designs.** Magnetic recording head manufacturing is one of the most competitive industries in the high technology sector. Costs are driven in part by the number and complexity of manufacturing steps, material costs, manufacturing yields and product return rates. Like many devices, costs for the MO SED are primarily driven by the package. 'Package-less Devices,' or Chip Scale Devices (CSD) are gaining increasing acceptance. The MO SED is an ideal candidate for CSD production for the following reasons:
  - The prototype high sensitivity MO SED is totally passive and requires no external power. Detector is corrosion resistant due to the use of Gold metallization.
  - Detector is small (.022 X .032).

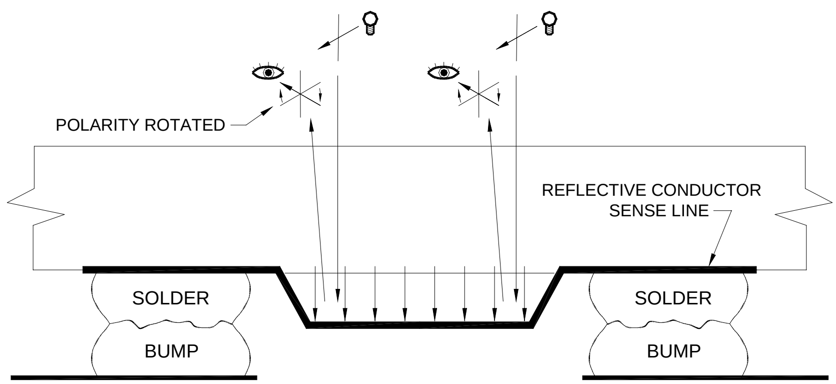

FIGURE 6 FLIP CHIP MO SED

Solder bumps will be fabricated onto prototype wafers using thin film, plating or spin coating technologies. After dicing, the bumped die can be processed through a standard semiconductor automatic flip chip die attach process. See Figure 6 for a schematic of a mounted flip chip MO SED.

Fabrication of High Sensitivity MO ESD Detectors

To produce a MO detector, an optically transmissive magnetic film is grown over a non-magnetic optically transmissive substrate in wafer form. The film is then patterned using photolithography processes and then etched to create individual pixels. The wafer is then selectively metallized to form the thin film conductive sense lines that lie adjacent to, or on top of the pixels. This thin metallic film will also serve as the reflective coating on flip chip mounted detectors. For traditional wirebonded detectors, the reflective coating is applied to the backside of the wafer using thin film deposition techniques. A passivation coating is applied to protect the thin film metallization. Flip chip detectors will then receive a ‘bump’ coating. 63%:37% Lead :Tin eutectic (Sn63) is the most common material used for flip chip semiconductor devices and will therefore be used to fabricate future flip chip SEDs.

After completion of processing, the wafer is sawed into individual die using standard semiconductor dicing techniques. The die can be assembled into appropriate packages or directly bump attached onto the ESD sensitive device. The sequence of wafer fabrication operations for both wirebond and flip chip configurations is shown in Figure 7, including patterning the substrate, Ion Milling the MO film and patterning of the sense lines. Figure 7 also shows the two basic forms of operation on the wirebond and flip chip configurations.

Suggested Applications in the MR/GMR Head Industry

There are a number of applications where the use of the MO SED can be cost effective.

1. The MO SED can be used as a test vessel in evaluating handling techniques that could generate ESD on Head Gimbal Assemblies.
2. The SED may be used as a recording device mounted on ESD sensitive piece parts such as Head Sliders or Mounting Combs that are delivered from a wafer foundry. Use of the MO SED would reduce and perhaps eliminate the need for expensive and time consuming inspections for ESD damage.
3. The detector can be used to evaluate transient pulses from the preamplifier to the head slider during operation, storage and end user handling. The sensor would discriminate whether head damage resulted from preamplifier pulses or from an external source. This capability would resolve whether head

damage actually resulted from an ESD event.

4. The detector can be used to monitor VCC voltage levels to power and ground planes that are generated by the PC board to the head drive external connector.
5. MO SEDs may eventually be used by manufacturers to insure that their ESD sensitive products have not been subjected to transients that would void a manufacturer's warrenty.

SED Detectors can be mounted on almost any surface. Non-conductive holding tools can be selectively metallized to form a sense plane on a portion of the tool surface where suspected ESD events occur. The detector is mounted onto the tool and connected between the sense plane and a ground plane. ESD events contacting the sense plane will be directed through the detector and the amplitude and polarity of the pulse will be permanently recorded. After the ESD sensitive device has been removed from the tool, the detector can be reset for reuse.

Experiment/Data

Evaluation runs containing the new MO SED configuration and materials were analyzed using a modified ORYX ESD simulator Model 700H, designed specifically for low level MR head ESD simulations. Test results are shown in Table II. Individual die were probed in wafer form using Micro-manipulator probes. A Nikon polarizing microscope was used to detect the MO switching. Individual die were subjected to progressively higher voltages until the domains shown in Figure 4 were observed to have switched. The same domain letters shown in Figure 4 are listed in Table II. After every test, the die was reset to determine repeatability of the detector test protocol. The data shows 5X improvement over previous detector designs. Additional improvements in repeatability are needed. It is anticipated that these improvements will result from a better understanding of high speed transient Electromagnetic (E-M) fields on Magneto-Optical materials. Improvements may also result from use of improved sense line architecture that is less dependent on transient E-M field fluctuations.

Voltage	Domains and Designed Thresholds						
	A+	A-	B+	B-	C+	C-	D+/-
±15	switched	switched	not	not	not	not	not
±25	switched	switched	switched	not	switched	not	not
±50	switched	switched	switched	switched	switched	not	not
±75	switched	switched	switched	switched	switched	switched	not
±100	switched	switched	switched	switched	switched	switched	not
±200	switched	switched	switched	switched	switched	switched	switched
±300	switched	switched	switched	switched	switched	switched	switched
±400	switched	switched	switched	switched	switched	switched	switched
±500	switched	switched	switched	switched	switched	switched	switched

Table II: Summary of HBM testing on MO Detectors

Summary

A new high sensitivity static event detector has been described. Initial characterization data demonstrate the ability to detect events as low as 15V, using HBM simulated ESD. The detector is economically fabricated on an extremely small scale using semiconductor wafer fabrication techniques. Because of its size, only a small space is needed for the ESD detector on a MR/GMR head, printed circuit board or packaging materials. Chip scale detectors have been designed to eliminate package costs and retain the small footprint of the SED. Applications for the high sensitivity SED are proposed.

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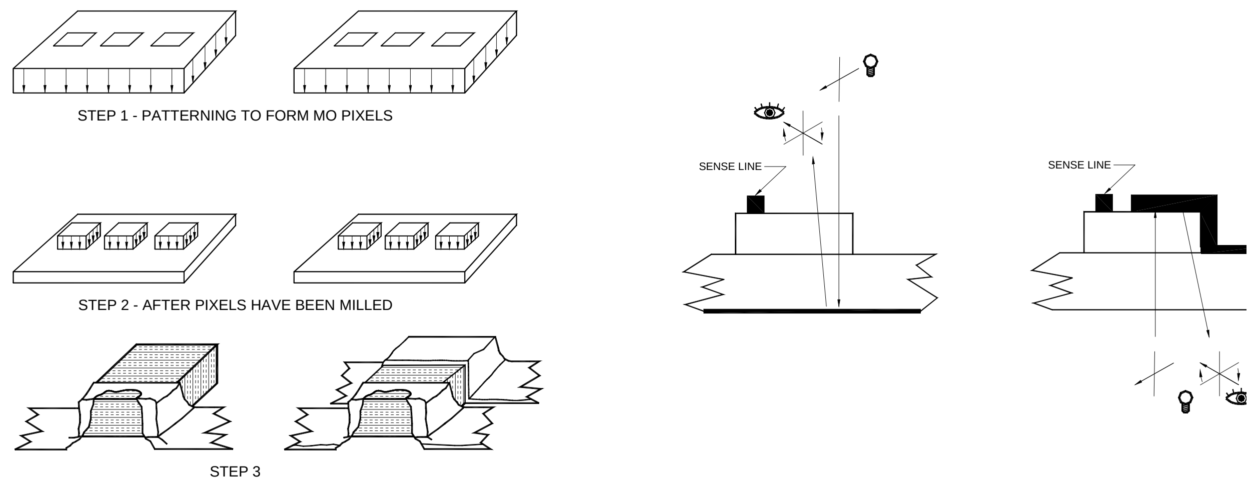

FIGURE 7 SEQUENCE OF OPERATIONS

Acknowledgements

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