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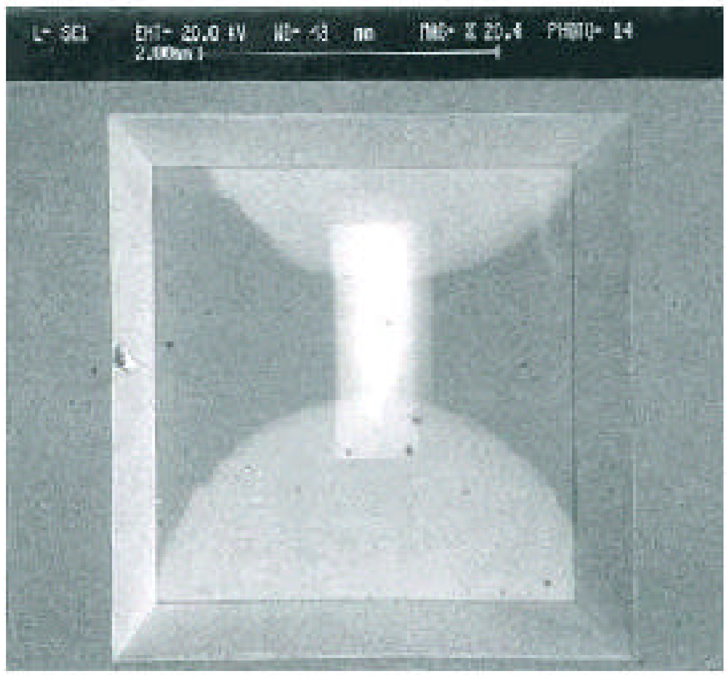

Giant Magnetoresistive (GMR) Sensor Microelectromechanical System (MEMS) Device

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The measurement of acceleration has been accomplished using several technologies in high-reliability applications such as guidance control, detonation, and shock/vibration measurement. Electromechanical, piezoelectric, piezoresistive, and capacitive acceleration sensors are available and the literature pertinent to giant mag-netoresistive sensors (GMR) for the above applications are scanty.

The GMR effect was recently discovered in sputtered metallic thin films consisting of magnetic layers a few nanometers thick separated by equally thin nonmagnetic layers. Large decrease in the resistance of these films is observed when a magnetic field is applied. The cause of this effect is the spin dependence of electron scattering and the spin polarization of conduction electrons in ferromagnetic metals. With layers of the proper thickness, adjacent magnetic layers couple antiferromagnetically to each other with the magnetic moments of each magnetic layer aligned antiparallel to the adjacent magnetic layers. Frequent scattering of electrons results in high electrical resistivity of the GMR device. If an external field over-comes the antiferromagnetic coupling, it achieves parallel alignment of moments in adjacent ferromagnetic layers; the spin dependent scattering of conduction electrons is decreased and resistivity decreases. The size of this decrease in resistivity can be 10% to 20% and higher in GMR materials with multiple nonmagnetic layers. The significant advantage of GMR sensor materials is the greater sensitivity to applied magnetic fields. This in-creased sensitivity of the sensor materials makes it possible to detect smaller change in the magnetic fields. Large signals from GMR material structures also help overcome electronic noise.

GMR sensors are composed of four thin films such as a sensing layer, a conducting spacer layer, a pinned layer, and an exchange layer. The thickness of all these layers is very thin except for the exchange layer which will al-low the conduction of electrons to frequently move back and forth between the sensing and pinned layers via the conducting spacer layer. The magnetic orientation of the pinned layer is fixed and held in place by the adjacent exchange layer, while the magnetic orientation of the sensing layer changes in response to the external magnetic field. A change in the magnetic orientation of the sensing layer will cause a change in the resistance of the combined sensing and pinned layers.

GMR sensors directly detect the magnetic field and they are sensitive to small changes in the magnetic fields, and can be used to measure position or displacement in linear and rotational systems. Some of the applications for GMR magnetic sensors are current sensing, linear or rotatory motion detection, linear or rotatory position sensing, ignition timing, throttle position sensing, etc.

DC magnetron sputtering has been used to deposit thin film multilayers in a nanometer thickness range in UHV camber to fabricate GMR sensor element. The silicon dioxide has been grown over Si substrate using thermal oxidation, which was used as a substrate in this study to fabricate GMR sensor element. The sputtering of GMR element materials was performed at room temperature in a Argon ambient. The structure of a typical spin valve is silicon/silicon dioxide/tantalum/copper/cobalt/FeMn/tantalum. Cobalt layer has been inserted between the permalloy and copper to enhance the GMR ratio and that will protect permalloy from mixing with the copper. Carbon and oxygen impurities in various layers have been observed to be reducing the GMR performance.

Thickness of the copper spacer layer, temperature stability, electrostatic discharge, change in magnetization, patterning of GMR element by lift-off process, annealing of hard magnetic thin film, and the field damage will influence the reliability of GMR characteristics. Cobalt and copper do not mix at moderate temperatures, however permalloy and copper do mix and if permalloy is used adjacent to copper, the spin valve will degrade around 200 $_{o}$C. GMR layers are extremely thin, only about 300 – 400 Å, so the temperature rise from a voltage spike can possibly melt the layers. There is also other possibility that of the magnetization changes if the temperature of the layer exceeds the Neel temperature of the antiferromagnetic layer. The GMR sensor material should have resistance to electrostatic discharge and resistance to thermal degradation.

The fabrication of GMR sensor involves three steps and they are as follows: a. fabrication of GMR sensor on the substrate, b. fabrication of the movable microstructure such as a membrane and finally, c. deposition of hard magnetic thin film onto the movable microstructure. Critical issues associated with the fabrication of a GMR sensor device are signal to noise ratio, geometry and lithographic definition of the spin valve on the substrate, magnetic properties of hard magnetic thin film, and process integration with surface and bulk micromachining processes.

Figure 1 shows the schematic of the complete GMR/MEMS sensor device. A silicon substrate has been chosen in this study and silicon nitride was deposited using low-pressure chemical vapor deposition (LPCVD) process. Silicon nitride on one side of the silicon substrate was patterned and plasma etched down to the silicon substrate. The silicon substrate was anisotropically etched until silicon nitride onto the other side of the silicon substrate to fabricate very thin silicon nitride membranes. Another silicon substrate has been chosen and the growth of silicon dioxide was performed by thermal oxidation. Giant magnetoresistive element has been fabricated using lift-off technique onto the silicon dioxide. These two chips can be bonded using anodic bonding or any other appropriate technique to assemble the device as shown in the Fig. 1. Figure 2 shows the manually packaged complete GMR sensor device that includes GMR element, silicon nitride micro-structure, and a hard thin film magnet deposited over the microstructure.

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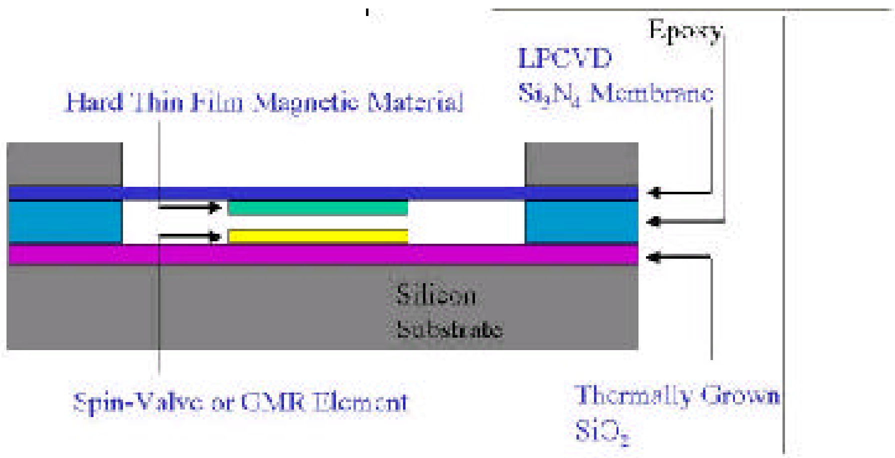

Figure 1. Schematic diagram of complete giant magnetoresistive (GMR) sensor device fabrication
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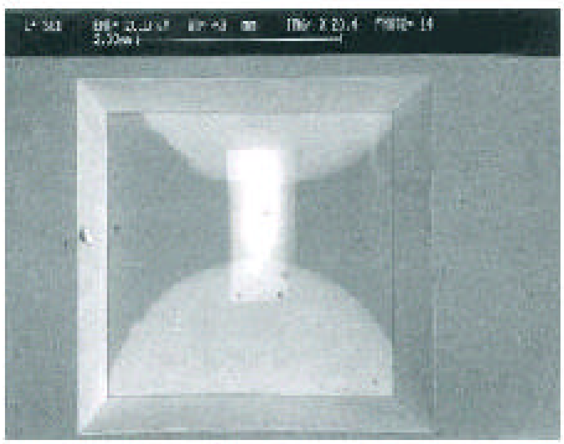

Figure 2. Scanning electron micrograph of the manually assembled GMR-MEMS sensor device.
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