Integrating Inspection Metrology

- ALD for DRAMs and Gates
- MEMS Microactuator for HDDs
- 300mm Test Wafer Stacker

FEOL: SPIE HIGHLIGHTS
- Immersion Optics to the Rescue
Hard disk drive performance enhanced by MEMS devices

Overview
Microelectromechanical systems technology is a collection of miniature sensors and actuators that are fabricated using semiconductor-manufacturing techniques. MEMS have been used since the early 1990s in airbag sensors and ink-jet printer heads. One promising new arena for MEMS devices is high-performance hard disk drives.

The need for microactuators
The need for inexpensive, high-performance data storage is skyrocketing. To meet increasing storage capacity requirements, disk drive manufacturers can either put more disks in a drive, which significantly increases component costs, or increase the amount of data that can be stored per disk by increasing areal storage density (i.e., the number of gigabits/sq in that can be stored on the disk surface). Increases in areal density require more precise head positioning as the read/write (R/W) head flies over the spinning disk. MEMS microactuators can be used to achieve the desired dynamics and precision control of the R/W head.

Design and fabrication considerations
MEMS fabrication techniques enable commercial microactuation due to their ability to produce devices of the size scale required, as well as the inherent cost advantages found in wafer-level batch fabrication. The magnetic microactuator (MAGMA) slider-level microactuator is essentially a very small electromagnetic voice-coil motor. Electromagnetic actuation provides the required forces using voltages that are readily available in the drive; electrostatic actuation would require much larger voltages to produce equivalent force. A current of 50mA will give an approximately ±5μm stroke. High-aspect-ratio coils structures provide low electrical resistance, minimizing power consumption.

The primary components for the MAGMA microactuator (Fig. 2), are a permanent magnet and conductive drive coil. In addition, high-permeability metal "keeper" elements are used above and below the magnet and coil to contain the electromagnetic field. Finally, silicon is used to create a rotor/stator structure with high-aspect-ratio spring flexures. On the bottom side of the silicon structure are cavities to which the slider (R/W head) and motor magnets are mounted. The top of the silicon...
structure has spacers to mechanically define the separation between the coil and the magnet. The MAGMA components are designed such that automated pick-and-place technology can be used for low-cost assembly.

Bulk silicon micromachining, as opposed to surface micromachining, was chosen because of the need for high-aspect-ratio structures. The high-aspect-ratio linear spring flexures used in the MAGMA are critical because they provide a large amount of stiffness perpendicular to the disk, while still remaining sufficiently flexible parallel to the disk, allowing a modestly sized driver to produce the needed stroke. Stiffness in the direction perpendicular to the disk enables MAGMA to withstand the high G-force specifications placed on disk drives during shock events such as a dropped drive. A deep reactive ion etching (DRIE) process is used to form the critical spring structures in the silicon substrate.

Drive coil fabrication

The fabrication of the copper drive coil utilizes a variety of methods (Fig. 3) [2]. The copper coils are formed by electroplating in a photopatterned, high-aspect-ratio photosistor mold (Fig. 4). The resist is subsequently stripped to allow for removal of the conductive plating seedlayer. Each coil layer is then encapsulated in a spin-on photosamagable epoxy, Microchem SU8, which has become extremely common in the MEMS industry for its high-aspect-ratio patternability as well as its mechanical and chemical robustness. Rather than build these components on a silicon substrate, they are fabricated on a metal wafer. This metal substrate will eventually be wet-etched from the opposite side to form the top keeper element.

Silicon body fabrication

The silicon rotor/stator body is formed using the DRIE process on a Unaxis DSE system. The DSE process utilizes the anisotropic silicon etch technique developed by Robert Bosch GmbH [3]. Figure 5 shows the silicon structure fabrication process. Approximately 50μm high mechanical spacers are formed by etching into one side of a 250μm thick, double-side-polished silicon wafer. These mechanical standoffs determine the precise separation between the top coil structure and the silicon rotor/magnet.

Next, oxide is deposited on the reverse side of the wafer with either thermal oxidation or plasma-enhanced chemical vapor deposition (PECVD). This oxide film is used as a hard mask for etching the silicon. A front-to-back contact aligner is used with standard lithography techniques to pattern the structure for the beams, slider cavity, and magnet/bottom keeper cavity. The oxide is then patterned with dry-etching processes such as reactive ion etching (RIE). The DRIE process is used to obtain vertical walls in the
narrow channels forming the beams. These beams, typically 10–50µm wide, act as spring flexures connecting the rotor and stator elements. Typical etching dimensions for these channels in this device are 50µm wide by 200µm deep. This etch goes completely through the remaining 200µm thickness of the silicon wafer (Fig. 5, step V). Figure 6 shows scanning electron microscope (SEM) images of a partially etched MAGMA structure.

During fabrication, the silicon rotor/stator devices are held into the wafer using breakaway silicon tabs [4]. This allows the components to be retained in wafer form after the through-wafer etch, and also for assembly of the other components (magnets, keepers, coils, sliders) to the silicon body at the wafer level. The tabs are formed in the same step as etching the beams. This can be accomplished by capitalizing on an otherwise undesirable etching effect called RIE lag, an aspect-ratio-dependent etching phenomenon. Silicon etch rate decreases as aspect ratio increases. A narrow trench (~2µm wide), which etches slower than the 50µm trenches defining the rest of the structure, does not etch completely through the silicon; the components are released out of the wafer by mechanical fracture of the tab structure in a controlled manner.

### Conclusion

MAGMA magnetic microactuators are fabricated using a collection of MEMS and conventional techniques, including DRIE of silicon and high-aspect-ratio electroplating. MAGMA devices have been successfully integrated and tested in HDDs. Substantial track-following improvement has been demonstrated internally during Seagate drive tests. The decision to include MEMS technology in commercialized products by HDD manufacturers continues to be a balance of performance benefits and the cost and risk associated with new technology.

### Acknowledgments


### References

1. US Patent 6,525,822 “Magnetic Microactuator.”

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