Sandia National Laboratories

MFG S&T Quarterly

MFG Science & Technology That Makes a Difference

May 2003—Vol. 1 No. 3

Atomic Layer Deposition of Wear-Resistant Coatings for MicroElectroMechanical Devices

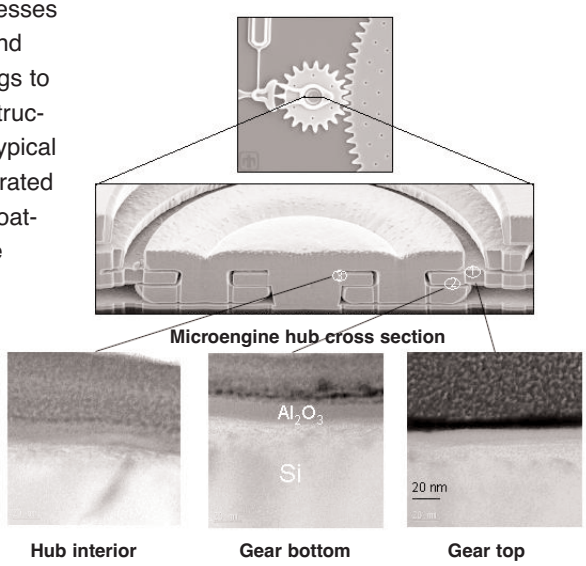
Friction and wear are major concerns in the performance and reliability of microelectromechanical (MEMS) devices employing sliding contacts. While many tribological coating materials are available, most traditional surface coating processes are largely line-of-sight techniques and are unable to apply conformal coatings to the high aspect ratio (height/width) structures such as gear hubs and teeth, typical of MEMS devices. We have demonstrated that thin, conformal, wear resistant coatings can be applied to silicon surface micromachined (SMM) structures by atomic layer deposition (ALD).

ALD is a chemical vapor deposition process that employs self-limiting surface reactions applied in a binary sequence, leading to atomic layer controlled growth. The self-limiting surface chemistry permits conformal coating of high aspect ratio structures, with monolayer precision. A binary reaction sequence for deposition of Al_2O_3, for example, using trimethylaluminum and water as precursors is as follows:

(A) $\text{-OH}^* + \text{Al(CH}_3\text{)}_3 \rightarrow \text{-OAl(CH}_3\text{)}_2^* + \text{CH}_4$

(B) $\text{-Al(CH}_3\text{)}^* + \text{H}_2\text{O} \rightarrow \text{-AlOH}^* + \text{CH}_4$

where surface species are indicated by the asterisks. Each half reaction involves the reaction between a gas phase precursor and a surface functional group. The surface reaction continues until all functional groups are consumed, and replaced with a new functional group. If the precursor is unreactive with the new surface functional groups, the reaction ceases at maximum coverage of one monolayer of reagent per half cycle. Application of the binary sequence ABAB… results in layer-by-layer controlled growth. At an appropriate process temperature where reactions are self-limiting, and sufficient exposure is allowed to coat all surfaces, deposition is extremely conformal and the process is relatively insensitive to other parameters such as pressure and exposure time.



Microengine hub coated with 10 nm of Al2O3 by Atomic Layer Deposition. Transmission electron microscope cross sections show uniform film coating on both exposed and shadowed surfaces.

The project investigators have constructed a viscous flow ALD reactor and introduced processes for depositing Al_2O_3 and ZnO. Future process development efforts will center on hard materials (metal nitrides) and solid lubricants (metal chalcogenides). To demonstrate the conformal coating ability of ALD processes they applied 10 nm thick film of Al_2O_3 on MEMS device structures with aspect ratio ranging from 0 to >100, shown above. Film thickness is uniform to within 5% on all surfaces and are shoichiometric Al_2O_3, with no evidence of contamination from other species, and are amorphous. Preliminary friction and wear data show that ALD films have promising properties for application to MEMS devices.

In addition to tribological films for MEMS devices, ALD processes can produce ultra-thin coatings for many potential applications in microelctronics, microoptics, 3-dimensional micro- and nanometer-scale structures, microfluidics, thermal and vapor barrier coatings, and others.

This project is supported by a Laboratory Directed Research and Development project and is a collaboration between researchers in 14100, 1800, 8300, and the University of Colorado

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Excellence in Project Department's Personnel & Production

Throughout the Manufacturing Enterprise (14111, 14181, 14186) signs are posted stating "Excellence in the Customer's Interest." Employees in these departments take several steps to assure excellence is established, not only with the products they measure and manufacture but also within themselves and the services they provide.

Employees in 14186-2 consist of experienced trades, journeyman, staff, and pioneering student interns with multiple skill levels. The experience obtained in projects, miniature machining, and AMTTP (14186-2) instills a commitment to provide a level of quality tailored to fit customer needs. Shop Lead-person Bill Vanselous handles customer orders, requests, and needs. With 25+ years experience, he's able to coordinate the variety of employees and jobs in the shop. He juggles an assortment of work schedules while recognizing educational requirements and time managements the students need. Bill sees that the customers are satisfied with quality products and services along with building quality employees and relationships.

(Excellence, continued on page 4)

Tech Updates

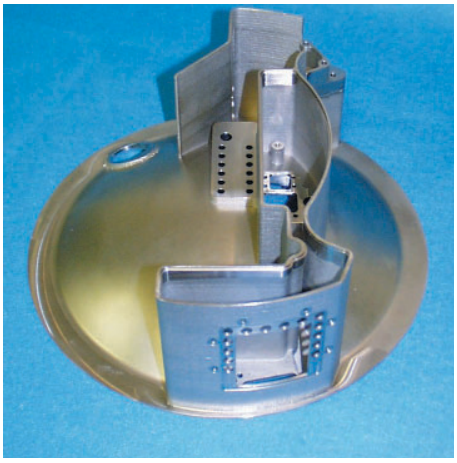
Hybrid fabrication process: machining + LENS®

The Manufacturing Enterprise (14111, 14181, 14186) recently completed a hybrid fabrication process that involved the machining of LENS® deposited geometry on a 12-inch diameter, domed, metal substrate. The goal of the project was to quickly produce a complex geometry prototype housing that could be used for design verification and testing purposes. The traditional process of fabricating a single housing from a solid billet of metal and thin-walled features with very high aspect ratio geometry on a dome presented time-prohibitive machining challenges. Another fabrication option was the investment casting of the housing, but this also proved to be difficult since only 3 housings were needed and the procurement of such low numbers resulted in no bidders.

Enter the hybrid fabrication process: machining + LENS.

The project began in October 2002, with the following processes and initial delivery of completed prototype housing in January 2003:

- The machining of a substrate that had a domed surface and added stock for finish machining after the LENS deposition.
- The LENS deposition of required housing geometry that included tall, thin walls and various thick pads and bosses made by spray depositing 316 stainless steel powder.
- Mechanical measurement of LENS deposition on stainless steel substrate using a coordinate measurement machine.
- The heat treatment of the part to annealed condition to minimize the internal stresses created by the laser welding process of adding geometry to the substrate.
- Machining of geometry on a 4- axis mill/turn center that included: turning of final diameters, milling of compartments, weld grooves, undercutting of shelves, windows, and drilling and tapping on both sides of the housing.
- Machining of a boss requiring a 5-axis process, both front and back.
- Sinker CNC electro-discharge machining of a side window that was unreachable using other methods.
- Electron beam welding used to attach an instrument shelf to the sidewall that has over-hanging geometry.



The hybrid process enabled fast fabrication of complex geometries infeasible with traditional processes.

The hybrid fabrication team consisted of Michelle Griffith, Mark Ensz, David Gill, Daryl Reckaway, Don Greene and Mark Harris from the Mechanical Engineering Dept.; and Doug Abrams, Bill Vanselous, John Cresap, Tony Bryce, Mike McCreakin, Erik Hart, Jo Bridge, Clarence Esquibel and Jonathan Lee from the Manufacturing Enterprise

By succeeding in establishing a new hybrid fabrication process, Sandia National Laboratories has an alternative to investment casting and traditional machining to manufacture components with frequent design iterations and the need for quick product delivery. With more opportunities to machine LENS deposited materials the Manufacturing Enterprise will establish machining and heat treatment parameters to help solidify this new process and create new partnerships.

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The Manufacturing Enterprise Keeps Pace with New Technology

The Manufacturing Enterprise recently installed a new "cutting edge" 5-axis mill/turn-machining center. The Mazak Integrex e-650H is a combination horizontal turning machine and multi-axis horizontal milling machining center. Installation was completed in February and the center is already cutting chips and filling hoppers by fabricating large aluminum structures.

The machining center will enable the manufacturing of large pieces of hardware by performing turning, drilling, milling and inspection operations on a single machine tool. This ability will reduce the number of machine set-ups resulting in less time to manufacture components and expedite the delivery to customers.

The new machine tool has a build envelope of 36-inch diameter swing and 120-inch between centers. It is equipped with an 80-position Automatic Tool Change (ATC) magazine, laser tool measurement system, large boring bar set-up with interchangeable ATC heads, XYZ axis traverse rate of 1575 inch/min and a work measurement system for on machine part acceptance.

The team, Walter Mclain, Roy Bonsack and Thomas Kaufmann, recently completed turning and milling programming training in Florence, Kentucky and are operating the 5-axis mill/turn machining center 2 shifts a day.

The capabilities of this new machining center are well suited for customers requiring fabrication of hardware that have complex geometries associated with monolithic housings, substructures and large-scale components.

This new machine tool will enhance the strategic partnerships with customers, as they seek manufacturing solutions and delivery of hardware.

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The new Mazak machining center with Roy Bonsack (left) and Walter Mclain.

6S Events Successfully Debut in Mfg. S&T Center

The Ceramics and Glass Department supports the SNL neutron generator production mission by manufacturing War Reserve (WR) active ceramics components (current stacks, rods, and voltage bars) used in ferroelectric power supplies. The department is interested in implementing lean/six sigma methodology to increase production efficiency and to provide efficient space utilization within our production layout. One key enabling activity for this implementation has been the use of 6S (Shine, Sort, Straighten, Standardize, Safety, and Sustain) Events, which are a focused, multi-day team effort to reorganize and improve the efficiency of a specific workspace. Recently, staff completed two 6S Events related to trades' personal space consolidation and grinding activities. These two events were closely linked since the movement of trades' personal space outside of the laboratory facilitated many options for equipment rearrangement. Shared personal space modules are now available to accommodate up to 30 trades personnel.

These two 6S Events featured outstanding support by personnel in the Facilities and Management Operations Center, Industrial Hygiene, and Neutron Generator Production. ES&H challenges for the grinding 6S Event were significant since the grinding room is considered contaminated with lead oxide due to long term grinding operations with ferroelectric Lead zirconate-lead titanate (PZT) materials. Twelve major pieces of equipment, and their associated utilities, were moved or rearranged during the event, including the identification and removal of three surplus items. This action enabled the creation of separate current stack, rod, and voltage bar grinding cells with standardized grinding and non-grinding equipment, as well as the establishment of a centralized equipment area for common items required for the grinding needs of the three component production operations. More functional laboratory furniture with respect to a grinding shop environment was obtained to displace generic laboratory furniture. Tools were also standardized across three different levels: general, equipment-specific, and personal measurement devices.

Before (top) and after (bottom) pictures show the 6S difference at three levels. Left, the overall workspace is spacious, organized and uncluttered. Center, new workstations are functional and ergonomic. Right, hand tools are organized and easy to find.

The benefits of these events were outstanding in terms of efficiency gains in both people and product flow for active ceramics production operations. At least as significant, however, is the increased pride and ownership demonstrated by production floor personnel in the design, reorganization, and sustaining of this new more efficient workspace. The department plans to further implement lean/six sigma methodology in other active ceramics-related production areas, as well as further spreading the positive benefits of such methods to other Mfg. S&T Center departments.

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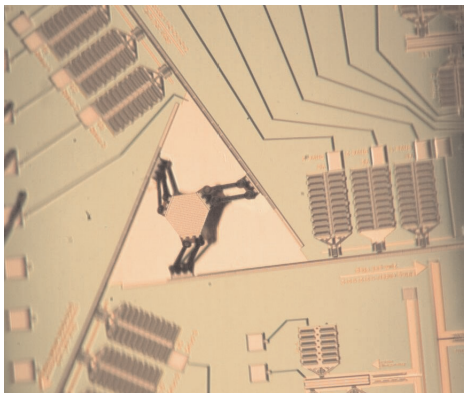
"It's the little things that make life worth living..."

On-Chip Spatial Position Devices and MicroDrop Ejectors

Since 1998 there have been on-going collaborative research efforts between members of the Mechanical Engineering Production Department (Gilbert Benavides, Ed Wyckoff and Bernie Jokiel) and members of the MEMS Device Technologies Department (Jim Allen and Paul Galambos) that have created very exciting and useful SUMMiT-V MEMS devices for meso-scale manufacturing applications. Two major successes of these collaborative efforts are the creation of spatial motion control devices for on-chip particle positioning and piston-driven fluid drop ejectors for the deposition of very small fluid droplets.

The CNC Micromachines LDRD completed at the end of FY02 demonstrated devices that are built in a planar state and then "popped-out" of the fabrication plane to provide controlled motion along arbitrary, three-dimensional (3D) paths. The devices are microscopic Parallel Kinematic Mechanisms (PKMs) that take up 1-3mm^2 of area on the surface of a microchip. These devices may be designed to produce different types of spatial motion including XYZ translation only, piston-tip-tilt, and spherical. Each device consists of three stationary Linear Stepping Track Drives (LSTDs - 2 μ step size, producing 100_N at 80V) that connected to a platform through semi-rigid jointed links. Simultaneous control of the linear position of the LSTDs allows the platform's position to be controlled in space.



An XYZ MEMS device attached to three LSTD's is shown popped-up above the fabrication plane. The platform is 230 microns across.

The Microdrop Ejector LDRD is an on-going project started in 2001, which has the ultimate goal of demonstrating a system capable of patterning microscopic fluid droplets in a precisely controlled manner on a substrate. The droplets are generated by an array of specially designed piston-driven ejector mechanisms capable of rapidly ejecting 2 μ diameter droplets. The ejector array is controlled spatially by a set of high precision, servo controlled stages. Drop placement and drop diameter is actively controlled by a vision system.

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Insider News

DOE Weapons Award of Excellence

According to Tom Hunter, VP, Nuclear Weapons Strategic Business Unit, "The tradition of honoring those that do great work in our Stockpile Stewardship program is long-standing… The award was created to give special recognition to those people directly associated with the stockpile modernization program… [The award recognizes] the special contributions of selected individuals and teams in meeting mission requirements."
Selection is determined at Sandia by NW deputies on behalf of the Program Directors. Winners are then submitted to NNSA headquarters.

Ken Peterson

Ken Peterson and the Common Radar Redesign Team—Awarded for excellence in engineering during the redesign of the Common Radar.

Ron Stone

Ron Stone and the Glass-to-Metal Seal Process Improvement Team—Characterized process requirements to achieve robust glass-to-metal seals while meeting programmatic time constraints.

Paul Cunningham

Paul Cunningham and the Neutron Generator Process Development Team (PDT)—The team provided accelerated development of laser weld, assembly and cleaning processes to support production of a Neutron Generator Subassembly in 2001. The PDT delivered reliable, documented manufacturing drawings and processes to support subassembly and qualification lots in 2001.

Kudos

Howard Arris and Manny Trujillo were recently honored by having their technical presentation at the October 2002 Electrical Manufacturing and Coil Winding Conference selected for publication in the spring 2003 edition of Magnetics and Business Technology Magazine. The title of their publication is "Development of A New Epoxy Encapsulant For Magnetic Components."
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ES&H Photo Contest Winners

Carla Chirigos (top) and Mike Sanders (right) tied for 1st Place in the New Mexico category in the 2nd Annual ES&H photo contest. Other winners were: **Kauai**— Richard Padilla(1st), Danielle Nieto (2nd);**Tonopah**—Stephanie Salinas(1st), Annemarie Rader(2nd); **NM**—Herbert Sutherland (3rd); and **Honorable Mentions** to Jennifer Payne, Dick Jones, TJ Roseth and Tim Goering.
The Third Annual ES&H photo contest is set for December 2003-February 2004.
Contact Stephanie Salinas, ssalina@sandia.gov.

MS&T Participates in Corporate Mentor Program

The Corporate Mentor Program addresses Sandian's business needs for the development of people, for the appreciation of diversity, and also capitalizes on experience and skills of long-time Sandians. There are a number of significant benefits for both the Mentor and the person being mentored.

Mentors have the opportunity to share critical program, organizational, and cultural knowledge, as well as share mutual interests and ideas. Mentors can make a difference by positively impacting another person's career and may also benefit from personal and professional growth.

Persons being mentored benefit from enhancing their understanding of corporate organizational strategy, direction and programs. They have a confidante and advisor who can help address career issues and optimize personal and professional development efforts.

Bev Silva has volunteered to be the Mfg. S&T coordinator and has been working on recruiting Mentors and "Mentees" for the FY03.To find out more about the history, benefits, and to join this program please visit: www.irn.sandia.gov/HR/Training/ecd/mentor.htm

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(Excellence, continued from page 1)

He offers experience and advice, mixed with patience, tolerance and respect while acknowledging the skill level of each intern. Bill values our customers and recognizes the need for developing a good reputation. He explains that a machinist's reputation clearly is established by their quality of work. When a project is completed, the machinist signs it off indicating that the product is correct and complete to the specifications necessary and ready for delivery.

This 14186-2 machining team provides manufacturing service and project management to produce R&D hardware, small-lot production, test fixtures, and laboratory equipment. Their machinery includes multi-axis live spindle tooling lathes, CNC lathes, CNC milling machines, RAM and wire-cut EDMs, precision miniature machine tools and a CNC high speed machining center. They use customer provided solid models to manufacture hardware or they can produce the solid model from sketches and blueprints. The machinists are able to build, procure, and assemble unique prototype production hardware with diverse quality requirements. They have the capability of manufacturing parts ranging from microscopic sizes to proportions measured in feet and tons.

Student interns are led by Chuck Townsend and Jack Stephens who are busy mentoring 16 student interns this spring. They spend their days furnishing guidance while working one-on-one with students on job processes and training, while providing steps to success for all students. Members of this team are motivated and competent. They're trained to standards, which determines specific job performances and employee accountability. When a part is completed and the machinist checks and signs the quality checklist, the customer can be assured quality is what they will receive!
Contact: Doug Abrams (505-844-1124, dgabram@sandia.gov

Hands-on Minds-on Technology Programs

Sandia and the Diversity, EEO & AA Services Department sponsor three Science and Engineering programs that serve as educational supplements to middle school students. Each program targets a specific ethnic group but is available to students of other ethnicities. MANOS, the Dream Catcher Science Program and HM Tech have their programs in either February or June. Brenda Barajas-Romero coordinates the MANOS program while Steve Baca and Phil Gallegos, among others, serve as volunteers. Tricia Toya coordinates the Dream Catcher Science Program with the help of planning committee members Ernie Correa, Miriam Hilborn, and Jason Tillotson. The deadline for June registration is quickly approaching. Interested students and volunteers are encouraged to contact Trisha Toya at 845-9019, pltoya@sandia.gov.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2003-1397P