Fabrication of a Fully-integrated Multiwatt µTurboGenerator


Sponsorship: US Army Research Laboratory Collaborative Technology Alliance

There is a need for compact, high-performance power sources that can outperform the energy density of modern batteries for use in portable electronics, autonomous sensors, robotics, and other applications. Building upon the results presented in [1], the current research is aimed at fabricating a fully-integrated, multiwatt micro turbogenerator on silicon that can produce 10 W DC output power (Figure 1). One of the main challenges involves the seamless integration between silicon and the magnetic components required to generate power. The generator requires a NiFe soft magnetic back iron and laminated stator for flux redirection as well as NdFeB permanent magnet pieces to serve as flux sources (Figure 2). In addition, copper windings must be fabricated above the laminated stator to couple to the alternating flux in order to extract electrical power from the machine.

Great strides have been made in the past year to quantify the requirements on the magnet pieces that will go into the rotor housing. Manufacturing accuracy of the pieces is critical because variations in the magnet geometries create an overall rotor imbalance, which can cause the rotor to crash during transcritical operation. A procedure in which the gaps around the magnet pieces are filled with solder and then polished back using chemical-mechanical planarization has been developed; this process can reduce the effective imbalance of the rotor by an order of magnitude.

The assembly and packaging procedure for the turbogenerator is also critical because the embedded permanent magnets cannot withstand temperatures much above 150 °C. This temperature restriction rules out the use of fusion bonding for the final die-level assembly after rotor insertion. Based on results presented by Choe, et al. [2], an eutectic In-Sn bonding scheme that requires only 140 °C has been researched. In this scheme, Cr/Au is deposited on one bonding surface and Cr/Sn/In/Au is deposited on the other surface; both depositions are done using an e-beam evaporator without breaking vacuum. By painting no-clean flux on both surfaces and compressing the dies together on a hot plate, we form the bond.

![Figure 1: Conceptual rendering of the fully-integrated generator. Back iron and magnet pieces will be inserted into the empty cavities of the rotor, which will be supported by gas thrust and journal bearings. Electrical connections are taken out from the backside of the die.](image1)

![Figure 2: Magnetic rotor test structure with back iron plated and sample magnet pieces inserted. The magnets shown in this photo were not manufactured to the correct size, but they demonstrate what a completed rotor might look like. (Courtesy of F. Herrault, GIT)](image2)

REFERENCES


A MEMS-relay for Power Applications

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Sponsorship: NSF Collaborative Research: Atomic Plane Electrical Contacts

Contact travel and heat dissipation are important requirements of electrical power switching devices such as MEMS-relays and MEMS-switches. Whereas low-power MEMS-based RF switches have been vigorously studied, few studies have been reported on high-power MEMS-relays. This paper presents a MEMS-relay for power applications. The device is capable of make-break switching; has large contact travel, on the order of 10’s of µm; and has low contact resistance, on the order of 120 mΩ. Testing has demonstrated current carrying capacity on the order of several amperes and hot-switching of inductive loads, on the order of 10mH, without performance degradation.

The MEMS-relay, shown in Figure 1a, is bulk micromachined in (100) silicon and bonded to a glass substrate. Anisotropic etching is used to fabricate the oblique and parallel (111) contact surfaces, having nanometer-scale surface roughness [1]. Figure 1b shows a cross section of the open fabricated contacts. An offset between the wafer-top and the wafer-bottom KOH masks produces the contact geometry shown. The silicon contact metal surfaces are created by evaporation and electroplating with a conductive film, shown in Figure 1c. A thermal oxide layer provides insulation between the actuators and the contacts. Deep reactive ion-etching (DRIE) is used to pattern a parallelogram-flexure compliant mechanism and a pair of rolling-point “zipper” electrostatic actuators [2]. Nested masks are used to pattern both wafer-through etches. Figure 2 illustrates the process used to fabricate the device.

**REFERENCES**


A Silicon-etched, Electrical-contact Tester
Sponsorship: NSF Collaborative Research, Atomic Plane Electrical Contacts

We are developing a bulk micromachined contact tester to investigate the electro-tribological performance of micro- and nano-structured planar electrical contacts [1]. The test device features parallel, planar, nanometer-scale surface roughness contacts etched in silicon coated with thin conductive films. Contacts used in microsystems, probes and interconnects are subject to heat dissipation and to electro-mechanical tribological effects. With an understanding of how nanoscale surface and subsurface material structure affect electrical contact resistance and mechanical contact wear, a deterministic manufacturing process could be developed to design electrical contacts from crystalline plane surfaces as potential high performance contacts for MEMS devices and related applications.

The microfabricated contact tester, shown in Figure 1 and in Figure 2, consists of a pair of parallel planar contact surfaces with nanometer roughness patterned onto two (100) Si substrates. Anisotropic etching is used on one of the substrates to create a membrane that serves as a compliant mechanism for the contact tester. A thin conductive film, i.e., Au, is patterned onto the contacts in a Kelvin configuration. The two-piece tester architecture allows for inspection of the contacts before, during, or after testing without destruction of the test device. In one embodiment of the tester, a quasi-kinematic coupling enables the alignment between the substrates while providing the initial gap between the contacts. Similar quasi-kinematic designs fabricated in silicon substrates have reported repeatability on the order of 1 micrometer [2]. In a second embodiment of the MEMS-tester a patterned oxide film is used to provide the initial space between the contacts. The tester will be loaded using a commercial nanoindenter to bring the surfaces into contact as contact resistance is measured as a function of the force.

Figure 1: Schematic view of the contact tester.

Figure 2: Exploded view of the contact tester. The back side of the top coupon indicates the patterned metal used for the Kelvin contact configuration.

REFERENCES
A novel sensing technology for unmanned undersea vehicles (UUVs) is under development. The project is inspired by the lateral line sensory organ in fish, which enable some species to form three-dimensional maps of their surroundings [1-2]. The canal subsystem of the organ can be described as an array of pressure sensors [3]. Interpreting the spatial pressure gradients allows fish to perform a variety of actions, from tracking prey [4] to recognizing nearby objects [2]. It also aids schooling [5]. Similarly, by measuring pressure variations on a vehicle surface, an engineered dense pressure sensor array allows the identification and location of obstacles for navigation (Figure 1). We are demonstrating proof-of-concept by fabricating such MEMS pressure sensors by using KOH etching techniques on SOI wafers to construct strain-gauge diaphragms.

The system consists of arrays of hundreds of pressure sensors spaced about 2 mm apart on etched silicon and Pyrex wafers. The sensors are arranged over a surface in various configurations (Figure 2). The target pressure resolution for a sensor is 1 Pa, which corresponds to the noiseless disturbance created by the presence of a 0.1-m-radius cylinder in a flow of 0.5 m/s at a distance of 1.5 m. A key feature of a sensor is the flexible diaphragm, which is a thin (20 µm) layer of silicon attached at the edges to a silicon cavity. The strain on the diaphragm due to pressure differences across the diaphragm is measured. At this stage, the individual MEMS pressure sensors are being constructed and tested.

In parallel to the construction of a sensor array, techniques are being developed to interpret the signals from a dense pressure array by detecting and characterizing wake structures such as vortices and building a library of pressure distributions corresponding to basic flow obstructions. In order to develop these algorithms, experiments are being performed on coarse arrays of commercial pressure sensors.

**REFERENCES**


