**Treatments To Produce Stabilized Aluminum Mirrors for Cryogenic Uses**

Selected heat treatments are performed between and after fabrication steps.  
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Five metallurgical treatments have been tested as means of stabilizing mirrors that are made of aluminum alloy 6061 and are intended for use in cryogenic applications. Aluminum alloy 6061 is favored as a mirror material by many scientists and engineers. Like other alloys, it shrinks upon cool-down from room temperature to cryogenic temperature. This shrinkage degrades the optical quality of the mirror surfaces. Hence, the metallurgical treatments were tested to determine which one could be most effective in minimizing the adverse optical effects of cool-down to cryogenic temperatures. Each of the five metallurgical treatments comprises a multistep process, the steps of which are interspersed with the steps of the mirror-fabrication process. The five metallurgical-treatment/fabrication-process combinations were compared with each other and with a benchmark process. Separate tests showed that forged AL6061 with the same processing method would yield slightly better mirrors than those made from AL6061-T651 plates.

This work was done by Wahid Zewari, Michael Barthelmy, and Raymond Ohl of Goddard Space Flight Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Goddard Space Flight Center, (301) 286-7351. Refer to GSC-14736-1.

**Making AlNₓ Tunnel Barriers Using a Low-Energy Nitrogen-Ion Beam**

Ion-beam parameters can be controlled to optimize properties of AlNₓ layers.  
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A technique based on accelerating positive nitrogen ions onto an aluminum layer has been demonstrated to be effective in forming thin (<2 nm thick) layers of aluminum nitride (AlNₓ) for use as tunnel barriers in Nb/Al-AlNₓ/Nb superconductor/insulator/superconductor (SIS) Josephson junctions. AlNₓ is the present material of choice for tunnel barriers because, to a degree greater than that of any other suitable material, it offers the required combination of low leakage current at high current density and greater thermal stability. While ultra-thin AlN films with good thickness and stoichiometry control are easily formed using techniques such as reactive molecular beam epitaxy and chemical vapor deposition, growth temperatures of 900 °C are necessary for the dissociative adsorption of nitrogen from either nitrogen (N₂) or ammonia (NH₃). These growth temperatures are prohibitively high for the formation of tunnel barriers on Nb films because interfacial reactions at temperatures as low as 200 to 300 °C degrade device properties. Therefore, deposition by reactive sputtering and nitridation of thin Al layers with DC and RF nitrogen plasmas have been successfully used to form AlN barriers in SIS junctions. However, precise control over critical current density \( I_c \) has proven to be a challenge, as is attaining adequate process reproducibility from system to system.

The present ion-beam technique is an alternative to the plasma or reactive sputtering techniques as it provides a highly controlled arrival of reactive species, independent of the electrical conditions of the substrate or vacuum chamber. Independent and accurate control of parameters such as ion en-
A process that employs silicon-on-insulator (SOI) substrates and silicon (Si) micromachining has been devised for fabricating wide-intermediate-frequency-band (wide-IF) superconductor/insulator/superconductor (SIS) mixer devices that result in suspended gold beam leads used for radio-frequency grounding. The mixers are formed on 25-µm-thick silicon membranes. They are designed to operate in the 200 to 300 GHz frequency band, wherein wide-IF receivers for tropospheric-chemistry and astrophysical investigations are necessary.

The fabrication process can be divided into three sections:

1. The front-side process, in which SIS devices with beam leads are formed on a SOI wafer;
2. The backside process, in which the SOI wafer is wax-mounted onto a carrier wafer, then thinned, then partitioned into individual devices; and
3. The release process, in which the individual devices are separated using a lithographic dicing technique.

The total thickness of the starting 4-in. (10.16-cm)-diameter SOI wafer includes 25 µm for the Si device layer, 0.5 µm for the buried oxide (BOX) layer, and 350 µm for the Si-handle layer. The front-side process begins with deposition of an etch-stop layer of SiO₂ or AlN, followed by deposition of a Nb/AlN/Nb trilayer in a load-locked DC magnetron sputtering system. The lithography for four of a total of five layers is performed in a commercial wafer-stripping apparatus. Diagnostic test dies are patterned concurrently at certain locations on the wafer, alongside the mixer devices, using a different mask set. The conventional, self-aligned lift-off process is used to pattern the SIS devices up to the wire level.

The beam-leads are formed as extensions from the SIS devices by using a bilayer lift-off process with poly(methyl methacrylate) (PMMA) and photoreist. After defining the beam-leads, the interfacial layer between the PMMA and photoreist is etched in an oxygen plasma. Ultraviolet irradiation is used to expose the PMMA, which is then developed in chlorobenzene. The wafer is then placed in the sputtering system, where a seed layer of Nb/Au is deposited to enhance adhesion. The Au beam leads are grown to the desired thickness in an electron-beam evaporation system. After deposition, the unwanted gold is easily removed by lift-off in acetone.

The Beam of Nitrogen Ions impinges on the aluminum substrate surface layer, forming an ultra-thin layer of AlN. The apparatus used in the present ion-beam technique includes a vacuum chamber containing a commercial collimated-ion-beam source, a supply of nitrogen and argon, and an ion probe for measuring the ion dose. Either argon or nitrogen can be used as the feed gases for the ion source, depending on whether cleaning of the substrate or growth of the nitride, respectively, is desired. Once the Nb base electrode and Al proximity layer have been deposited, the N₂ gas line to the ion beam is vented and purged, and the ion-source is turned on until a stable discharge is obtained. The substrate is moved over the ion-beam source to expose the Al surface layer to the ion beam (see figure) for a specified duration for the formation of the nitride tunnel barrier. Next, the Nb counter-electrode layer is deposited on the nitride surface layer. The Nb/AlN/Nb-trilayer-covered substrate is then patterned into individual devices by use of conventional integrated-circuit processing techniques.

The hysteretic nature of the current-voltage characteristic along with the high subgap ratio indicate the incidence of nitrogen ions chemically reacted with the Al layer as expected, to form a continuous AlN barrier. Chemical analysis of the barrier performed using x-ray photoelectron-spectroscopy confirmed the presence of AlN. Critical current density Jc ranged from 550 to 9,400 A/cm² with subgap-to-normal resistance ratios ranging from 50 to 12.6. The Jc was found to decrease with increasing dose and increasing beam energy. The run-to-run reproducibility was determined to be very good. The spatial variation of the ion current density was also measured and correlated with Jc over a 76-mm Si wafer. Some junctions were also found to be stable annealing up to temperatures of 250 °C. This technique could be applied to form other metal nitrides at room temperatures for device applications where a high degree of control is desired.

This work was done by Anupama Kaul, Alan Kleinsasser, Bruce Bumble, Henry LeDuc, and Karen Lee of Caltech for NASA’s Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1), NPO-41297.