Nanoengineered charge-drain film for electron-optical MEMS in the REBL e-beam column

William M. Tong, Alan D. Brodie, Françoise Kidwingira, Mark A. McCord
KLA-Tencor, 5 Technology Dr., Milpitas, CA 95035
Anil U. Mane, Jeffrey W. Elam
Argonne National Laboratory, Argonne, IL, 60439

Electrostatic charging has long been a vexing challenge to high-resolution e-beam optics. It becomes particularly acute in electron-optical MEMS in which there is a large surface area in proximity of low-energy elections. In REBL (Reflective E-Beam Lithography), the Digital Pattern Generator (DPG) is an electron-optical MEMS with >1M individually addressable lenslets that are demagnified 100x onto the wafer. One approach to overcoming charging is to coat the MEMS with a charge-drain film that has resistivity in between those of a semiconductor and an insulator (~10^4 to 10^9 Ω-m). The material should have very high dielectric strength (>10 MV/m) and its resistivity could be tailored to satisfy the need of the individual device. In addition, because most electron optical MEMS have 3D structures, the film deposition should be isotropic for coating occurs on all surfaces. Few materials in nature have resistivity in this range. Substitutional dopants in insulators tend to be deep in the band gap. Our previous material for this charge-drain film was a homogeneous binary oxide with a controlled number of oxygen vacancies serving as n-type dopants. However, under a high electric field it broke down in 2 days, severely limiting the lifetime the DPG.

We developed a new type of material consisting of nanoclusters of MoO_{3-x}, a conductive metal oxide, embedded in Al_2O_3. The film is grown by Atomic Layer Deposition, an isotropic deposition technique. The nanoclusters are formed because the Mo is deposited in metallic form onto the Al_2O_3, which has a high surface energy. Consequently the deposition occurs through the islanding mode. The Mo islands are then partly oxidized after they are formed. Al_2O_3 has one of the highest dielectric strengths among all oxides because its oxygen vacancy states lie deep in the band gap; it protects the MoO_{3-x} from stoichiometry change, thus conserving the number of carriers in the film and maintaining its dielectric strength. Figure 3a shows the resistivity of the film can be tailored by varying the concentration of the MoO_{3-x} nanoclusters. This was important for locating the process window for our DPG's maximum performance. The film also has very high dielectric strength. Figure 3b shows the high stability of the resistivity of the MoO_{3-x}/Al_2O_3 compared to the binary films when subjected to a strong field of 25 MV/m. We applied the films to our DPG and greatly improved its performance: the contrast ratio of a bright and dark pixel improved to 50:1. Most of importantly, the longevity of the DPG improved from a week to >3 months.

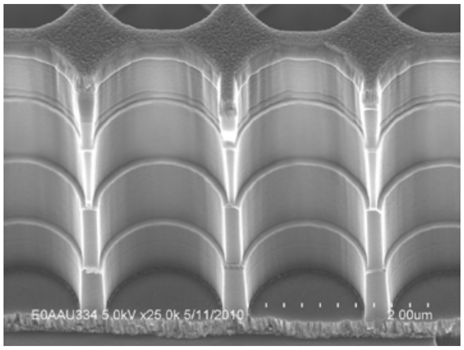

Figure 1: SEM Cross section of the REBL DPG MEMS device

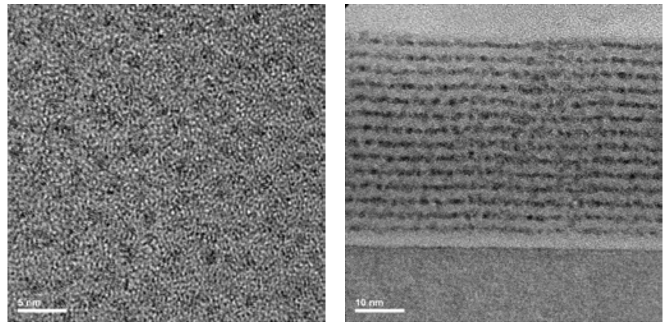

Figure 2: Plan view (L) and cross-section (R) TEM images showing the ALD charge-drain film structure of MoO_{3-x} nanoclusters multilayers embedded in the Al_2O_3 matrix.

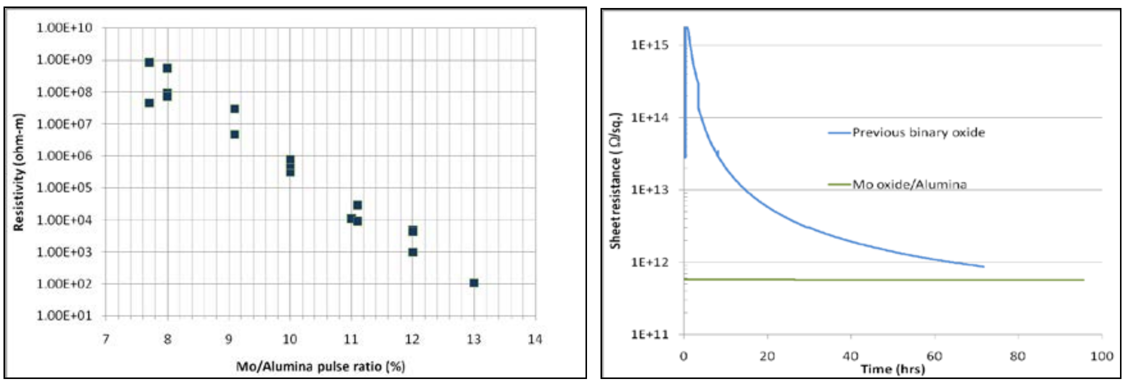

Figure 3: (L) Resistivity of the charge-drain film can be tailored by adjusting the concentration of the MoO_{3-x} nanoclusters. (R) The sheet resistance of the old binary oxide films and an 80 nm MoO_{3-x} /Al_2O_3 ALD film held at a constant field of 25 MV/m. The former's decayed within days. The latter showed great stability.

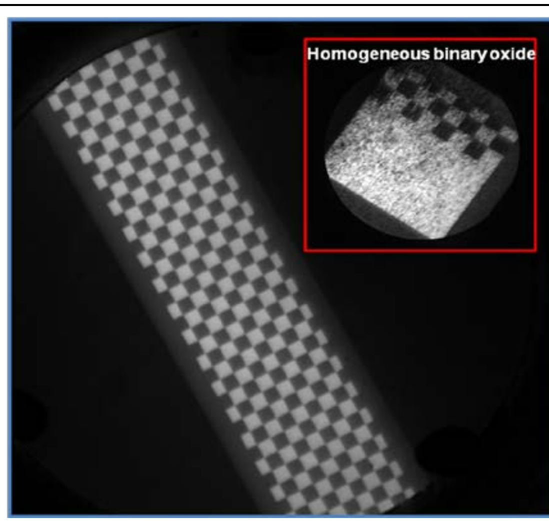

Figure 4: Comparison between DPGs with the binary oxide and the MoO_{3-x} /Al_2O_3 ALD charge drain films, showing the new film has greatly improved the image quality.