Application Note

Aduro™

Tungsten Wire Deposited with IBID

Introduction

Electron and ion beam induced deposition (EBID and IBID) has evolved as an *in situ* method for creating well-defined structures at the micro and nanoscale. EBID and IBID are also widely used as a maskless lithography method for creating custom electrical contacts to micro and nanoscale materials. Many factors affect the characteristics of the deposited materials, such as microscope parameters (current density and dwell time), substrate-related variables (morphology and thickness), and feed gas-related variables (chemistry and feed rate). Specific experimental approaches are recommended for each parameter.

The electrical properties of the deposited material must be well known to accurately interpret electrical data from devices. The four point probe method is a well-known technique to measure the resistance of a material by eliminating the contribution of contact resistance. This technique uses two separate pairs of probes, one pair to pass current and the other to sense voltage. The amount of current that passes through the circuit is known and the voltage is measured. The measured voltage is divided by the sourced current to determine the sample resistance.

In this application note an Aduro heating and electrical biasing SEM was used to study and tune *in situ* IBID metal deposition conditions and to perform *in situ* four point probe measurements on the resulting structures. The Aduro SEM system combines a stage with active sample supports called E-chips™, an electronics control unit (ECU) and the Aduro electrical software, which works seamlessly together to create a highly versatile tool for *in situ* electrical measurements in the SEM. The E-chips, ECU, and software can be interchanged between microscopes.

The software contains five modes of electrical operation, including one for four point probe experiments, DC Current and Voltage Biasing, Current-Voltage, and MOSFET, allowing users to choose the measurement that best suits their experiment.

Experiment

Tungsten is used by many researchers and can be used to make electrical contacts to samples, or used as a protective layer when creating FIB lamella. To understand the deposition characteristics of W deposited by IBID, a Hitachi NB5000 FIB/SEM (Ga+ ion beam at 40.0 kV) was used to deposit W wires from a $W(CO)_6$ precursor across four Au leads on an electrical E-chip. The Au leads were patterned using photolithography directly on top of a 50 nm thick, amorphous silicon nitride membrane.

Initial testing used standard conditions: 5 μs dwell time at 0.83 nA and dimensions of 32 x 3 μm. Under these conditions holes formed in the silicon nitride membrane as a result of beam etching. When the pattern size was increased from 32 x 3 μm to 40 x 4 μm, a reduction in etching and a more continuous pattern was observed. Further refinement to 5 μs dwell time at 0.07 nA, a 40 x 1 μm W wire pattern was achieved without etching the silicon nitride support (Figure 1).

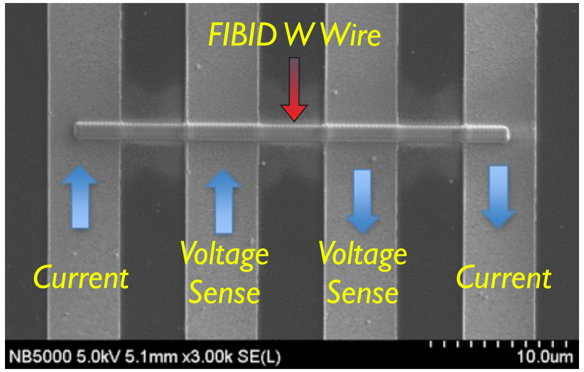

Figure 1

Subsequent to deposition, four-point probe was used to measure the resistance of the tungsten. Measurements showed that the IBID W formed ohmic contacts with the Au leads and has an average resistivity of 50 μΩ cm, which is only one magnitude difference from bulk W and among the lowest obtained for IBID W wires tested.

Discussion

This example illustrates the need for developed deposition recipes for high purity metal to avoid unnecessary etching of the thin silicon nitride membrane. If the ion beam current is too high or the dwell time too long, the beam can etch holes in the membrane. Smaller ion beam currents, as well as using the electron beam to deposit metal onto the membrane can help maintain its structural integrity.

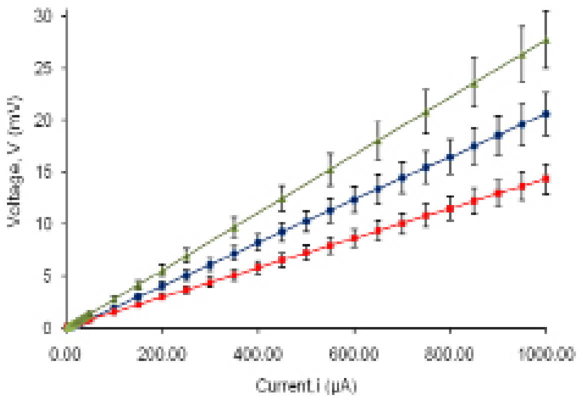

Figure 2: courtesy Dr. Donovan Leonard, Oak Ridge National Laboratories

In situ electrical measurement capability of Aduro is a powerful tool. By using one of the 5 different modes of operation in the electrical software, the electrical characteristics of a device can be measured within the microscope without breaking vacuum or exposure to air. With direct access to beam-deposited materials users can probe and evaluate device performance immediately following deposition.

Fine tuning of beam deposition conditions can quickly optimize performance by providing immediate feedback. Properties of the device can also be measured using other tools found on the FIB, including SEM and EDS, as a function of electrical biasing or temperature when using a Thermal E-chip.

Applications

Applications utilizing IBID and EBID include metal deposition for electrical contacts, contacts to other controlled geometries for electronic devices, nanodots, nanopillars and nanowires. In these applications it is important to understand the deposition characteristics to maintain structural integrity of the membrane, the device, and the contact characteristics to ensure meaningful electrical measurements. Contact us to discuss the full range of capabilities of the Aduro with the Electrical E-chip sample supports for your applications. We can be reached at (919) 377-0800 or contact@protochips.com.