Fall 10-5-2015

Fundamental nanomechanic investigations using combinatorial deposition techniques

Rachel Schoeppner
EMPA, rachel.schoeppner@empa.ch

Aidan Taylor
EMPA

Jakob Schwiedrzik
EMPA

Gaurav Mohanty
EMPA

Vipin Chawala
EMPA

See next page for additional authors

Authors
Rachel Schoeppner, Aidan Taylor, Jakob Schwiedrzik, Gaurav Mohanty, Vipin Chawala, Lazlo Petho, Keith Thomas, Johannes Zecher, Carlos Guerra-Nuñez, and Johann Michler

FUNDAMENTAL NANOMECHANIC INVESTIGATIONS USING COMBINATORIAL DEPOSITION TECHNIQUES

Rachel Schoeppner
Rachel.Schoeppner@empa.ch
Aidan A Taylor, Jakob Schwiedrzik, Gaurav Mohanty, Vipin Chawala, Laszlo Petho, Keith Thomas, Johannes Zechner, Carlos Guerra-Nuñez, Johann Michler,

Laboratory for Mechanics of Materials and Nanostructures, Empa, Thun, Switzerland

Key Words: Combinatorial materials library, PVD, nanoparticle, ALD, thin-film deposition

Combinatorial materials design of thin films allows for the investigation of broad ranges of both thickness and composition within a single sample; this can be utilized both for fundamental nanomechanics investigations and for the optimization of thin films for engineering applications. Using a unique self-constructed deposition chamber that combines magnetron sputtering, e-beam evaporation, nanoparticle deposition and atomic layer deposition (ALD), the architectural design of thin films can be tailored to study multiple physical and chemical properties.

Recent investigations have focused on using this chamber's unique ability to create a gradient composition film of up to three different materials with a range of approximately 20 vol% for each material, allowing for a broad range of compositions to be tested in a single sample. This is highly beneficial in the optimization of thin film performance. Specifically, two different alloys with varying composition have been studied recently: a CuZrTi bulk metallic glass and a NbWTa solid-solution alloy. Si wafers were sputtered by PVD, resulting in composition gradients, to investigate mechanical properties and glass formation as a function of composition in the CuZr, CuZrTi, and NbWTa systems. Composition was measured using XRF and correlated with mechanical properties, such as elastic modulus and hardness, measured using nanoindentation. Structural properties of the NbWTa three-component solid-solution alloy was also investigated as a function of the changing composition: tracking the change in the lattice parameter using XRD and the solid-solution strengthening using nanoindentation. The NbWTa sample was also used in an adhesion study to survey the effect of composition on the interfacial adhesion, measured via the Marshall and Evans (1984) method, between the film and a 500 nm thick layer of Al_2O_3 deposited using ALD.

The same method can be used to create multilayers with different layer thicknesses across a single wafer. In this way, the fundamental deformation and strengthening mechanisms of multilayers can be probed at a range of layer thicknesses. An additional chamber mounted to the system allows for in-line ALD of a variety of different oxides. This adds the capability for interface engineering using ceramic layers with sub-nanometer thickness control. Initial studies of this capability have focused on proof-of-concept trilayer systems consisting of Al_2O_3 and TiO_2 ALD layers sandwiched between thicker Cu layers deposited by PVD. Physical and mechanical characterisation of these trilayers, including micropillar compression, has demonstrated that the interfacial adhesion is good and that nanometer thick ALD layers can provide significant hardening to Cu thin films.

A newly integrated shutter controller has been specifically designed and manufactured to allow for even more control over coating design. By specifically programming the shutters it is possible to create thickness gradients of two or three different materials, which can then be annealed to create a film with compositional gradients over almost the complete spectrum. Furthermore, the shutter system can be used to deposit a grid of samples with different deposition conditions, compositions, or layer thicknesses on the same wafer, cutting down sample manufacturing time and eliminating uncontrollable errors due to day-to-day differences in deposition chamber conditions.

The newest addition to the PVD chamber is the NanoGen50 nanoparticle generator manufactured by Mantis Depositions Ltd., which uses an adaptation of traditional magnetron sputtering to force agglomeration of the sputtered ions into small particles. Recently, the first known nanoparticle reinforced metal films using PVD were produced using Cu nanoparticles in a Zr matrix. The microstructure, particle size and density were characterized using STEM and initial nanoindentation investigations were conducted to determine how nanoparticle inclusion effects the hardness and modulus of these new films.