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Low cost technique for measuring in situ strain of nanostructures

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Abstract

A novel, inexpensive device for measuring the strain of thin films during the deposition process is described. The measurement of the electrical resistance of the commercial strain gauge provides the strain values from which the stress of the film/substrate can be derived. Metallic thin films have been investigated over temperatures ranging from 22 to 100 °C. Plotting residual strain after cooling, it was possible to obtain the thermal strain component and its subtraction it was possible determine the intrinsic component strain.

We observed a generic stress evolution from compressive to tensile, then back to compressive stress as the film thickened, in silver and copper layers.

The performance of the measuring system are presented and discussed. Advantages and limitations of usage of the system are given as a conclusion.

Keywords: Strain gauge; In situ measurement; Thin films; Intrinsic stress

1. Introduction

There is an increasing need for real-time, in situ monitors for expert control of electronic materials fabrication and processing [1,2]. Here, we demonstrate a new application to determine strain accumulation during thin-film growth. While the approach is very general and can be applied to wide variety of materials and coatings, we illustrate our studies with results on silver and copper thin films and multilayers. We chose Ag and Cu since they have negligible mutual solubility at the deposition temperature, thus the multilayers are expected to have sharp interfaces; moreover important previous studies [3,4] of this materials allow comparison and validation of our measure system [5]. In this paper in situ measurements of film stress are presented utilizing a recently developed technique [6] in which the variation of the electrical resistance of the commercial strain gauge, glued on the back surface of the substrate is monitored in real time. In this way the curvature of the substrate can be determined, and from this the residual stress in thin films is calculated. It has been carried out the evaluation of the residual stresses in the silver and copper single layer.

2. Experimental procedure

The materials (silver, copper) have been evaporated using a UNIVEX 300 (Laybold Inc.) thermal evaporator. A quartz crystal thickness monitor has been used to control the evaporation rate and the thickness during the deposition. The deposition rate is 0.1 nm/s. The background pressure is 10^{-5} mbar. The Si (100) with native oxide has been chosen as substrate for the well-known elastic constant and electric properties. A rectangular beam 2 cm long × 0.2 cm wide × 86 μm thick is clapped to the side end. The substrate temperature has been measured using thermocouples attached to the backside of the cantilever. In this work 1.5 × 1.2 mm grid commercial strain gauges type 1.5/

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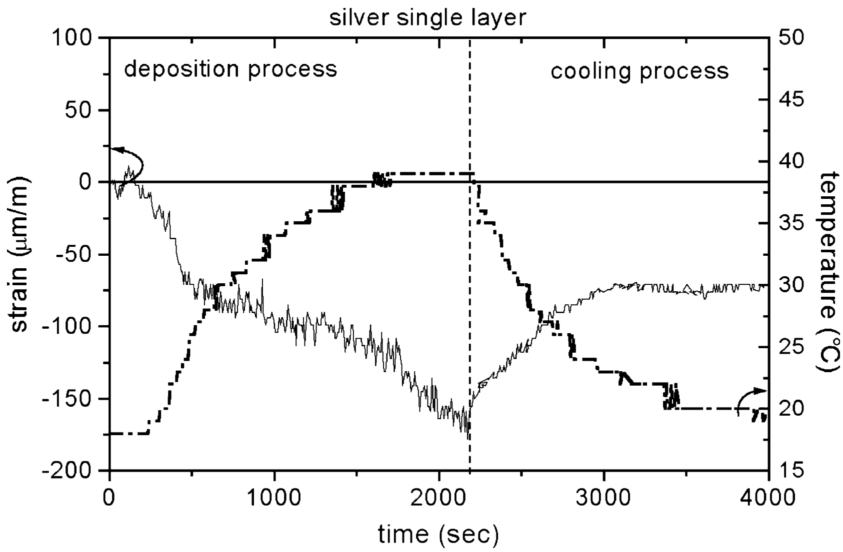

Fig. 1. Sample temperature and strain during and after deposition of silver single layer.

120LY11 (HBM 9 industries) were used. The grid was glued with adhesive Z70 HBM.

Silver and copper very thin films were examined ex situ using atomic force microscopy (AFM) Nanoscope IIIa (Digital Instruments). All images were recorded in tapping mode (TM-AFM) using silicon tips. The root mean square (RMS) value of surface roughness was calculated on all scan area (1 μm^2). Thicker films were observed by scanning electron microscope (SEM) XL40 Philips in plan view and in cross-section.

2.1. Error evaluation

When the gauge experiences a deformation, the cross-section of the conductor changes as well as its electrical resistance. The strain is calculated from the variation of the electrical resistance by the equation:

$$\varepsilon = \frac{1}{K}\frac{\Delta R}{R_0} \quad (1)$$

where $\Delta R = R_f - R_0$ is the change in the electrical resistance during the deposition process, K is a gauge factor provided by the manufacturer of the strain gauge [7].

The apparent strain refers to the change in the measurement signal due to temperature under conditions where the mechanical loading of the strain gauge is zero or constant. A response to temperature occurs if during the observation period the strain gauge's temperature or that of its environment changes. The response to temperature is reversible and the temperature effects disappear when the original temper-

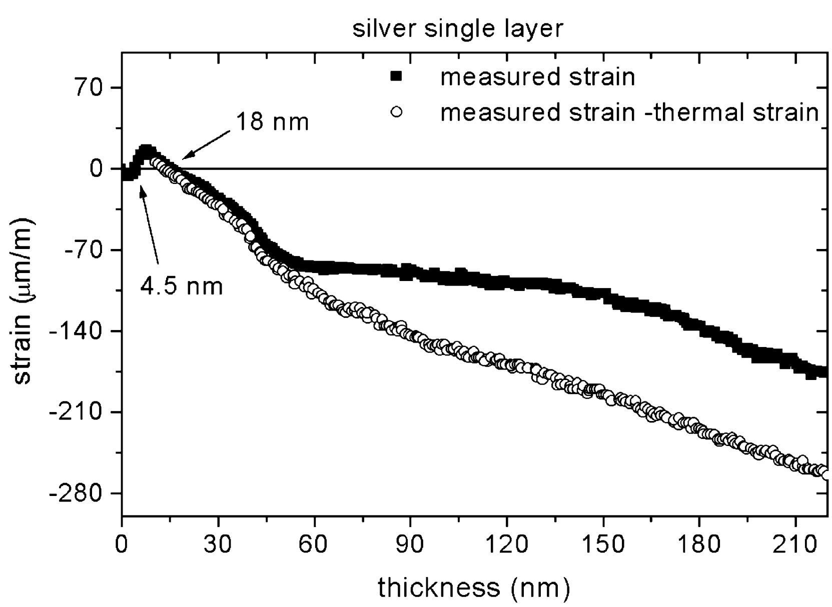

Fig. 2. Measured strain and intrinsic strain vs. silver thickness during deposition.