A preliminary study on sputtered-deposited ruthenium thin films

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I. INTRODUCTION

Metallic ruthenium thin films have attracted growing attention for various application in IC technology. Ruthenium metal having low resistivity and high purity, is a candidate material for capacitor electrodes in dynamic and ferroelettric random access memories (DRAMs and FRAMs); as gate metal, due to its relatively high work function, in future MOSFETs and as magnetic layers in ferromagnetic random access memories [1]

In recent years metallic ruthenium has been investigated for application in Extreme UV (EUV) optics, both for grazing and normal incidence mirrors, due to the combination of optimal optical properties and chemical stability. In particular it has been found a good candidate material to be used as a capping layer in multilayer normal-incidence X-ray/EUV mirrors, because of its relatively high oxidation protection [2].

This report is dedicated to the investigation of ruthenium thin films as optical coatings, and more specifically to the properties of metallic ruthenium thin film deposited by magnetron sputtering. Coatings properties such as grazing angle reflectivity, film topography and composition are reported.

II. EXPERIMENTAL

The experimental apparatus used at Laboratorio Materiali for producing X-Ray/EUV mirrors is described elsewhere [2]. For this study a 2 inches Ruthenium target (99.5% purity) is put onto a UHV type II unbalanced magnetron sputter source driven at 150 W rf power at 13.56 MHz.

Argon (99.9999%) is used as process gas at the operating pressure of 1.9 mTorr. The base pressure of the chamber is of about 5.0 x10^{-7} mbar.

Three samples have been grown in different sputtering conditions to test morphology and composition as a function of sample position and plasma ion assistance: samples A and B have been deposited by up-ward sputtering, with sample surface normal to target axis at the target-to-substrate distance of 16.5 cm; sample B has been grown with bias applied to substrate holder. Sample C has been deposited off-axis with sample normal perpendicular to target axis at a distance from target of 8 cm and 4.5 cm off-centre. As for sample A, no bias has been applied to substrate that was kept at ground potential.

Non-Rutherford Backscattering Spectrometry (n-RBS) measurements have been performed to determine Carbon and Oxygen impurity concentration and Ru thickness. The CN 7 MV Van de Graaff accelerator has been used with a 5760 keV α-beam at the scattering angles of 170°.

AFM measurements have been performed using a DME Scanning Probe Microscope, operating in "non-contact" mode. A probe with a 10 nanometer radius tip has been used. The data have been calculated from images taken over an area of 2x2 μm^2 with 256x256 point array.

Optical performance of metallic ruthenium films has been tested by reflectivity measurements with the facility available at Dipartimento di Ingegneria dell'Informazione (Università di Padova).

III. RESULTS

From ion beam analysis the Ru areal densities for samples A, B and C, are respectively 2.3, 6.5, 3.2 x10^{18} atoms/cm^2. Then, assuming Ru bulk density, thickness layer result about 300, 900, 400 nm respectively.

For samples A and B Oxygen/Ruthenium and Carbon/Ruthenium ratios are under detection limit (Tab. 1). On the contrary, off-axis sample C shows a greater C impurity concentration.

Tab. 1: *n-RBS analysis of sputtered ruthenium thin film.*

sample	O/Ru	C/Ru	Ru dose (10^{15} at/cm2)
A	<0.04	<0.005	2300
B	<0.06	<0.008	6500
C	0.08±0.02	0.040±0.007	3200

Morphology of Ru layers has been observed by AFM analysis: while sample A and B show comparable low roughness, sample C is characterized by a much higher roughness, indicating that sputtered atoms impinging not normally onto the growing film lead to a pronounced columnar structure, as it is shown in Figures 1 and 2.

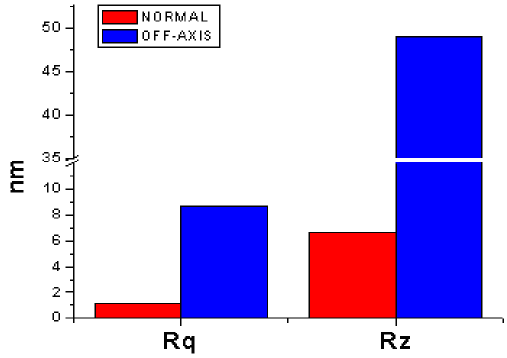

Fig.1: *R_q (Root Mean Square) and R_z (Ten point Height) for Sample A (named 'normal') and Sample C (named 'off-axis')*

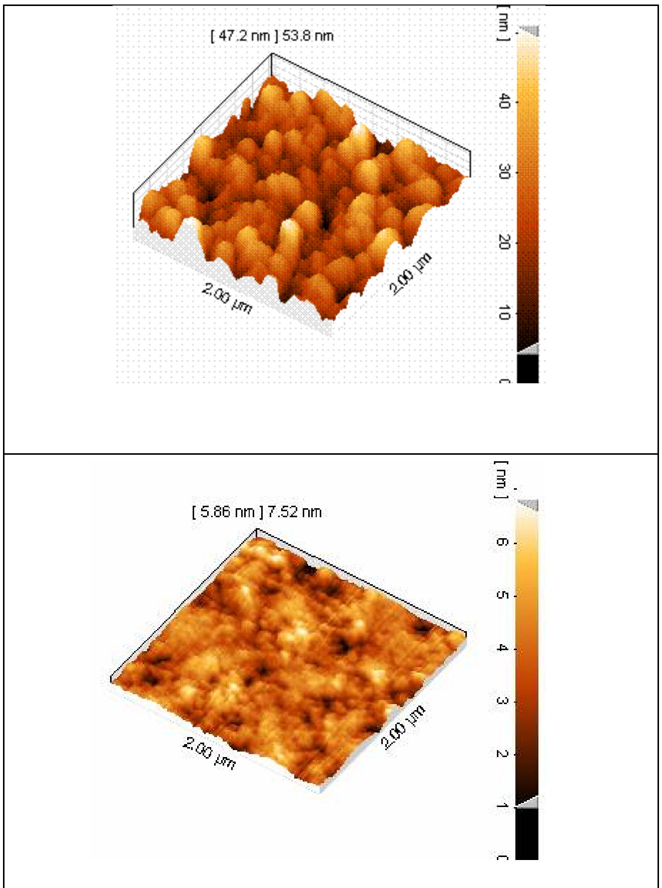

Fig. 2: *2x2 µm AFM images of ruthenium coatings: sample C (up) exibits a columnar structure characterized by higher roughness. Sample A (down) shows a smoother surface typical of denser films.*

As far as grazing angle reflectivity is concerned, in Figure 3 the results for samples A and B are reported for incident e.m. radiation at λ=13.5 nm.

Reflectivity *vs* incidence angle curves are compared to that of "ideal" Ruthenium thin films (i.e. films with no impurities, no oxide capping layer, no roughness and having density and optical properties of 'bulk' Ruthenium). The discrepancy from ideal case indicates that there is room for improvements of optical quality. Furthermore the reflectivity difference between samples A and B indicates that the optical properties are dependent on the plasma ion assistance conditions.

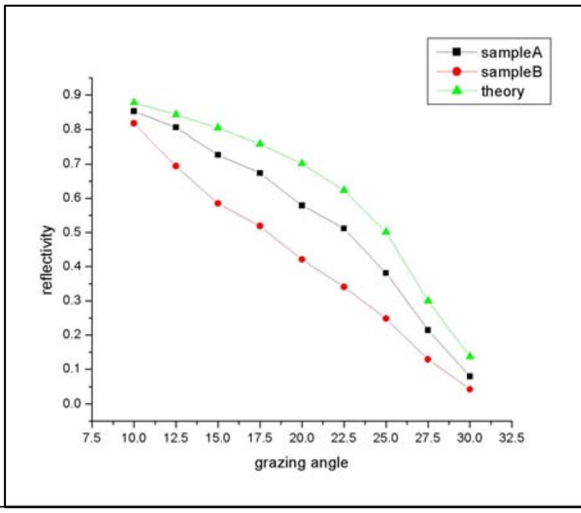

Fig.3: *Reflectivity vs. grazing incidence angle for samples A and B, superimposed to the curve of 'ideal' ruthenium. The measurements have been taken at λ=13.5 nm.*

IV.CONCLUSIONS

This preliminary report shows that by changing the sputtering deposition conditions it is possible to produce ruthenium layers with different topography and purity. This technique allows deposition of thick, dense and quite pure films whose reflectivity depends on the level of ion bombardment of the films.

Further investigations will be performed in order to better understand the correlation between the microstructure of magnetron sputtered-ruthenium thin film to their optical performance.

[1] T. Aaltonen et. al., Chem. Vap. Dep., 9(1), 45 (2003);
[2] S. Bajt, et al. Opt. Eng. 41, 1797-1804 (2002);
[3] V. Rigato and A. Patelli, in X-Ray and Inner-Shell Processes (AIP, Roma, Italy, 2002), Vol. 652, p. 103.