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On the secondary electron emission phenomenon when originating from very thin layers*

K. Makasheva, *Member, IEEE*, M. Belhaj, G. Teyssedre, *Member, IEEE*,
C. Rigoudy, S. Dadouch and L. Boudou

***Abstract*— The secondary electron emission phenomenon lays down the principle of operation of many physical devices and processes. Although it is fairly well described in the case of irradiation of metals there is still lack of information on the secondary electron emission when originating from dielectrics. In this work we report on the secondary electron emission resulting from very thin layers. It is found that for dielectric SiO_2 layers of less than 100 nm of thickness a departure from the general behaviour occurs for incident primary electrons with energy of around 1 keV. The departure in the electron emission yield heavily depends on the layer thickness. The case of nanostructured layers – dielectric matrices containing metal nanoparticles is also considered in the study.**

I. INTRODUCTION

Secondary electron emission is a process of release of electrons from materials. It results from the energy transfer of impinging energetic particles (electrons, ions, photons) to the material surface. This physical phenomenon is largely involved in scanning electron microscopy (SEM) [1], plasma physics [2], space applications [3, 4], particle accelerator [5], etc. Given the large number of devices using secondary electron emission for their operation a lot of effort was made during the last century to determine the electron emission yield (EEY) from different materials, conducting and/or insulating ones [6]. The secondary electron emission is a complex phenomenon that depends on many parameters related to the primary particles (electrons, ions, their energy, incident angle distribution, etc.) or to the nature of the studied material, especially when dealing with insulators due to the charging effect for low energy primary electrons [6, 7]. Without loss of generality we limit our study to EEY generated by electron impact.

This work represents a new insight in the secondary electron emission from very thin dielectric layers and opens the discussion on nanostructured layers with metallic nanoparticles embedded in dielectric matrices. The study of nanostructured layers aims to account for the gradually increased conductivity of the layer up to a conductive one. To prevent from target charging and consequently to determine the real secondary electron emission yield a short pulse irradiation by primary electrons (PE) was applied.

II. EXPERIMENTAL PART

A. *Samples elaboration*

Thin silica (SiO_2) layers, 100 nm-thick, were thermally grown on Si-substrates at 1100°C under slightly oxidizing atmosphere using a N_2-O_2 gas mixture containing 1.0% of O_2. The targeted thicknesses were obtained after chemical etching of the SiO_2 layers using hydrofluoric acid (HF). The samples were then abundantly rinsed with deionized water.

A single layer of silver nanoparticles (AgNPs) was deposited on the surface of SiO_2 layer in the plasma of axially-asymmetric capacitively-coupled RF discharge. The discharge powered electrode (smaller electrode) was Ag-made target to bear the silver sputtering. The plasma was maintained in pure argon at low pressure (p = 5.4 Pa) with RF power of P = 80 W ($V_{dc} = -1000$ V). The sputtering time was fixed to 5 s. More details about the plasma process are given elsewhere [8].

B. *Characterization methods*

The thicknesses of SiO_2 layers were determined by spectroscopic ellipsometry using a SOPRA GES-5 ellipsometer in the range 250–850 nm. The recorded spectra were modeled with Bruggeman's model to extract the SiO_2 layer thicknesses. The monolayer of AgNPs was observed by SEM. The size and density of AgNPs were obtained after image processing.

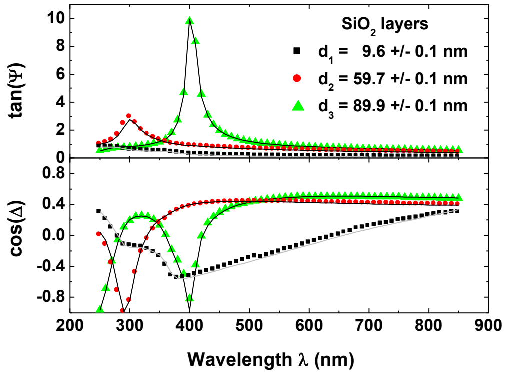

Fig. 1. Recorded ellipsometric spectra (dots) and the simulated spectra (lines) for the studied SiO_2 layers.

The EEY, encompassing backscattered and SE emissions, was studied in the low energy range, from few eV up to 2000 eV. The measurements were performed under high vacuum (5×10^{-7} Pa). The sample surface was monitored by Auger electron spectroscopy to account for impurities. All experiments were performed with very low contamination

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level. The experimental arrangement and the applied procedure are described elsewhere [9].

III. RESULTS AND DISCUSSION

The recorded spectroscopic ellipsometric spectra, alongside with the simulated spectra, are presented in Fig. 1 for the three SiO_2 layers. The obtained layer thicknesses are of 9.6, 59.7 and 89.9 nm. Keeping the thickness of the silica layers less than 100 nm allows for study of the SE features in correlation to PE penetration depth and of the cascade of events following the energy deposition.

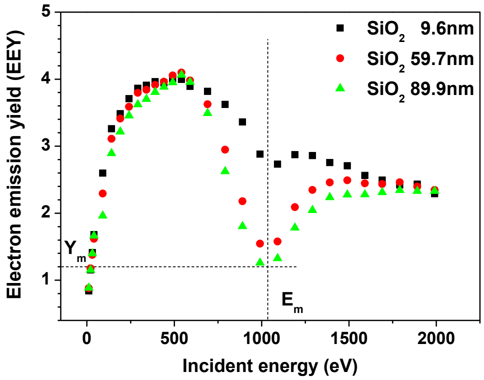

Fig. 2. EEY from very thin silica layers.

Figure 2 represents the EEY from the SiO_2 layers in the low energy range up to 2 keV. As typical for dielectric materials the EEY is much higher than unity. The maximum yield $Y_m = 4.0$ is achieved for energy of the PE of 500 eV. The obtained value is in accordance with reported in the literature data [7]. For PE of energy $E_m \approx 1$ keV we observe a departure from the general trend of EEY. The obtained dip is heavily dependent on the layer thickness. Such behavior can be related with increased conductivity of the layer, suggesting radiative induced conductivity.

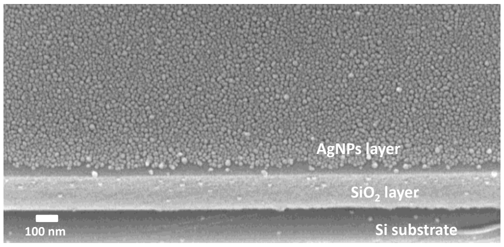

Fig. 3. SEM image (tilted at 30°) of the monolayer of AgNPs deposited on thermally grown silica layer.

The obtained monolayer of AgNPs is shown in Fig. 3. After processing of the SEM images taken in plane view we obtained mean size of the AgNPs of 20 nm and a density of 3.6×10^{11} cm^{-2}. The AgNPs are isolated and the inter-particle distance is of about 5 nm.

Figure 4 shows that the EEY from isolated AgNPs deposited on SiO_2 thin layer combines properties of metallic silver and the underlying dielectric layer. The maximum yield is reduced to the value of a continuous silver surface and the modulation depth is lowered as the conductivity of the surface is increased through charge transport in the plane.

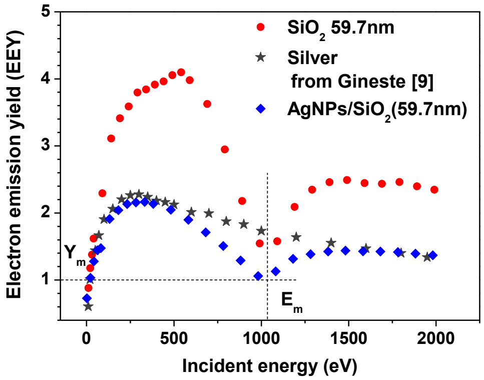

Fig. 4. Comparison of the EEY from SiO_2 (d_2 = 59.7 nm), silver surface (adapted from [9]) and a structure of monolayer of AgNPs deposited on SiO_2 (59.7 nm) on Si-substrate.

IV. CONCLUSION

In this contribution we have reported on the EEY from very thin layers. It is found that for dielectric SiO_2 layers of thickness less than 100 nm a departure from the general behaviour occurs for incident electrons with energy of around 1 keV. The departure in the electron emission yield heavily depends on the layer thickness. The case of nanostructured layers containing metal nanoparticles shows smooth transition when increasing the layer conductivity.

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