Coincidence of the Electron and Ion Beams at Auger Profiling in Microelectronics

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Abstract – **The article presents and discusses the methods for coincidence of the spots of electron and ion guns. The problem has great practical value for precise depth profiling. The Auger profiling gives information for the vertical die architecture and for the layers in the researched technological experiment. This is the main AES preference and a cause for its widespread use in microelectronics. The applicability and performance of the methods are discussed.**

Keywords – **Auger electron spectroscopy, microelectronics, ion beam, electron beam, profiling**

I. INTRODUCTION

Auger electron spectroscopy (AES) is the first method for surface analysis, used in microelectronics (ME). The literature sources point out hundreds applications. This is the case, because its analytical capabilities combine element analysis (for almost the whole periodic table) with informational depth only several atomic layers. At utmost importance especially for ME are the additional possibilities for easy quantification and depth profiling. The last gives information for the vertical die architecture and for the layers in the technological development experiment. Profiling was used: I. For process characterization [1, 2] (passivation, photolithography, chemical and plasma etching, metallization, layers' deposition, oxidation – as technological process or harmful phenomenon, diffusion and ion implantation, and packaging); II. For quality control and as a failure analysis tool [3]. The profiling importance increases persistently [4], because ME requires at present the exactitude of the element composition to be combined with depth separation at atomic order.

As in other analytical methods, the standard profiling in AES combines Auger spectral analyses with ion sputtering. The spectrum gives information for the element composition in the analyzed spot from the surface. The in depth composition of the specimen is traced by alternating consecutively analytical and etching steps (or performing analytical steps during the continuous sputtering). On the other hand, the precise depth profiling (without decreasing of depth resolution) requires exact matching of the analyzed and the sputter areas (a problem alias in the literature "coincidence of the electron and ion guns" and "overlapping of the electron and ion spots").

The purpose of the current work is to present and discuss methods for this coincidence. Despite its upmost importance for the practice, the literature data for the topic is scarce, because it seems this is regarded as a daily round question that has acceptable solution for each laboratory. Most of the presented data below is obtained during

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conversation with colleagues-analysts. But the work is not only addressed to the Auger analysts, but mainly for the engineer-developers of devices and technologies as the clients, participating in the die development.

II. EXPERIMENTAL

The experimental setting comprises of an electron gun, an electron spectrometer, an ion gun and a sample stage, Figure 1, as everything is well known and standardized [5, 6].
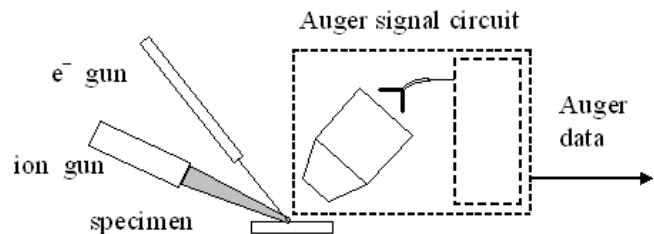

Fig. 1. Block circuit of a classical Auger experiment

Considering the discussed topic we can separate the ion guns used for Auger profiling into 3 groups:
A. Simple ion guns using static beam;
B. Ion guns with x-y beam deflection;
C. Ion guns focusing spot with dimensions a few μm.

The group A guns are rarely used nowadays and are not a subject of our discussion (they require an initial mechanical tuning of the middle of the etching spot in the analyzed spot from the sample). The group B guns are simple electrostatic devices. Their widespread application is due to their low cost and possibility to be added to already existing apparatus. Their ion beam can be focused and shifted (generally – and scanned) on the surface (the sample). Without focusing the ion current density distribution is a Gaussian (Figures 2 and 3 are for a mono-focus ion gun). The focusing forms distribution with greater centralized "homogenized" areas. We will note that with type B guns, a scan with size of the order of the intense central area can be performed, which provides an area with a significant homogeneous current without significantly decreasing the sputtering rate. The group C guns are usually more complex devices. They work in scanning mode, ensuring homogeneous density of the current in the scan area. The larger scan slows down the sputtering rate (in inverse proportion to the square of the characteristic size of the scanned area).

III. RESULTS AND COMMENTS

A. Specifying the details for the presented problem

We assume that the **e-G**un focus is brought in coincidence with the electron **A**nalyzer **F**ocus on the

desired analyzed surface (EGAF point). Also the middle of the focused ion spot has to be put in the EGAF-point. The methods for coincidence the etching and analyzed spot will be covered in subsection *B*.
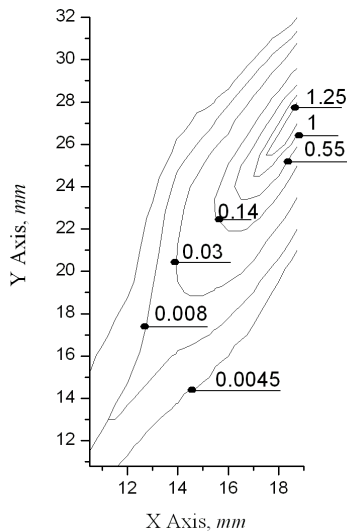

Fig. 2. The ion current density distribution (for ion gun mod. CI-40 /Riber/) is taken in the sample' plane with Faraday cup with an aperture diameter 25 μm. Gaussian' axis represent the spatial position of the ensemble "guns-spectrometer-sample". (Due to the symmetry only half spot is presented.)
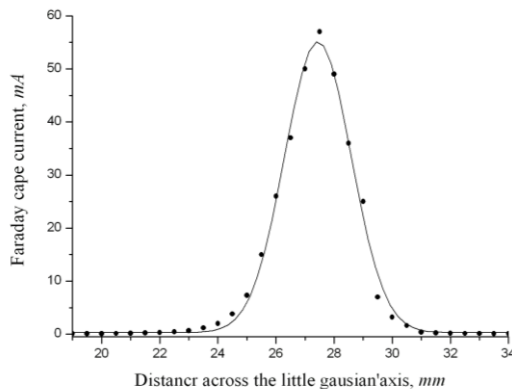

Fig. 3. The ion current density distribution
(from Fig. 2) across the little Gaussian' axis.

B. Methods for coincidence the etching and the analyzed spot

a) By etching of thin insulator layer. The ion sputtering of the insulator' layer (e.g. 30-50nm SiO_2/Si) is performed until the etched spot appeared on the surface' layer. The etched spot (result of the local removal of SiO_2 by the ion sputtering) appears where the ion current density is highest (the medium of the ion beam, the Gaussian' center). The etched spot is observed by its different contrast in the electron induced current (EBIC) image. EBIC is the current flowing to ground due to the fall of the beam on the sample. It is dominated by the local conductivity of the layer (of the local volume under the electron beam) – so the absence of a dielectric layer (eliminated by etching) is clearly visible. EBIC-image is electron microscopy mode, wherein the image brightness is modulated by the current

(rather than the secondary electrons). The sample is previously put in the EGAF-point, which is therefore the center of the EBIC image. The displacement of the etching spot of this center gives the un-coincidence of electron and ion beam. The coincidence requires several steps, at each of which is etched a new sample to bottom. At each step the ion gun' deviation plates voltage is changed while the spot came in the center of the screen. Therefore this method is one of the slowest and most labour-consuming. We should also add to its shortcomings the lack of direct indication for the focusing of the ion beam (for the focusing could be concluded by the sputtering time of the layer at each step). However we will note that this is the only method giving the sputtering rate.

b) By the trace from the beam in the EBIC image from thin insulator layer (put in the EGAF-point). As initial setup this method doesn't differ from the previous one. On the other hand here the result from the etching is not waited for, but the ion spot indication (its image – obtained by the EBIC contrast) is used directly. Since the obtained image reflects the ion current density distribution, this method allows a focusing of the ion beam. The coincidence is done again by changing the voltage on the ion gun' deviation plates. Coordination between the thickness and the conductivity of the insulator layer might be necessary for the specimen.

c) By Faraday' cup, [7]. The method consists of optimization of the ion current, registered by the cup, Figure 4. The center of the cup hole is fit in the EGAF-point; the ion gun' axis should be normal towards the aperture plain). The controlling gun voltages change. The aperture diameter should be a few times (and even better an order) smaller than the characteristic size of the ion spot. A few quick current checks at positions close to the center position can provide additional information for the ion beam focusing.
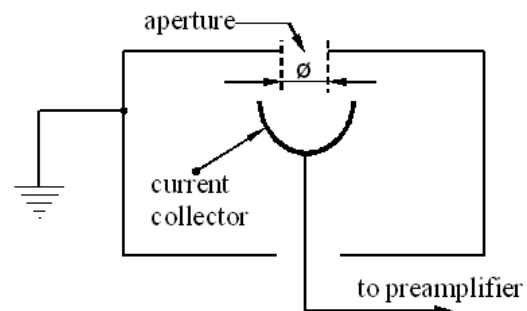

Fig. 4. Faraday' cup principle wiring diagram

d) By the electrons, induced by the ion gun. The ion beam produces electron emission. The peak of the induced by the ion bombardment "elastic" electrons in the spectrum is monitored (we should remind that the analyzer is focused on the analyzed surface). The peak is most intense, symmetrical and narrow if the ion beam is focused precisely and its focus is on the EGAF-point. It is most convenient the peak to be in differential mode while being observed in fast mode through oscilloscope (such practice is a daily routine for the Auger analysis when one brings the electron gun focus in coincidence with that of the analyzer). Additionally, at precise tuning, the energy position of this peak in the spectrum (at an average of the

position of the positive and the negative wing in the differential spectrum) should be at the ion gun energy. This setting should be done on a surface made by material with high ion-electron emission.

e) By the ion-induced Auger peak of the aluminum from the Al probe. This method uses the high ion-induced Auger electron emission of the aluminum. The probe is an Al disk with diameter around 1 mm, prepared on the surface (or also in depth) of the specimen, Figure 5. The tuning is achieved, by maximizing the intensity of the low-energy Al Auger peak. It is convenient to fix the energy of the analyzer at the minimum of the differential LVV peak, which is around 52 eV for ion-electron emission. This method can prove to be perfect and most universal. Therefore some companies producing surface analytic apparatus add a build-in Al probe in their highly specialized sample' manipulators. This is justified since the probe can be used several thousand times.
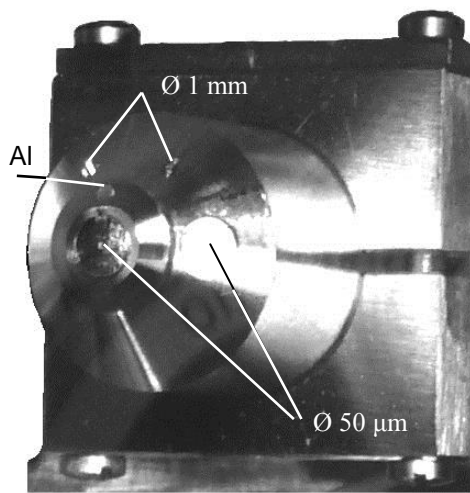

Fig. 5. Commercial coincidence tool (aluminum probe and Faraday cup with 4 different space-oriented diaphragms

f) By combining the ion and the electron image. This method is only applicable for guns with narrow enough beam, allowing the obtaining of the scanning image by ion beam induced electron. The focusing for such beam on the analyzed surface is not a problem (it is performed as in SEM but in fact isn't critical for the profiling, which in this case is done by a scanning of the ion beam). The coincidence of the ion image with the classical SEM image (obtained by the e-gun) is done by the ion gun's deviation plates. We should note that for sharp-focusing ion guns (with a spot' dimension less than 10 μm), this method appears to be the only applicable.

g) By scanning of the ion beam. Introducing this item is somewhat conditional and it is rather presented to underline that the necessity of coincidence (of the electron and the ion beams in Auger profiling) depends on the assigned analytical task. The optimally focused ion beam leads to the maximum gun's sputtering rate. If the last is required for the particular analysis, the focusing is absolutely necessary. However if the analysis requires profiling at speed a few times or even one-two orders lower, the focusing requirements decrease. The simplest way to achieve this decrease is by scanning of the ion beam. The received "blur" of the ion spot equalizes the ion current density distribution. At large enough scanning it might turn out that there is no need to center the ion spot. It is enough to increase the scanning until reaching the necessary (for the analysis) ion current density, measured by the Faraday' cup put at the sample's place.

For better clarity and easier comparison we introduce all of the described methods in TABLE 1.

C. Comments for the application of the methods for the coincidence and the profiling in the analytical practice

Dominant for the setup is the analytical task being solved, which determines the profiling. For example, precise sputtering with speed close to the nominal for the used gun (thick layers) requires careful tuning (mandatory including a focusing). On the contrary, at slow sputtering speed towards the nominal, the precise sputtering can be achieved with appropriate scanning (The ion milling used at some spectral AES analyses should also add here.). Therefore, which coincidence method will be used, the most important is the apparatus base, particularly the type of the ion gun and the availability of tuning options (or the possibility such ones to be additionally upgraded).

Important factor for the discussed tuning is the apparatus mistuning. Where the last is not essential a single precise tuning over long period of time is performed. During this period only tuning tests are made or partial sub-tunings.

TABLE 1. MAIN CHARACTERISTICS OF THE DISCUSSED IN THE ARTICLE METHODS FOR COINCIDENCE THE ELECTRON AND THE ION BEAMS. LEGEND: **A** – BY ETCHING OF THIN INSULATOR LAYER; **B** – BY THE TRACE OF THE BEAM IN THE EBIC IMAGE ON THIN INSULATOR LAYER; **C** – BY FARADAY' CUP; **D** – BY THE ELECTRONS, INDUCED BY THE ION GUN; **E** – BY THE ION-INDUCED AUGER PEAK OF THE AL PROBE; **F** – BY COINCIDENCE THE ION AND THE ELECTRON IMAGE; **G** – BY SCANNING OF THE ION BEAM.

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Method	Precision	Speed	Focussing	Samples	Notice
A	Very well	slow	yes	yes	It's the only one useful for ion guns using static beam. Additionally it provides sputtering speed.
B	Well	fast	Not very well	yes	The image doesn't correspond linear to the ion current density.
C	Very well	fast	yes	-	FC is required.
D	Very well	fast	yes	-	
E	Very well	fast	yes	*	Al-probe is required (sample or option).
F	Very well	fast	yes	-	
G	Well	fast	no	-	In order to decrease the ion current density. Significant area can be covered.

The situation is significantly different for apparatus, where daily optimization of the analytical electron gun's parameters is made. It is obvious that this disrupts – at least partially – the previously made setup of the whole group/ensemble. Before starting the coincidence of the ion gun towards the new position, it is good the check the lateral displacement of both spots towards the new situation. If it is of no significant, it can be compensated by additional weak scan of the ion beam (without significantly lowering the sputtering rate). In general such scan (with amplitude 20-30% from the size of the central intense area from the ion spot) is useful approach during profiling.

IV. CONCLUSION

Auger spectroscopic profiling gives information for the vertical die architecture and for the layers in the technological research experiment.

The increased importance for profiling is a tendency in the application of Auger analyses in microelectronics.

The precise profiling in AES requires a coincidence the electron and the ion beams.

We introduce methods for coincidence of the electron and the ion beams, as their practical application and performances are discussed.

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