

ON THE ABSORBED CURRENT IMAGE IN A SCANNING ELECTRON MICROSCOPE

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ABSTRACT:

The absorbed current image in a Scanning Electron Microscope (SEM) is studied. In particular the hypothesis of Johnson and Kammarath about the relationship between the contrast in this imaging mode and the sample resistivity is tested from a quantitative point of view. It is concluded that the Johnson and Kammarath mechanism can not explain the high contrast difference observed when several elements are present in a sample. A mechanism is proposed to explain the properties of the absorbed image.

I. INTRODUCTION

The absorbed current image in a Scanning Electron Microscope (SEM) is still not well understood. At the present time only limited information can be found in the current literature about this imaging mode. According to Kimoto¹

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and others^{2,3} the contrast produced in the absorbed current mode can be described by the equation:

$$I_a = I_o - (I_B + I_s) \quad (1)$$

where I_a , I_B , and I_s are intensities of absorbed, backscattered, secondary electron signals, respectively, and I_o is the intensity of the incident beam. Since I_o is a constant the contrast to be obtained according to (1) is a mixture of that obtained in backscattering and secondary electron modes. However it is well known that the atomic number contrast is enhanced when samples are observed in the absorbed current mode. This fact has been widely used in routine alloy work but no satisfactory explanation has been given. Johnson and Kammarath³ have stated that the increase in atomic number contrast in the absorbed mode could be related to the sample's electrical properties. Thus local differences in electrical resistivity of the various species present in a sample will produce differences in contrast. Those authors however do not show any quantitative result to support their hypothesis. In the present work we intend to determine in a quantitative way whether or not the electrical properties can produce the extra atomic number contrast as suggested by Johnson and Kammarath. We intend as well to determine the mechanisms that could be involved in the contrast of absorbed current images.

II. EXPERIMENTAL TECHNIQUE

Samples for the experiment were prepared by vacuum evaporation of several metals and insulators. A highly polished aluminium disc was used as substrate. It was observed that the substrate did not present any topographical detail up to a magnification of (\times) 1000. The deposited materials were Al, Pd, Au, Cu, Sn, Ag, NaCl and KCl. These materials were deposited as rows lying parallel to each other along the substrate. Several preliminary tests determined that this arrangement was the most convenient for the deposited materials. The mean thickness of the deposited films was about $2 \mu\text{m}$ for metals and $5 \mu\text{m}$ for insulators. A Monte Carlo calculation of the penetration depth of the electrons for the various materials used in this experiment was performed. The values obtained for the maximum penetration of electrons were: $0.57 \mu\text{m}$, 844 \AA , $0.24 \mu\text{m}$, $0.19 \mu\text{m}$ and $0.40 \mu\text{m}$ for Al, Au, Ag, Pd and Sn, respectively, and $2.4 \mu\text{m}$ and $2.3 \mu\text{m}$ for the NaCl and KCl, respectively. Thus in all the cases no contribution from the substrate to the signal intensity was

expected. In the Monte Carlo calculation the technique described by Murata⁴ was used. The acceleration voltage in the Monte Carlo calculation was taken as 7.5 keV.

Samples were observed on a standard SEM. During the observation the sample was tilted to the angle that produces a maximum height in the signal intensity for the reflective mode. The magnification during the observation was (\times) 50. The signal intensity profile was observed in the wave form monitor and photographed in a short persistence CRT. Measurements of signal intensity were performed on printed photographs.

The signal intensity of the Cu was taken as the zero level. Therefore the intensities were reported relative to the copper (which was present in all the samples). We define the contrast between two elements as $I_a - I_b$ where I_a and I_b are the intensities of each element relative to that of copper.

The sample containing the NaCl and KCl films was covered with a Au-Pd film to reproduce the usual working conditions in the observation of insulators.

Several sources of error such as the noise in the signal, irregularities in the intensity profile on the boundary between two elements... etc., were calculated. The total error obtained is indicated in each case. Samples were examined by secondary electron image to make sure that no topographic contrast was present.

III. RESULTS AND CONCLUSIONS

The intensity of the signal for the several imaging modes is presented in Figure 1 in Histogram form. It should be noted that the values for KCl and NaCl can not be directly compared with the ones for metals because their intensities could not be normalized due to the presence of the Au-Pd coating on these samples.

The pair Pd-Ag is very important because the atomic numbers are close together ($Z = 46$ and 47 , respectively) and the resistivities differ by almost an order of magnitude ($10.8 \mu \Omega \text{ cm}$ and $1.59 \mu \Omega \text{ cm}$, respectively). This pair let us test directly the hypothesis of Johnson and Kammarath since a small atomic number contrast is expected in this case. This is experimentally observed in Table I where the contrast between pairs in the different modes is given. As can be seen the contrast of Ag-Pd is zero within the experimental error for the reflexive mode. However in the emissive mode Ag has a somewhat higher intensity than Pd due to its higher yield of electrons. On the other hand for the absorbed mode the signal of Pd is less intense (on the negative axis) than that of Ag. This latter is not in agreement with the complementary nature of the

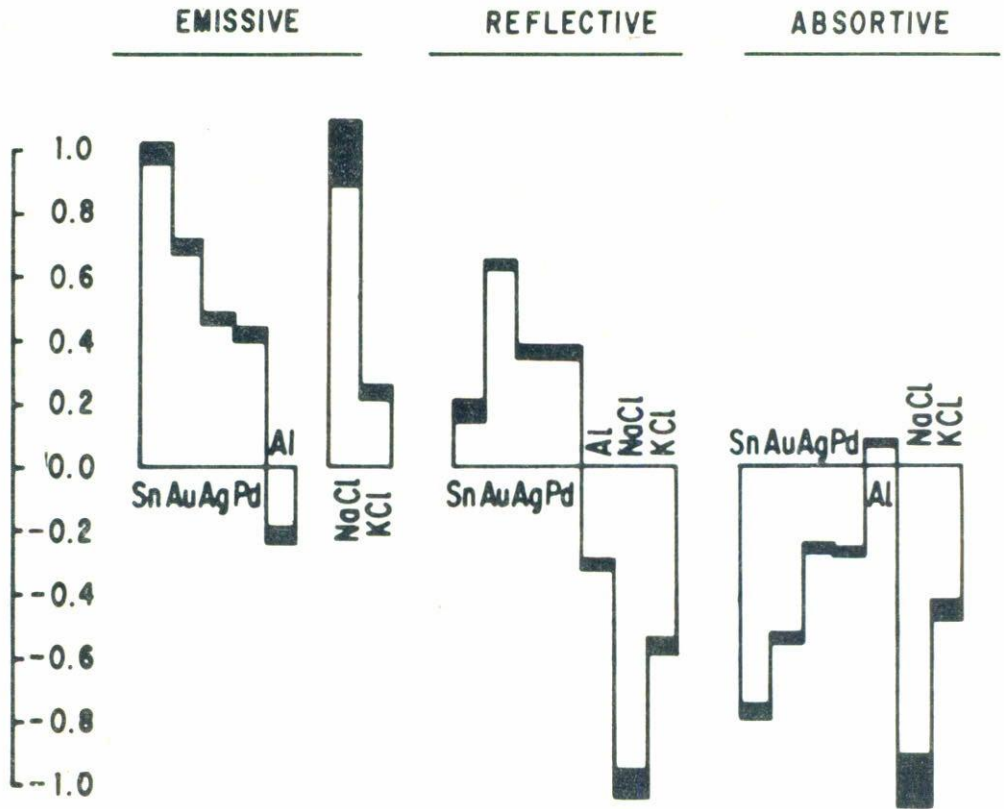


Fig. 1. Intensity (in arbitrary units) of the emissive, reflective, and absorptive signals for several materials.

absorptive and emissive modes and seems to support the hypothesis of Johnson and Kammarath. The extra contrast observed for this pair in Table I is not due to topography or atomic number. However it should be noted that the contrast observed in this case is not enough to explain the high contrast difference usually observed in alloy work.

In Figure 2 the image contrast is plotted versus the difference in atomic number for several metals. Figures 2a, 2b and 2c show the emissive, reflexive and absorptive images, respectively. As can be seen in this Figure in the emissive mode the contrast increases with the difference in atomic number. There is not a simple relationship between contrast and atomic number difference.

TABLE I

Contrast (in arbitrary units) between different pairs of elements in each operation mode.

	EMISSIVE	REFLECTIVE	ABSORPTIVE
Sn-Au	0.30 ± 0.02	0.47 ± 0.02	0.24 ± 0.02
Sn-Ag	0.52 ± 0.02	0.18 ± 0.02	0.53 ± 0.02
Sn-Pd	0.59 ± 0.01	0.19 ± 0.01	0.51 ± 0.01
Au-Ag	0.22 ± 0.01	0.29 ± 0.01	0.29 ± 0.04
Au-Pd	0.29 ± 0.01	0.28 ± 0.01	0.27 ± 0.01
Ag-Pd	0.07 ± 0.01	0.01 ± 0.01	0.02 ± 0.01

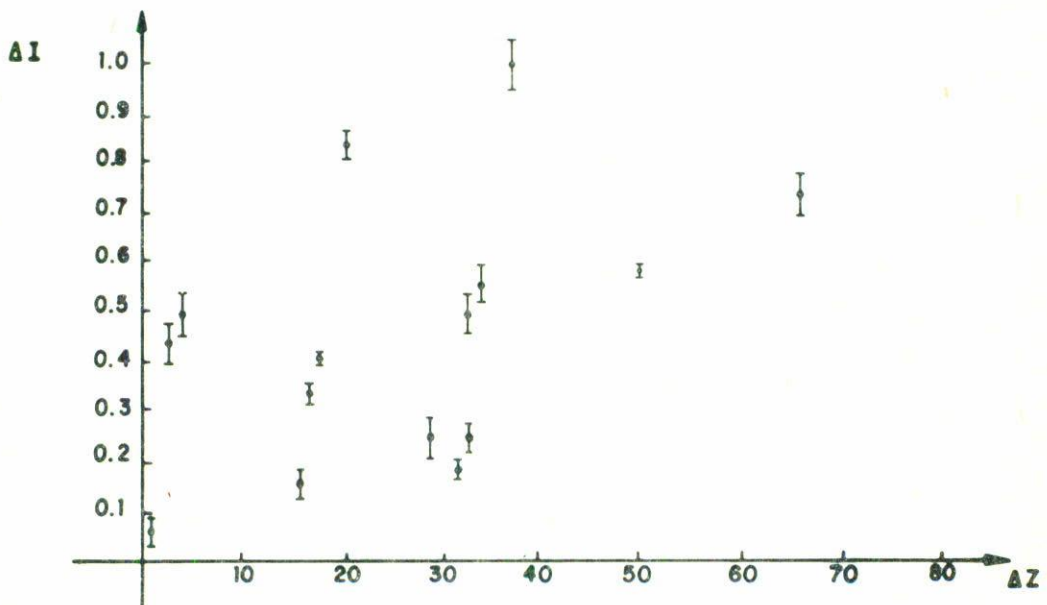
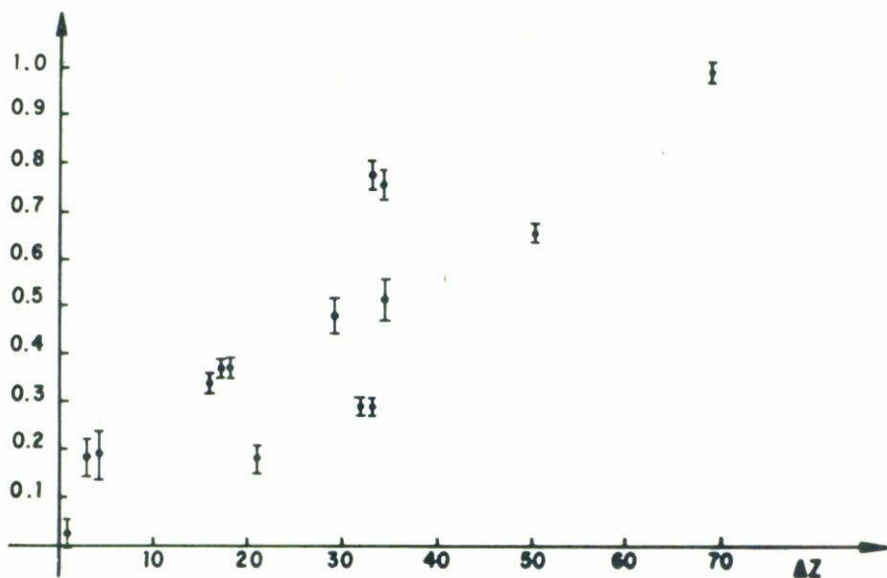


Fig. 2a. Emissive mode. Contrast between metals (in arbitrary units) versus their difference in atomic number (ΔZ). The y-axis represents the signal intensity in arbitrary units.



g. 2b. Reflexive mode. Contrast between metals (in arbitrary units) versus their difference in atomic number (ΔZ). The y-axis represents the signal intensity in arbitrary units.

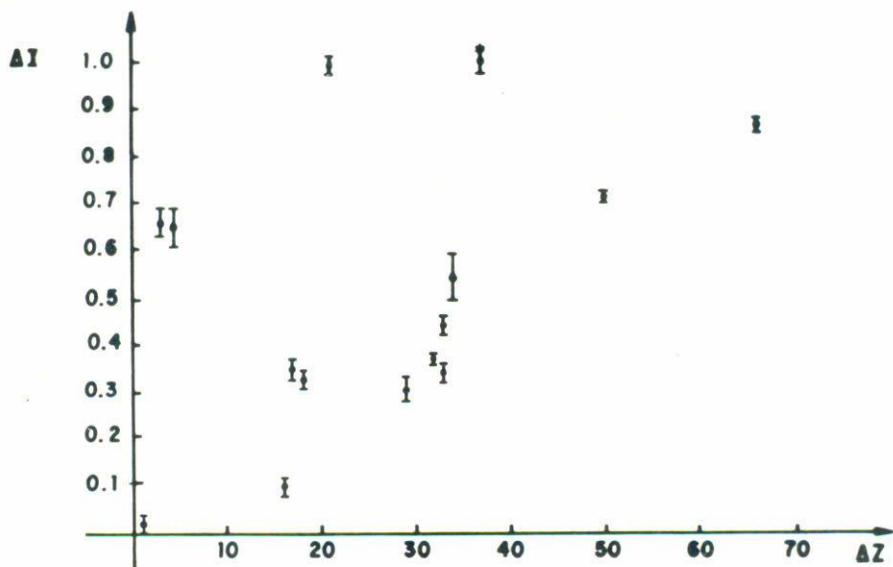


Fig. 2c. Absorptive mode. Contrast between metals (in arbitrary units) versus their difference in atomic number (ΔZ). The y-axis represents the signal intensity in arbitrary units.

Of the three operation modes only for the case of the reflexive mode can a general tendency to produce a straight line (except near to the origin) be observed. As can be seen in Figure 2c the contrast in the absorptive mode increases more strongly with the difference in atomic number than that of the emissive mode. The points are somewhat less scattered. This indicates a more defined dependence of contrast on atomic number in this mode. When plots of contrast versus several parameters such as mean free path of the electrons, number of atoms per unit volume, resistivity and atomic radii are made, the resultant curves are very complicated. No direct information about the role of those different parameters can be obtained.

The results can be explained by the following mechanism: in the formation of the absorbed current image all the backscattered electrons are contributing. On the other hand the secondary image contains only a portion of the backscattered electrons which are those that strike directly on the collector. The missing part of the signal produces the difference in contrast between the absorbed and emissive modes. Then equation (1) can not be applied directly to the analysis of those signals. The resistivity of the sample has observable effects only on the contrast. However this is a minor contribution since a high difference of resistivities is required to produce a small difference in the contrast.

We can then conclude from the experimental results that the non complementary nature of the absorbed and the emissive images seems to be more related to the geometry between sample and collector than to the electrical properties of the sample.

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REFERENCES

1. S. Kimoto, *Jeol News* 10c, 1,2 (1972).
2. G.R. Booker in *Modern Diffraction and Imaging Techniques in Materials Science*, Eds. S. Amelinckx, R. Gevers, G. Remaut and J. Van Landuyt (North Holland Publishing Co., 1970).
3. L.N. Johnson and W. Kammarath, *Proceedings of the SEM Annual Simposia (ITRI) (1972)* 90.
4. K. Murata, *Jap. Jour. Appl. Phys.* 10 (1971) 6.

RESUMEN

Se estudia las propiedades de la imagen de electrones absorbidos en un microscopio de Barrido. La hipótesis de Johnson y Kammarath sobre la relación entre el contraste de la imagen y la resistividad de la muestra es examinada desde un punto de vista cuantitativo. Se concluye que el mecanismo propuesto por Johnson y Kammarath no es adecuado para explicar el experimento y se propone un mecanismo alternativo.