Advanced microscopic techniques used for integrated circuits authenticity analysis

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Abstract. Many electronic systems used in industry or other special areas are put at risk by counterfeit electronic components occurrence, especially by semiconductors. These counterfeit components represent a serious threat for systems functionality and reliability. We can take as a fraudulent or as a suspicious component any component of unknown origin, which we can find any difference in contrast to the original manufacturer component of the same model. This article describes advanced microscopic techniques used in problems with counterfeit integrated circuits. Their genuineness evaluation ability is discussed and illustrated with several microscopic images.

1. Introduction
The electronic component counterfeits have appeared a couple years ago and the electronic assemblies are confronted with this serious threat more and more. Methods for evaluation of genuineness of the electronic components, especially integrated circuits are based on a comparative analysis where we have the reference - authentic component from reliable source. Their known features are evaluated with particular component and its features. Features can be either obtained through the complex various electrical measurement resulting in definite characteristics or through visual inspection. Visual inspection is relatively available method for wider circle of customers but its possibilities are limited to outward dissimilarity of the component. During visual inspection the magnifying glass, stereomicroscope or classical optical microscope can be used, the attention is focused on dissimilarities in labelling and its structure, type size, position of its individual parts, producer logo, date production coding, thermal indents etc. There is also possible to scrutinize grain surface or check a presence of the layers hiding marks after original labelling. Geometry of the component housing, its size, edge bevelling, rounding corners, spacing, shape and size of terminals can be considered as the further appearance dissimilarities. Besides visual inspection, these parameters can be measured. If we have the component from authentic producer, mentioned parameters are fixed and known together with their tolerances. In case of counterfeit components they can significantly differ. There are another advanced methods which make this comparison easier and more precise and at the same time they belong to non-destructive methods with respect to preservation of the functionality of the component.

2. Used instruments
We have specific microscopy laboratory equipped except others with scanning electron microscope Zeiss EVO® MA 15 with sputter coater Quorum Q150R, laser scanning confocal microscope Zeiss
LSM 700 for Materials, atomic force microscope Agilent 5420 with microwave vector network analyser PNA N5230A allowing us use of scanning microwave microscopy.

3. Used advanced microscopic techniques

3.1. Scanning electron microscopy (SEM) equipped with electron dispersive X-ray spectroscopy (EDS)

This method is based on the wave properties of electrons. Focused beam of high-energy electrons is used for generation a group of signals at the surface of the solid specimen which is in low or high vacuum chamber. Mentioned signals are derived from electron-sample interactions and disclose information about the sample’s surface, its chemical composition or crystalline structure. The electron beam is scanned in a raster scan pattern, it ranges from centimetres to a few micrometres in width; as a result two-dimensional image with large depth of focus is produced. Image shows spatial variations and looks rather like three-dimensional image. Spatial resolution up to order of nanometres can be achieved, some samples can be seen in Figures 1 and 3. It is also possible to select any point or small area located on the sample, this approach is especially useful during qualitative or quantitative analysis at determination of chemical composition, which is illustrated in Figures 2 and 4 on the revealed chip.

**Figure 1.** SEM - the thermo-compression micro-bond of the gold wire at chip contact area.

**Figure 2.** SEM + EDS mapping - the thermo-compression micro-bond of the gold wire at chip contact area with chemical components imaging.

**Figure 3.** SEM – Area of chip description including logo.

**Figure 4.** SEM + EDX mapping - Area of chip description including logo with chemical components imaging.
Mentioned method has some limitations. Electrically insulating samples must be coated with conductive layer (we also have sputter coater available - Au, W, C) when higher spatial resolution is required. The EDS detector cannot detect very light elements (H, He, and Li) and has relatively poor energy resolution and sensitivity to elements present in low quantity when compared to wavelength dispersive x-ray detectors (WDS).

3.2. Laser scanning confocal microscopy (LSCM)
LSM 800 is a confocal laser scanning microscope that uses laser light in a confocal beam path to capture defined optical sections of the sample and combine them in a three-dimensional image stack. Its aperture is arranged in such a way that out-of-focus information will be blocked and only in-focus information can be detected. An image is generated by scanning in x,y-direction. In-focus information appears bright while out-of-focus information is dark. By changing the distance between sample and objective lens, the sample is optically sectioned and an image stack is generated. By analysing the intensity distribution of a single pixel through the image stack you can calculate the corresponding height. The height information over the whole field of view can then be combined to form a height map.

The confocal laser scanning microscope is the useful instrument for materials analysis. We used this instrument for precise imaging and deep inspection of 3D surfaces' high precision topography of the analysed integrated circuit which is illustrated in Figure 5 and Figure 6.

3.3. Atomic force microscopy (AFM) with scanning microwave microscopy (SMM)
Atomic force microscopy is a derived method from scanning probe microscopy where intermolecular forces are measured over the sample surface. Despite the lateral resolution of AFM is quite low (roughly 30 nm) due to the convolution, the vertical resolution can be up to 1 Å. To acquire the image resolution, AFMs can generally measure the vertical and lateral deflections of the cantilever by using the optical system with laser beam and four-segments of photo-detector. For tip positioning the high resolution piezo-ceramics position system is used. SMM measures electromagnetic interactions of the microwave from a tip or aperture with the sample under test on a scale that is significantly less than the wavelength of the radiation. With this techniques we are able to map not only topography of the material, but also physical properties of conductors and semiconductors, such as impedance, capacitance, dielectric constants or dopant density at the nanoscale measure, as can be seen in Figures 7 and 8. Maximal area which we can measure with this technique is about 90 x 90 μm. The
main disadvantage is the re-location of the specific part of the specimen when altering the method. Another can be relative slow measurement which takes in tens of minutes.

Figure 7. AFM/SMM – measured capacitance map of PNP transistor.

Figure 8. AFM/SM - measured dopant density map of PNP transistor.

4. Conclusion
SEM and LSCM in our laboratory has big advantage which is possible use of correlative microscopy. We can choose unique sample centric correlation of images and data to advance our work beyond the limiting boundaries of a single microscopy technique. Our aim and direction for the future is further developing of the existing, experimentally verified microscopic methods. We also are trying to verify how to involve Raman and terahertz spectroscopy together with other analytical methods convenient for counterfeit semiconductor components and other fake electronic components detection and evaluation.

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