Crystal Orientation Mapping of Copper Interconnects using EBSD

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The semiconductor industry is committed to introducing copper interconnects in place of aluminum for the latest generation of semiconductor devices. With its greater current carrying capacity, the use of copper should enable further reductions in device geometry, power consumption and heat generation, and lead to higher performance and longer battery life in portable devices.

Grain orientations, crystallographic 'texture' trends and boundary types are crucial in determining properties such as electrical resistively, strength and corrosion resistance. These parameters may be implicated both in the performance of the device and in failure mechanisms, which are of great importance in determining reliability.

Our work demonstrates that high-resolution electron backscatter diffraction (EBSD) is now both possible and routinely achievable using both hot and cold field emission gun scanning electron microscopes (FEGSEMs). Our results demonstrate that EBSD can be successfully used to map grain orientation and to reveal and classify grain boundaries for this application. EBSD offers a new tool for engineers and researchers for development, process optimization and failure analysis of semiconductor devices.

Previously, such work would have been in the domain of transmission electron microscopy (TEM), with the accompanying complexities of obtaining and interpreting results. Using EBSD on a FEGSEM not only offers a very cost effective alternative, with simple operation and interpretation of results, but also has the considerable advantage of comparatively simple specimen preparation. This, combined with the ability to inspect large areas of sample, makes EBSD a particularly powerful new contender in this field of research.

EBSD An Overview

Electron backscatter diffraction is a comparatively new technique for scanning electron microscopy (SEM), filling the gap between TEM and x-ray diffraction studies, and, in many cases, negating the need for these more traditional techniques.

EBSD uses a specialized camera fitted to an SEM, and when the microscope geometry permits, simultaneous use of other techniques, such as Energy Dispersive Spectroscopy (EDS) is possible. EBSD enables the determination of crystal orientations from very small features, and the observation of texture trends on a micro-scale. It is a surface sensitive technique which uses data acquired from a depth of the order of tens of nanometers. The system used for this work was an Oxford Instruments Opal™.

Very high spatial resolutions can be achieved using advanced electron optics, or cold FEGSEMs, which both offer superior imaging performance and have greatly enhanced imaging capabilities over conventional tungsten gun microscopes. EBSD can be used with either hot (Schottky type) or cold FEGSEMS, which both offer superior imaging performance, but which have slightly different operational characteristics.

We use a special low light, Peltier cooled, CCD camera, which provides low noise characteristics and high sensitivity. The camera images electron backscatter patterns (EBSPs) from a phosphor screen mounted at the end of a tube inserted into the vacuum chamber and placed close to the specimen. The sample is steeply inclined to maximize the contrast in the diffraction patterns that are produced when the beam falls on a crystalline area. The diffracted electrons are emitted in a series of bands, known as Kikuchi bands, which relate to the crystal planes within the sample. These fall on the phosphor screen causing light to be produced, which is imaged by the CCD camera. The positions of the bands, which contain information relating to the symmetry and orientation of the crystal, are identified using the Hough transform.

Crystal Orientation Mapping

The positions of the Kikuchi bands are analyzed, from the known crystal structure, and the pattern indexed to give the orientation of the crystal. In mapping, this process is automated to obtain a pattern for every point in the image, index it, and plot the orientation on a crystal orientation map (COM). Each orientation, which can be described using standard Miller indices, is assigned a color code based on the inverse pole figure.

Color Key

Every measurement made is plotted as a point in the inverse pole figure, which can be colored (Figure 1) to make a color key. Thus color the represents the crystal orientation at each point on the crystal orientation map (COM). This makes it possible to display subtle variations in orientation, show which crystal plans lie parallel to the sample surface, and permit visualization of crystal rotations.

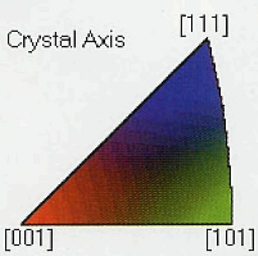


Figure 1

Crystal Orientation Map

From the crystal orientation map (Figure 2), it is relatively simple to visualize (*e.g.* for a cubic material) that the face of the crystal {100} is parallel, or nearly parallel in this case, to the surface when a shade of red is shown, the edge {110} when green is shown, and a corner {111} when blue is shown. However, visualization is made even simpler by clicking on the image to see the orientation at that point displayed as a crystal model.

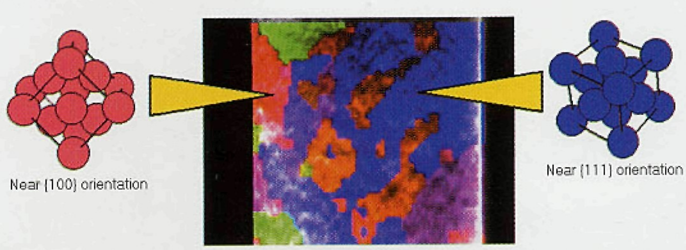


Figure 2

Range of measurements

Because the COM is essentially a grid of data points stored in the computer, a wide range of measurements and post acquisition processing of the data is possible, and the whole process can be interactive.

The system can be operated manually, to obtain information rapidly about particular features of interest, or automatically, for mapping. The COM can be combined or compared with the sample morphology for easy visualization of crystallographic trends.

Orientation and Crystallographic trends

Localized orientation measurements can reveal the presence of particular crystallographic trends or 'textures'.

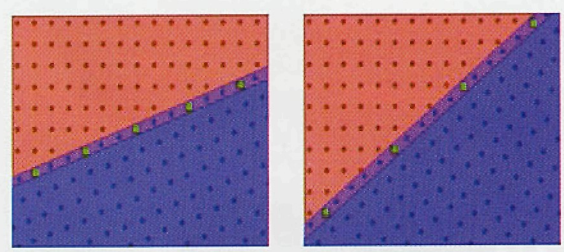
Misorientation and Grain Size

Measurement of misorientation (the relationship between two regions of discrete orientation), enables the identification and characterization of grain boundaries and the calculation of grain size. The presence and distribution of various phases may also be identified and mapped.

Coincident Site Lattice (CSL) Boundaries and Special Features

The distribution of grain boundaries is particularly important, playing a major role in determining physical properties such as strength, corrosion resistance and electrical parameters. Grain boundaries may be broadly categorized by the misorientation angle across a boundary, high- and low-angle boundaries having different properties. While grain boundaries are generally a region of disorder between the crystal lattices that make up the different grains, special types of boundaries exist where a degree of order is present. These are of great interest to engineers as their properties differ from disordered boundary types.

Coincident site lattices occur when atomic sites are shared between two lattices. The regularity with which atoms are shared is given a number, the Sigma value. For example, if every third atom is shared (Figure 3), the boundary is termed a 'sigma 3' boundary. A powerful facility of EBSD is its ability to differentiate and plot the distribution of the many boundary types, and their sigma values.



Sigma 3 type boundary. Every third atom is shared.

Sigma 5 type boundary. Every fifth atom is shared.

Figure 3

Copper Interconnects

Using high resolution EBSD, we mapped a series of copper metallized tracks, which were arranged in a test pattern to present a variety of track widths.

Early trials had shown us the importance of having a clean, undamaged sample surface on a crystallographic scale. We found that conventional polishing and etching were inadequate for delicate semiconductor materials, but that plasma etching, which is commonly used in the semiconductor industry, gave us excellent results. The use of reactive gases with plasma etching further, and dramatically, reduced the etching time needed.

After preparation by plasma etching, EBSD using cold FEGSEM revealed detail of the structure of the copper conductors. These filtered images (Figure 4) are at a magnification of 20,000, with tilt correction, and contain 2156 measurements. Pixel size is 87 nm, and the presence of individual grains is clearly visible in the COM image, as are special CSL boundary types in the CSL distribution. Boundaries shown in green are Sigma 3 types, accounting for 83% of special boundary types present.

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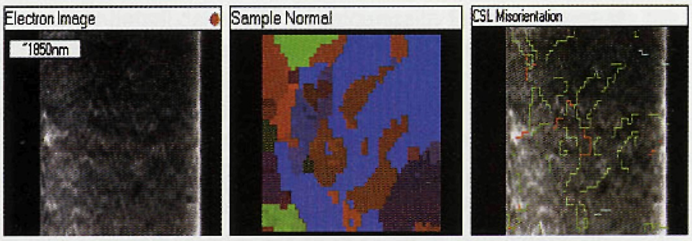

Electron Image　　COM　　CSL Distribution

Figure 4

Trials were also done using a hot FEGSEM. Figure 5 shows the results of an EBSD scan, using hot FEGSEM, carried out on a 200 nm copper interconnect at 200,000X magnification. The selected area shows predominantly a single 100 oriented grain bordered by 111 oriented grains. Crystal mimics show the actual orientations depicted as unit cells. Again, a predominance of Sigma 3 CSL boundaries was observed. The 'Sample Normal' map shows the 'click & drag' feature where a line drawn across a boundary shows the misorientation angle and common axis, displayed on the image.

Misorientation map showing grain boundaries　　CSL distribution showing Sigma 3 boundaries　　Texture map and colour key for map set

Figure 5

Sample Preparation

Good sample preparation was very important in achieving these results, but was relatively straightforward using plasma etching and the following common good practice techniques to minimize heating effects.

- Use equipment with a water-cooled sample electrode.
- Ensure good thermal conductivity to the sample.
- Use the lowest possible power level, consistent with an adequate etching rate.
- Use the lowest possible exposure time, consistent with an adequate etching rate.
- For long exposure times make a number of short exposures with intermediate cooling periods.
- Use a temperature monitor on the sample if available.
- Where no temperature monitor is available, a good indicator is that the sample should still feel cool when it is re moved from the equipment immediately after cleaning.

Conclusion

EBSD is a powerful tool for studying the properties of narrow copper tracks on semiconductors, capable of providing far more information than a conventional electron image. EBSD can reveal crystalline structure, grain size and crystallite orientation, enabling semiconductor scientists to relate electrical properties to internal structure and correlate them with process parameters.

The work described here demonstrates that excellent results from copper interconnect samples can be simply achieved using EBSD and sample preparation techniques which are already familiar to the semiconductor industry.