Microstructural Characterization of Metal Thin Films for IC Interconnects

Materials Challenge

The manufacturing of integrated circuits (IC) requires the fabrication of conductive interconnections between the many active semiconductor regions from deposited metal thin films. The microstructure of these films has a direct impact on the reliability of the IC devices. Failure often occurs by electromigration, which is the diffusional transport of metal ions. Diffusion rates are a function of microstructure; therefore, it is important to be able to accurately characterize film microstructure to improve the reliability of the devices.

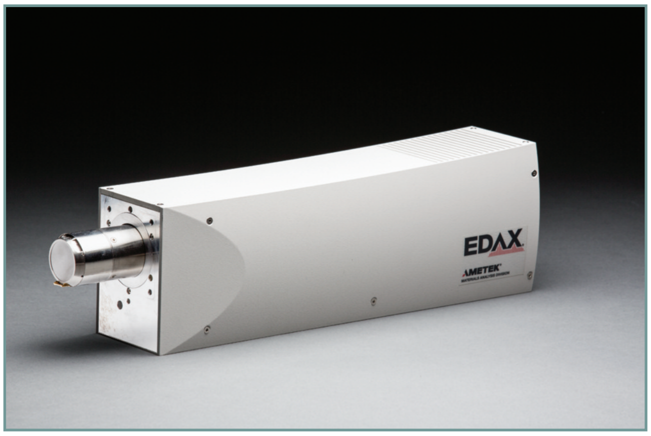

Figure 1. Hikari EBSD Camera

Comparison with Existing Solutions

One traditional technique for measuring thin film microstructure is X-ray diffraction (XRD). Using XRD for characterization has some limitations:

- XRD can be time consuming, especially to obtain full crystal orientation information.
- XRD does not measure grain size directly, but only infers size from diffraction peak broadening. There are many competing factors involved in broadening which must be distinguished.
- XRD is insensitive to variations in grain sizes between approximately 100 nm to 10 µm, which is a common grain size range for metallic thin films.
- XRD provides no information on the grain boundary character of the material, which strongly influences the diffusional properties and resistance to electromigration failure.

Another possible microstructural characterization technique is transmission electron microscopy (TEM). This technique also has limitations when applied to metal films:

- TEM requires intensive and time consuming sample preparation prior to analysis.
- TEM requires expert operators to accurately measure crystal orientation and grain boundary character.
- TEM orientation measurements are generally collected manually, making data collection time consuming.
- TEM provides a finite number of measurements, limiting the full description of the crystal orientation distribution and the grain boundary character.

In contrast, electron backscatter diffraction (EBSD) provides a fast and automated solution to measure thin film microstructure. The advantages of EBSD include:

- EBSD has fast data acquisition rates. With the Hikari Camera Series, a full microstructural analysis can be obtained in one minute.
- EBSD provides a comprehensive description of the microstructure. It provides information on crystal orientation, grain size, grain boundary character, phase distribution, and local plastic strain.
- EBSD has a spatial resolution below 50 nm for traditional EBSD and below 10 nm for transmission-EBSD and can also analyze areas larger than 1 cm x 1 cm. This allows for high spatial resolution data collection and large area analysis to meet most microstructural analysis requirements.
- EBSD measures statistically relevant data. At greater than 1,400 measurements per second, over one million individual orientation measurements can be taken in less than 12 minutes.
- EBSD requires little sample preparation for analysis of metallic thin films.

Microanalysis Results

Aluminum has traditionally been used for IC metallization. Electromigration behavior and mean time to failure of the material are strongly dependent on crystal orientation, grain size, and grain boundary behavior. A selection of EBSD maps was collected at 650 points per second from an alloyed aluminum film (Figure 2).

The mapping area and sampling step size were varied to obtain different total data collection times. The results, summarized in Table 1, show that a statistically representative sampling of film microstructure can be collected in one minute. Texture results calculated from the orientation data show a strong (111) preferred orientation. From previous research, the (111) orientation has been shown to increase the mean time to failure of IC devices after interconnect fabrication.

Scan	Time (min)	Ave Grain Size (μm)	(111) Texture
1	1	3.75	13.4
2	5	3.96	13.8
3	5	4.14	13.3
4	60	3.97	13.6

Table 1. Results from EBSD scans collected at 650 indexed points per second from aluminum thin film.

As IC device dimensions shrink, copper has been increasingly implemented as the interconnection metal due to its higher conductivity. As with aluminum, grain boundaries act as diffusion paths aiding electromigration failure. However, with copper, coherent twin boundaries within the microstructure have diffusion rates lower than random high-angle grain boundaries. Increasing the fraction of twin boundaries through film deposition and thermal processing reduces the unfavorable diffusional paths and improves mean time to failure. EBSD is well-suited to measure a large number of grain boundaries and to classify them as either helpful twin boundaries or detrimental random high-angle grain boundaries. Figure 3 shows an EBSD grain map, where twins are included or excluded during the grain calculation. The grain size of the copper film with twin boundaries excluded (1.4 µm) is a better indicator of electromigration performance and lifetime than when the grain size measurement includes twins (500 nm). EBSD is unique in its ability to measure grain size without twin boundaries and therefore can be effectively used to optimize processing conditions, improving semiconductor device lifetime.

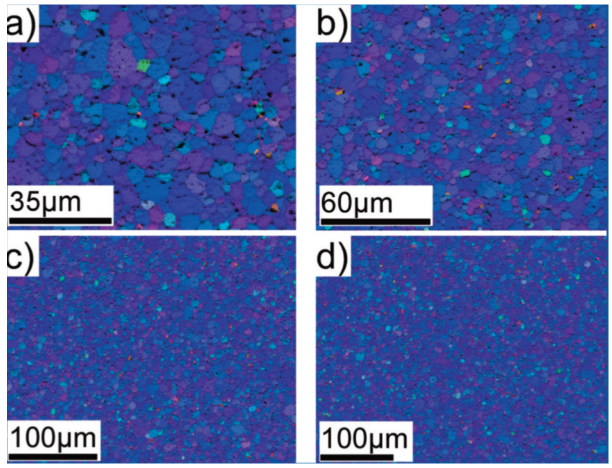

Figure 2. Orientation maps from aluminum film collected for a) 1 minute, b&c) 5 minutes, and d) 60 minutes.

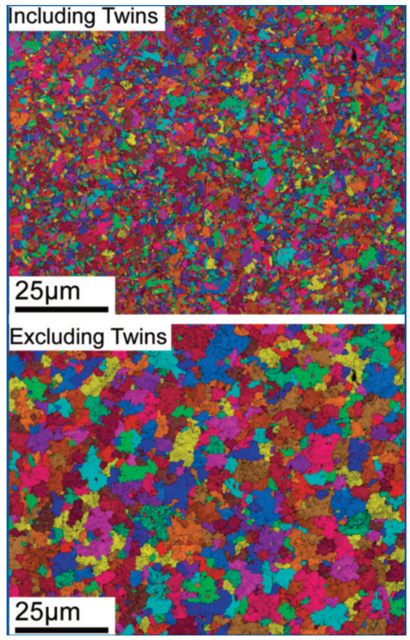

Figure 3. Grain maps for copper film where twin boundaries are included (top) and excluded (bottom) from grain determination. Calculated grains are randomly colored to show size and morphology.

Recommended EDAX Solution

The EDAX TEAM™ EBSD Analysis System is the recommended solution for this application. For customers interested in obtaining elemental analysis information, the TEAM™ Pegasus Analysis System containing both energy dispersive spectroscopy (EDS) and EBSD detectors is recommended. The Hikari EBSD Camera Series and Octane Silicon Drift Detector Series are suitable for crystallography and elemental analysis, respectively.