MATERION

Electronic Materials

Newton's Evolution into a Leader in Tantalum Materials

From research to production, Newton's material expertise dates back to the 1950s.

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Materion's Newton facility has a rich and storied history dating back to 1940. Some of the early successes at Newton, which operated as the National Research Corporation, included the development of freeze-dried coffee (Holiday Coffee), frozen orange juice concentrate (Minute Maid), blood plasma, and the metallization of paper and plastic substrates.

Evolving from a research-focused company to a production-focused company in the early 1950s, the National Research Corporation began producing titanium from titanium tetrachloride using the Hunter Process. Early success with the Hunter Process was extended to the production of tantalum powder from tantalum pentachloride. Additionally, the sodium reduction of tantalum salt (K_2TaF_7) produced pure tantalum ingots for mill products; this process is still used in Newton to manufacture 'Q' powders today. This ground-breaking work culminated in the investment of a new plant to produce capacitor grade powders.

Over the next 40 years, Newton saw numerous ownership changes, as well as various technical challenges. In the early 1960s, the site built a tantalum powder facility to focus on high-purity tantalum metal and tantalum oxide (Ta_2O_3)-based capacitor materials. During that period, significant learnings about the formation, isolation, and purification of high-purity tantalum metal set the future course and direction of the Newton facility.

During that same time, the United States was locked in a heated race with the USSR to put a man in space. The 'space race' contributed heavily to the need for rapid computational capability and the ability to crunch large amounts of numerical data rapidly. IBM worked closely with NASA to develop the 'mainframe' computer technology. They also needed to understand the complex math related to putting a person in space, circling the globe, and bringing the astronaut back to Earth safely. In large part, NASA was an early adopter of IBM's computer technology, enabling space travel and revolutionizing the electronics industry at the same time. Tubes and transistors were about to be replaced by integrated circuits. Interestingly, IBM and Newton unknowingly shared a combined destiny within the semiconductor industry, but this would not become evident for another 30 years.

As the computer industry and integrated circuit technology continued to evolve, a drive towards greater miniaturization and higher performance became the focus for most integrated circuit makers. Although roughly ten elements were used in the earliest integrated circuits, the drive for smaller, faster, and higher functioning chips resulted in the need to incorporate even more elements.

Where early integrated circuits contained roughly 1,000 transistors, today's integrated circuits may contain over 50 billion transistors. This evolution relied heavily on the ability to shrink circuitry via enhancements in photolithography, and more recently, the adoption of new materials to drive improved performance.

The advancement of integrated circuits – according to Moore's law – meant that the number of transistors would double every eighteen months, thereby reducing the spacing of the transistors and decreasing linewidths, while increasing device performance. This was accomplished by reducing the critical linewidths of the transistors from 1 micron (1000 nanometers) down to 10 nanometers (Figure 1). As this trend is expected to continue, performance requirements of new materials and related diffusion barriers have become increasingly more stringent.

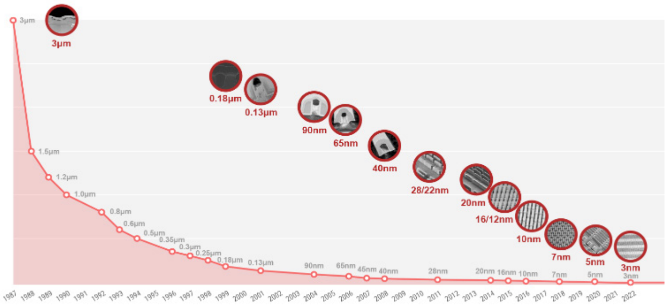

Figure 1: The evolution of transistors from 1 micron to <10 nanometers

Source: TSMC

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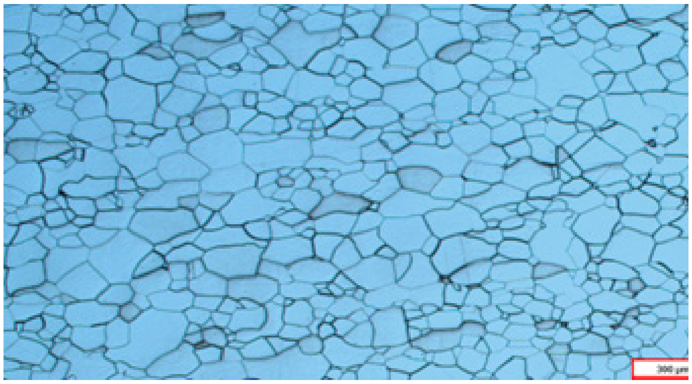
As the device circuitry became longer and more convoluted, signal propagation delay began to slow down device performance. Therefore, there was a need to address the RC time constant delay. Some companies focused on lowering the dielectric constant and capacitance of the insulators (C) while IBM focused on changing the resistance (R) of the interconnect circuitry. This focus on lowering the resistance led to the adoption of copper interconnect wiring, which replaced the long-standing aluminum metallization. Both copper and aluminum can readily diffuse into silicon and the neighboring dielectric materials, altering their basic properties and performance. The standard diffusion barrier used for aluminum was titanium nitride (TiN), but this was not sufficient for copper metallurgy. Therefore, finding a suitable diffusion barrier for copper required significant and systematic exploration.

In the late 1990s, it was determined that a tantalum (Ta)/tantalum nitride (TaN) barrier film provided sufficient diffusion barrier properties between copper, silicon, and the insulators, while also affording good electrical performance with long-term operating reliability. Newton's long history of manufacturing high-purity tantalum immediately put them in a position to capitalize on the need for high-purity tantalum sputtering targets, enabling the wider adoption of copper interconnect technology.

In 1999, a Tantalum Sputtering Target Team was formed in Newton. The team's goal was to produce tantalum discs with uniform metallurgical properties. Initially, the team sought to create discs with fine uniform grain size and high purity characteristics. They were successful in product development activities and Gen 1 launched in 2000. As seen in the ingot structure below (Figures 2a and 2b), achieving a fine grain size in half-inch thick discs was challenging.

Ingot Grain Structure

Disc/Plate Grain Structure



Figures 2a and 2b: Ingot grain structure and disc/plate grain structure

As the business grew and demand for tantalum sputtering targets increased, the sputtering performance of Gen 1 became an important factor for end users, including logic and memory semiconductor chip manufacturers. Film thickness and uniformity needed to be controlled within very narrow control limits to ensure optimal sputtering and device performance. While tantalum sputtering target texture and variation was realized to have an impact on the thin-film sputtering rate and device operational performance, texture control and repeatability became increasingly critical for future device nodes.

Texture or the distribution of grains with specific crystallographic orientations within a tantalum sputtering target had to be controlled. The three primary crystallographic orientations in tantalum, a BCC metal, are the <100>, <110>, and <111> crystallographic orientations as seen in the graphic below (Figure 3).

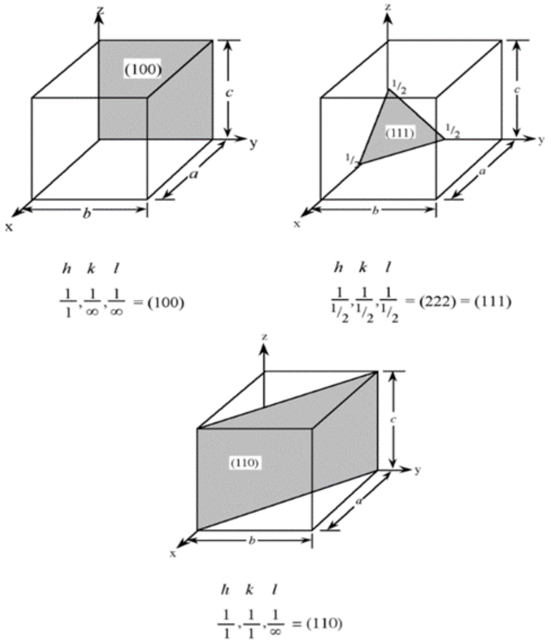


Figure 3: Depiction of crystallographic orientations in BCC metals like tantalum

Many factors influence texture in processed tantalum, but some factors are more important than others. Texture variation is three dimensional and directly impacts sputtering performance as each of the three crystallographic orientations has a different sputtering rate. <110> orientation displays the highest Ta sputtering rate, <100> the second highest Ta sputtering rate, and <111> the lowest Ta sputtering rate (Figure 4). This texture variation is one reason why it's so difficult to produce tantalum with a uniform microstructure. The sputtering rates affect the film thickness and uniformity; any variation in the sputtering rate results in variation in the film thickness. If the film thickness goes out of control, the sputtering process must be halted, and the target is taken out of service.

Since diffusion barrier layers are exceedingly thin and continue to become thinner with shrinking device dimensions, careful control of the sputtering rate is essential for semiconductor device manufacturing. As linewidths shrink, the diffusion barrier cannot take a disproportionate volume from the conducting metal circuits. Therefore, the industry is driving to further reduce the diffusion barrier thickness, while simultaneously maintaining excellent barrier properties and electrical performance.

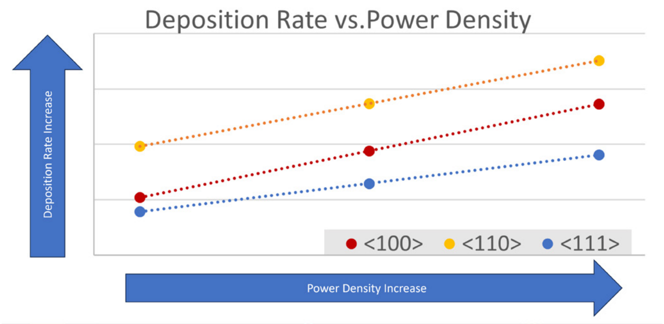


Figure 4: Sputtering rates versus crystallographic orientation

Evolution of Texture Control in Tantalum Discs

Uncontrolled Texture

Controlled Texture

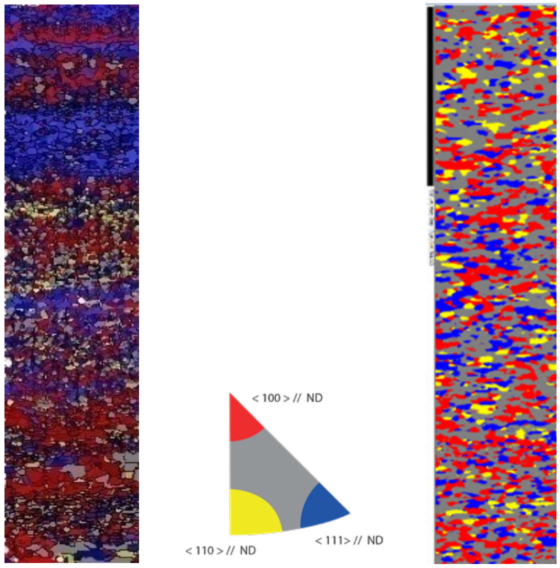


Figure 5: EBSD images of uncontrolled texture (left) versus controlled texture developed in Newton (right)

To help measure and control texture within tantalum discs, electron backscattered diffraction (EBSD) is the preferred method employed because it is fast and has become less expensive over time. Newton utilizes this method of measurement to study and understand the influences of various process variables on the observed texture of tantalum discs. This has allowed us to develop more uniform textured products and minimize texture variation within our existing products. These products will have predictable sputtering performance through the life of the target and from target-to-target. This level of control is required by our customers that manufacture integrated circuits with tantalum-based diffusion barriers.

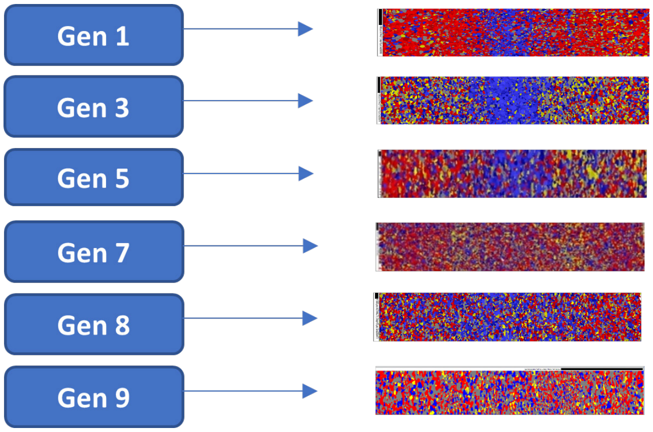


Figure 6: EBSD images demonstrating the evolution of controlled texture in tantalum sputtering discs over time and product improvements based upon continuous learning in Newton.

Learning from our vast experience and leading the industry in the production of tantalum targets for the past decade, we also offer customized tantalum targets that meet the specific requirements of our customers. With our advancement in understanding texture and how to control it, we've strengthened our capability to provide a product that has evolved with the fast-growing semiconductor industry and its increasingly stringent requirements.