The Gold vs. Aluminum War Revisited

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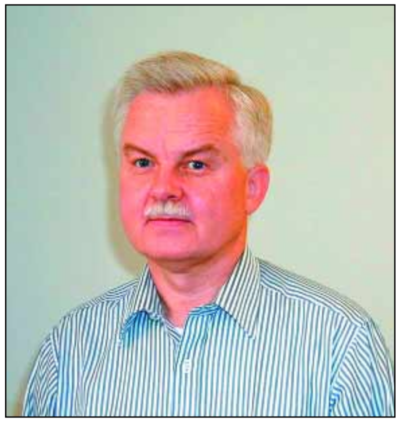
Isn't controversy an amazing thing? Claims and counter-claims are lobbed back and forth. Technical facts and opinions spin incessantly, though not inerrantly — especially when sales and marketing (read money) are involved. Well, the gold versus aluminum debate has resurfaced after 25 years, and discovering the truth seems nearly as difficult now as it was then.

In the 1970s, RF power transistor manufacturers fought each other tooth-and-nail for years to gain a customer acceptance advantage for their chosen transistor metallization systems. Remember the advertisements stating that aluminum is good for "ladders and lawn chairs" but *not* for RF power transistors? This was the catchy phrase trumpeted by PHI in one of its ad campaigns. I thought the campaign was rather creative, especially since I worked for a company on the aluminum alloy side of the fence. Electro-migration was *the* issue at the time, and 1 GHz to 3 GHz high-power aluminum metallized transistors could degrade in a matter of weeks or months. Evidence of electro-migration of aluminum and aluminum-silicon conductors was real and available and not pretty.

Remember "hillocks," "whiskers" and "void growth," "step coverage thinning," etched "mouse holes," metal grain size, passivation effects and Jim Black's electro-migration equation? The theory and practice of improving electro-migration test results were quite well researched and understood. Reducing current densities by increasing cross-sectional areas (thickening metal layers), as well as employing aluminum-copper-silicon alloys, allowed a manufacturer to build acceptable aluminum RF power transistors that had electro-migration lifetimes of at least 50 to 150 years. We built hundreds of thousands, maybe even millions, of transistors with that system.

Nonetheless, the damage to aluminum (and aluminum-based alloys) had been done. Gold was superior in direct "apples-to-apples" electro-migration comparisons, so every aluminum-based system began losing out in the marketplace. Nearly all RF power transistor manufacturers eventually switched to gold-based metallization systems.



Howard Bartlow has been designing, fab processing, assembling, testing and trouble-shooting RF power transistors for more than 30 years. He has served in engineering and management positions at Monsanto Research, TRW Semiconductor, Communications Transistor Corp., Acrian, Inc., Microwave Modules and Devices and Spectrian Inc. He has a bachelor's degree in Engineering Physics. He serves as president of HdB Engineering, working on BJT, LDMOS, GaAs MESFET, SiC MESFET, RF power module and packaging technologies for both commercial wireless and military applications. He holds 11 patents plus two pending, and lives in a suburb of Portland, OR. The RF power industry continues to challenge him today with the development of newer materials and technologies that demand creative engineering and problem solving.

So why has the debate re-surfaced now? Why not keep using the overall superior gold-based metallization systems? In a word — LDMOS. New, power LDMOS transistors look a lot like some transistors built in CMOS fabs for integrated circuits. The thousands of lessons learned in process controls, techniques and engineering developments for CMOS integrated circuits over the years can apply directly to LDMOS devices. And LDMOS power transistors work particularly well for many linear power amplifier applications.

However, CMOS fabs are highly reluctant to use any gold processing for fear of cross-contamination of gold atoms into CMOS wafers. The fear is great enough that no gold is even allowed near many CMOS wafer fabrication areas. Since CMOS integrated circuits easily enjoy a dominant business level versus RF, the CMOS line dictates what fab processes can be used. Unless the fab is completely separate, gold metallized LDMOS metallizations sometimes are simply ruled out. Thus, for some companies, the need arose to make aluminum-based metallizations work in RF power again. We now hear about "gold-free" metallizations and hot metal processes as if gold metallizations were somehow "bad" or outmoded. Not so.

Compared head-to-head with equal stripes, currents, temperatures and conditions, gold will always be superior to aluminum and its alloys. Physical properties still matter. At the same time, I will say that some aluminum

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alloys (Al-Cu-Si, for instance) can be made very resistant to electromigration and are considered useful for high-power RF devices. These two systems can be made functionally acceptable for electro-migration characteristics.

Where gold shines (pun intended) as most superior is in the non-traditional reliability considerations for transistors—*beyond* electromigration. Consider the table of characteristics at right.

Gold	Aluminum
Superior electrical resistivity 2.1 E-6 Ohm-cm	Electrical resistivity 2.6 E-6 Ohm-cm
Superior thermal conductivity 300 W/mK	Thermal conductivity 220 W/mK
Chemically relatively inert	Chemically active—oxidizes and corrodes easily
Melting point ~ 1,063 C	Melting point ~ 660 C
High Atomic weight—197	Low Atomic weight—27
Excellent step coverage	Sometimes poor step coverage and etch uniformity problems
Excellent flexural fatigue resistance—especially important in wires	Poor flexural fatigue resistance—especially important in wires
Superior CTE—14 ppm/C	CTE—24 ppm/C
All gold metal system possible—package, wires and chip metal—no intermetallics	Gold, aluminum and copper metals—package, wires and chip metal are different (potential intermetallics like "purple plague")

▲ **Table 1. Non-traditional reliability considerations for the use of gold vs. aluminum in transistors.**

A good example of a reliability problem beyond electro-migration occurred in the mid 1970s. The PAVE PAWS program (Precision Acquisition of Vehicle Entry-Phased Array Warning System) demanded high-peak RF power pulsed transistors. The company I worked for built a transistor (that I designed) using an excellent aluminum-copper-silicon metal system for devices that performed admirably—for a while. Unfortunately, after 1 million to 2 million pulses, the aluminum bond wires began to break and open up. Performance degraded slowly, then dramatically. The failures were caused by aluminum bond wires being temperature cycled by high currents, which made them expand, flex slightly and begin to work-harden. Eventually, the aluminum wires would break, and the transistor performance would degrade. The problem took months to discover in systems depending on maximum operating conditions. In this case, we switched to a gold metal system and gold wires and completely resolved the failure mechanism. But it was too late for the application, and many millions of dollars were lost.

Aluminum susceptibility to environmental acids, bases, salts and oxidation is also well known. Corrosion can readily damage any RF power transistor, especially under voltage bias conditions. Gold is much more inert to chemical assault.

Intermetallics (the old "purple plague" failure mechanisms) are a potential problem for aluminum-based systems because packages are gold metallized. Package gold plating reduces oxidation, corrosion and soldering wetting problems and is recognized universally as ideal for electrical contacting. A gold transistor metal system uses only one metal (gold) for contact between package, wires and chips (dice). Therefore, no intermetallics such as purple plague can occur. An all-gold system is inherently more reliable.

Finally, the methods for applying gold to the chip surface tend to be very conformal. As a consequence, gold processing-induced uniformity problems are minimal when compared to the aluminum etch and step-coverage difficulties often encountered. Consistency of final product minimum cross-section dimensions are therefore more easily achieved with gold. The result can be that a supposed aluminum cost advantage is negated or even tilted toward a yield increase with gold metallizations.

With this whole picture in mind, I would ask the reader to go back and study the physical property table one more time, then tell me: should the need ever arise, which metal system you would prefer in your pacemaker? ■