COMPARING THIN FILMS FOR PRECISION RESISTOR NETWORKS

ADI'S NICKEL-CHROMIUM FILM SYSTEM vs. TANTALUM NITRIDE

by Tom Parello and Dr. Carl Drumheller

For resistor networks, especially high-precision designs for use with op amps in analog data processing, thin-film monolithic construction is increasingly being preferred to matched assortments of wirewound and bulk metal-foil discrete resistors. The many reasons include the potentially high tracking accuracy of thin films, efficient use of space and weight, long-term stability, low cost per element, low noise, and high reliability, as well as the capability of employing standard IC packages and assembly techniques (including chips for hybrids).

The degree to which these advantages are realized depends on the characteristics of the film system and the process employed. In *Dialogue* 8–1, the technology used with a high degree of success and consistency at the Resistor Products Division of Analog Devices (RPD), was described in some detail. Elsewhere in this issue, a few members of a new line of standard resistance networks for use by circuit designers are introduced.*

The key to the excellent overall results obtained with these networks is the nickel-chromium (NiCr, "Nichrome") film system. While comparison of NiCr thin films with discretes can easily be performed by even an unsophisticated designer, and the literature is replete with comparisons between thin- and thick-film networks, there has been little discussion about thin-film alternatives. It is our purpose here to compare NiCr with the principal commercially-available alternative, various forms of tantalum, and particularly tantalum nitride (Ta_2N), in terms of properties of interest to the circuit designer.

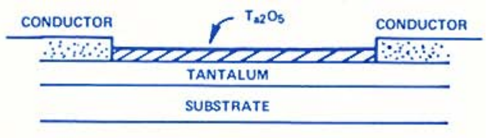

Figure 1. Tantalum pentoxide-tantalum film system

TANTALUM FILMS

Pure tantalum, while highly stable in adverse environments, and successfully employed in such devices as film capacitors, is unsuitable for high-precision resistor networks because of the low sheet resistivity and high temperature-coefficient of resistivity (TCR) of sputtered tantalum films. As Figure 1 shows, one approach to precision adjustment is to convert a portion of the tantalum to an insulating layer of tantalum pentoxide (Ta_2O_5), by a "wet-jell" anodizing process, thus increasing the sheet resistivity of the film and allowing some control over the resistance values. The process is slow and cumbersome, and large investments in special process equipment are required to build precision devices in volume.

The method principally employed, which provides a usable range of sheet resistivity and TCR, is to sputter tantalum in the presence of nitrogen, forming a mixture of Ta, Ta_2N, and interstitial nitrogen. This complex system is better than tantalum, but at the expense of its thermodynamic stability, which limits its useful range of resistivity to about 100Ω/square for applications requiring high stability. Also the difficulties of precise process control in forming so complex a film make it hard to keep film TCR's within a narrow range. Though it is possible to achieve quite low TCR's, the *practical* range of TCR's is about –50 to +200ppm/°C (Figure 2).

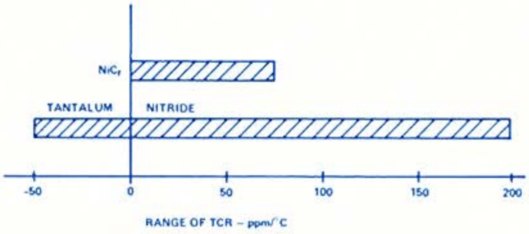

Figure 2. Comparison of temperature coefficient of resistance — tantalum nitride vs. nickel-chromium

CHROMIUM AND NICKEL-CHROMIUM

Pure chromium films encounter problems similar to the Ta films. If the Cr films are partially oxidized during deposition, problems similar to those existing with tantalum nitride films occur because of the intersitial problem. The solution, nickel-chromium (NiCr) films, eliminates the disadvantages of pure chromium and offers a wide range of parametric advantages over other systems. The NiCr films deposited by RPD are extremely stable alloys of nickel and chromium that are simpler to work with than the Ta_2N system. Since the long-term stability of NiCr films is generally over an order of magnitude better than for Ta_2N films, the design and production range of NiCr films can be quite wide. Figure 3 indicates qualitatively the limited range of film thickness available for usable sheet resistivity values. With NiCr, the available range of stable sheet resistivities (i.e., the vertical scale) is considerably greater than for Ta_2N.

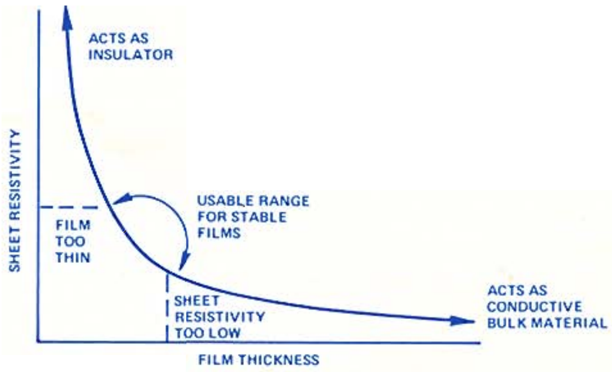

Figure 3. Qualitative relationship between sheet resistivity and film thickness

---

*For information on resistance networks, use the reply card. Request M3 for standard networks for op amps and converters; request M4 for custom networks.

COMPARISON

In comparing the properties of the two materials more specifically, it will become apparent that, though Ta_2N is usable in many applications, NiCr is better where long-term power stability, precision, and low-noise are necessary, combined with a high degree of device-design flexibility.

SHEET RESISTIVITY RANGE – Perhaps the key specification for a resistive film system is the sheet resistivity, in Ω/square. The wider the range of controllable sheet resistivities, the greater the range of circuit applications and the better the packaging density. Figure 4 compares Ta_2N and NiCr in this respect. The "figure of merit" is a composite qualitative representation of manufacturability, stability, and ease of use. Usable NiCr sheet resistivities range from below 50 to about 500Ω/square; for Ta_2N, the range is about 25 to 125Ω/square.

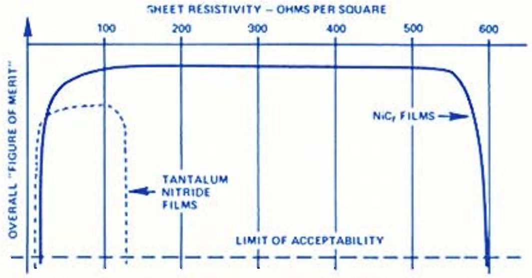

Figure 4. Comparison of overall suitability as a function of sheet resistivity – tantalum nitride vs. nickel-chromium

This flexibility of NiCr permits design of such products as the DIL-packaged AD1803 decade divider, which contains resistors ranging from 100Ω to 9MΩ, using a single reliable film deposition (see page 13). Other devices having essentially order-of-magnitude sheet-resistivity-range, but identical geometries, can be processed with no basic changes in the fabrication cycle.

ETCHING – In high-resistance applications, the higher the sheet resistivity, the wider the lines can be, with better yields and electrical tolerances, hence lower cost. Yields can drop disproportionately as linewidth decreases (and length increases), because of the increased importance of substrate and mask defects.

FILM STABILITY – For the majority of applications, the designer would like to see the properties of a network unchanged over a long period of time. Though all films drift to some extent, the striking contrast between Ta_2N and NiCr can be seen in Figure 5.

TRIM TECHNIQUES – Both film systems can be "tweaked" by diamond scribing, abrasive trimming, electrical pulse trimming, and laser trimming. Ta_2N can also be trimmed by anodizing. However automatic laser trimming is rapidly becoming the preferred method. With the NiCr system, the resistance values - - starting with a given set of masks and basically the same process - - can be adjusted, first by choice of sheet resistivity (50-500Ω/square), then by coarse trimming (several orders of magnitude possible), then by fine trimming to within tolerances approaching 0.001% or better, in production quantities.

NOISE – In addition to basic Johnson noise, resistors may have "excess" flicker and shot noise (see preceding pages). Flicker noise, due to fluctuations in resistivity (related to carrier path) can be significantly in excess of Johnson noise in Ta_2N because of the complex granular and interstitial structure. Shot noise, due to fluctuating carrier densities (generally found in semiconductors), may also be present in negative-TCR films, which are common with Ta_2N. On the other hand (Figure 6), NiCr films are among the lowest-noise resistance materials available today. Excess noise of -50dB (1/300) for a 10kΩ resistor, measured on a Quan-Tech test set, is typical. The advantages for low-level "front-end" applications is evident.

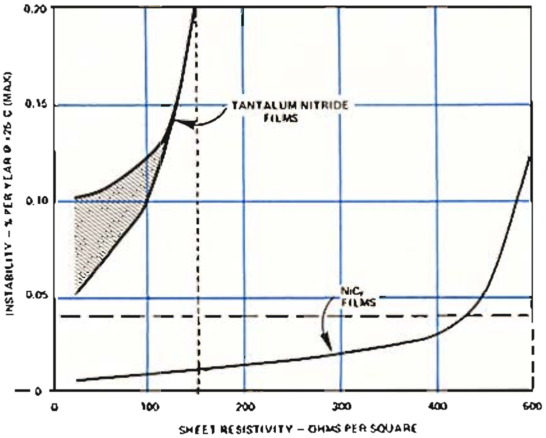

Figure 5. Comparison of drift stability (at about 10W/in² applied power-density) of tantalum nitride and NiCr resistance films. One year at +25°C ambient is considered equivalent to 250-500 hours at +125°C.

TEMPERATURE COEFFICIENT OF RESISTANCE – In solid-state components, poor noise performance is often accompanied by high TCR's (or vice versa), since similar mechanisms contribute to the measured effects. Ta_2N films generally exhibit widely-varying TCR's (Figure 2). High accuracy over wide temperature ranges is difficult to achieve when the film system can contribute errors of up to 0.02%/°C.

ENVIRONMENTAL CONSIDERATIONS – Under adverse conditions, Ta_2N does offer some advantages, since it is somewhat moisture- and abrasion-resistant, due to the thicker oxide layers that are formed when it is anodically trimmed. However, such conditions are no problem for NiCr with appropriate production methods and packaging techniques (e.g., in hermetically-sealed IC packages). Thin-film microcircuits with NiCr resistors are among the highest-reliability, Class I components in our most-stringent military systems. ▶▶▶

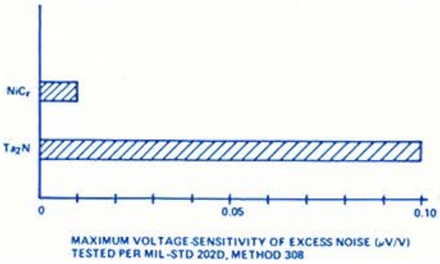

Figure 6. Comparison of excess-noise sensitivity of tantalum nitride and nickel-chromium