

Recent articles in various electronics publications have touted niobium capacitors as a viable alternative to tantalum capacitors from a performance, availability, and price standpoint. Many of these articles discuss improvements in materials and process technology which have not yet been accomplished. This Tech Topic is written with the intent of providing our customers with the facts about niobium capacitors as compared to tantalum capacitors, specifically their demonstrated performance data, physical properties, and cost.

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'Nb Capacitors compared to Ta Capacitors as a less costly alternative'

by John Moore (technical information based on work done by Brian Melody and Tony Kinard)

Niobium (Nb), like tantalum (Ta), is a member of the transition group of elements on the periodic table from the vanadium family. These metals have high melting points and are very good conductors of heat and electricity. Niobium and tantalum also belong to another group of metals referred to as "valve metals" because they can form anodic oxides on their surfaces that are generally highly insulating. The dielectric nature of this anodic film allows these metals to be good candidates for use as capacitor plate elements. The valve metals most commonly used for this purpose are aluminum and tantalum. Niobium was also used in the former Soviet Union as a capacitor plate element in the 1950's and 1960's, but these devices had high and unstable leakage current. Research into this leakage deficiency (1,2,3) found that the solubility of oxygen in the metal substrate is sufficient to facilitate oxygen migration from the anodic film into the substrate, thus rendering the oxygen-deficient portion of the dielectric layer electrically conductive and leading to shorting of the capacitor.

The problem of thermally-driven-oxygen-diffusion degradation of anodic niobium oxide films has been addressed recently by the addition of nitrogen or oxygen to the metal substrate for the purpose of modifying the oxygen diffusion kinetics (i.e., to reduce the rate of oxygen diffusion into the substrate). The addition of nitrogen has been pursued to the point of producing niobium nitride, NbN, and the addition of oxygen has been carried out to the point of producing niobium suboxide, NbO (4,5).

Using these niobium materials, KEMET has pursued the construction of solid niobium capacitors. Our efforts have been focused on the preparation of devices utilizing manganese dioxide as the cathode material. Through the use of some of KEMET's patented processes (6,7,8,9), niobium capacitors were produced; summary electrical results are listed below (mean data). Typical results for tantalum capacitors are provided for comparison:

D size 150uF/6V	Tantalum	Niobium
Cap (uF@120Hz)	149.0	149.4
DF (% @120Hz)	2.7	5.9
ESR (Ohm@100kHz)	0.115	0.107
25 C Leakage (uA@Vr)	0.51	4.69

The low-frequency DF is elevated, and the leakage is significantly higher than tantalum. ESR is essentially equivalent. The following life test data indicate that the higher leakage of the niobium capacitors doesn't necessarily imply less stable leakage over time (Figure 1). Although there is an initial shift in some of the population, leakage remains stable with time.

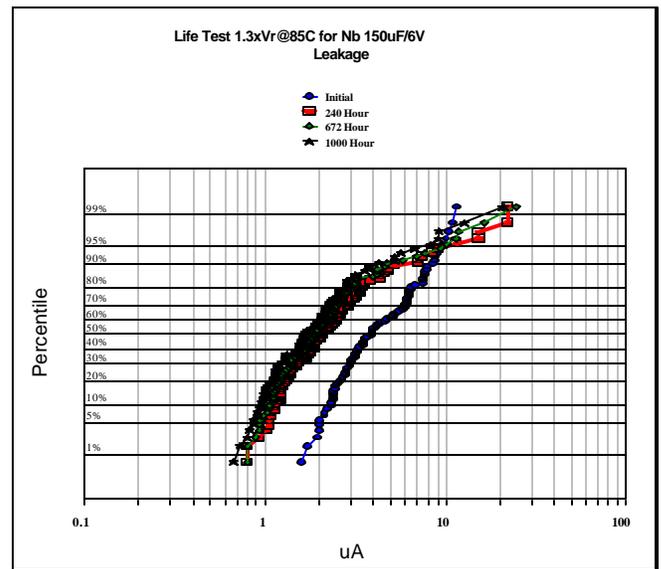


Figure 1

This is true even at higher temperatures as evidenced by the 125°C life test data illustrated in Figure 2.

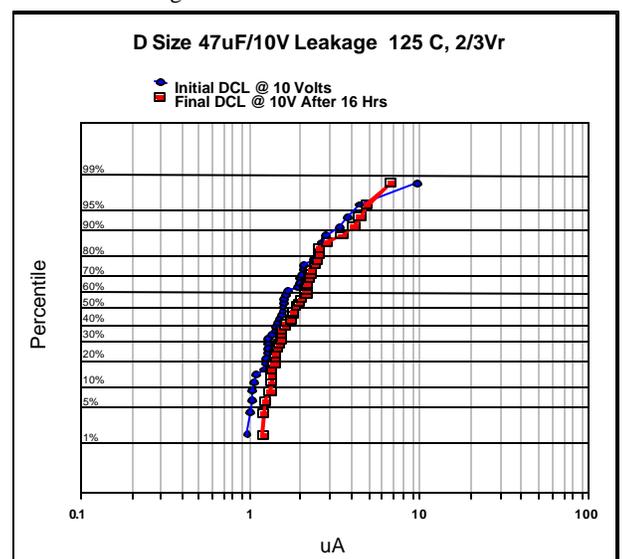


Figure 2

It should be emphasized that these results were only made possible by using an oxygen diffusion-stabilized version of niobium powder.—Prior efforts to manufacture niobium capacitors without these enhanced powders, and without the new processes KEMET has developed in formation and anode manufacturing, resulted in catastrophic leakage during processing.

The following table is a comparison of the physical properties of tantalum and niobium:

Name	Tantalum	Niobium
Symbol	Ta	Nb
Density	16.65 (g/cc)	8.57 (g/cc)
Dielectric Thickness	20 Angstroms/V	25 Angstroms/V
Dielectric Constant	26	41

As indicated in the table, niobium has a higher dielectric constant than tantalum, making it attractive for use as a capacitor because niobium can potentially deliver 1.57 times more capacitance than tantalum for any given surface area. However, at a given anodization voltage, the niobium dielectric layer is 25% thicker than tantalum, so its effective capacitance is reduced by 20% ($C=kA/d$). Therefore, for a given surface area (i.e., equivalent particle size and shape), niobium can provide approximately 1.26 as much CV as tantalum.

Unfortunately, niobium’s lower density (approximately half that of tantalum) means that half as much niobium powder, by weight, consumes the same anode volume as the denser tantalum material. For a given anode volume, then, niobium provides approximately 37% less CV. Stated another way, the charge of niobium powder would have to be approximately 2.5 times that of tantalum powder to produce the same CV from the same size anode. Based on the materials’ respective dielectric constants, this is not possible without changing the size and shape of the particles, thus changing the surface area per unit of weight. This very technology has been used in the past to increase the charge of tantalum powders, and would be applicable to niobium powders as well, but the fact remains that the inherent advantage to niobium is its dielectric constant, and that limits effective CV to 1.26 times tantalum.

In addition to the powder itself, there are other processing factors that still must be verified in a high-volume production environment. A formation-voltage-to-rated-voltage ratio similar to that used for tantalum is assumed to produce similar long-term reliability, but that is as yet unproven. It is also assumed that, on a production scale, niobium metal powders can be used with the same processing equipment and with the same process materials as tantalum, and that manufacturing yields will be similar.

The economics of niobium vs. tantalum will depend largely on the available charge differential between the two and the respective cost of the powders. The inherent dielectric constant advantage of niobium is insufficient to offset the density disadvantage. Niobium powder suppliers must be capable of producing powders with a minimum of two times the effective charge of tantalum powders. While the feasibility of this capability has been claimed, it has not been demonstrated. A review of the sample offerings currently available from various suppliers indicate that the maximum CV products offered in the “D” case size are 220uF @ 6VDC and 150uF @ 10VDC. In comparison, most tantalum manufacturers offer 330uF @ 6VDC and 220uF @ 10VDC.

The facts suggest that niobium powder should ultimately cost less than tantalum powder. This is due to a lower cost of ore. Niobium ore is indeed more plentiful than tantalum, and extraction is less costly because ore deposits are closer to the surface. However, under normal market conditions, ore cost represents less than 25% of powder cost, so the practical differential in powder costs is not nearly as large as some press releases have suggested. Furthermore, there is presently only one recognized niobium powder supplier, and the cost of niobium powder will be at this supplier’s discretion until more suppliers materialize.

Summary

1. Niobium capacitors that are similar in performance to tantalum capacitors can be made. Leakage and low-frequency DF will be higher, but the parts will perform acceptably in many applications.
2. The price of the niobium capacitors can be less than the price of similar tantalum capacitors, provided that niobium powder can be made at a CV/g approximately twice as high and at a lower powder cost than tantalum.
3. Price and supply stability of niobium is directly related to how many miners, developers, and processors get into the business.

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4. “A New Material for Capacitors: Niobium,” W. A. Serjak, L. Shekhter, T. B. Tripp, L. L. Lanin, K. Reichert, O. Thomas, and J. Viergege, Proceedings, 20th Capacitor and Resistor Technology Symposium March, 2000, pages 82-85.
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6. U. S. Patent Application No. US 2001/0004854, “Process for Producing Powder Metallurgy Compacts Free From Binder Contamination and Compacts Produced Thereby,” Keith Lee Moore, Brian John Melody, John Tony Kinard, David Alexander Wheeler, published June 28, 2001.
7. U.S. Patent No. 6,162,345, “Method of Anodizing a Metal Anode Prepared from Very Fine Metal Powder,” John T. Kinard and Brian J. Melody, Dec. 19, 2000.
8. U.S. Patent No. 6,183,618, “Process for Treating Impregnated Electrolytic Capacitor Anodes,” Brian J. Melody, John T. Kinard, and David A. Wheeler, Feb. 6, 2001.
9. U.S. Patent No. 6,162,345, “Method of Anodizing a Metal Anode Prepared from Very Fine Metal Powder,” John T. Kinard and Brian J. Melody, Dec. 19, 2000.