# TECHNICAL INFORMATION

## NIOBIUM OXIDE TECHNOLOGY ROADMAP

by
T. Zednicek, S. Zednicek, Z. Sita
AVX Czech Republic s.r.o., Dvorakova 328, 563 01 Lanskroun, Czech Republic

C. McCracken, W. A. Millman, J. Gill
AVX Limited, Long Road, Paignton,
Devon TQ4 7ER, United Kingdom

**Abstract:**

Recent developments in tantalum technology have resulted in a new type of solid electrolyte capacitor based upon niobium oxide. Capacitors made from niobium oxide powder exhibit interesting features to the end users such as significantly reduced ignition failure mode, better load resistance, reduced cost, etc. This paper will give an overview of the current "state of the art" on this technology and also identifies key future development directions for the medium and long term.

# NIOBIUM OXIDE TECHNOLOGY ROADMAP

by
T. Zednicek, S. Zednicek, Z. Sita
AVX Czech Republic s.r.o., Dvorakova 328, 563 01 Lanskroun, Czech Republic
Phone: +420 467 558 126 Fax: +420 467 558 128

C. McCracken, W. A. Millman, J. Gill
AVX Limited, Long Road, Paignton,
Devon TQ4 7ER, United Kingdom
Phone: +44 1803697200 Fax: +44 1803697326

## Introduction

Capacitor development remains a dynamic field, with rapid technology growth during the last few years. While some mature technologies show decreasing average annual growth (AAG), others, just emerging face significant challenges for future high volume usage. Leaded tantalums, foil aluminum and some film capacitor types have slowed down their growth below 5% AAG. Tantalum chip capacitors, on the other hand, are probably at their peak of about 10% AAG while multilayer ceramic capacitors are still in expanding mode with AAG close to 25%. New technologies based on niobium metal (Nb) and niobium oxide (NbO) powder's have recently entered the arena

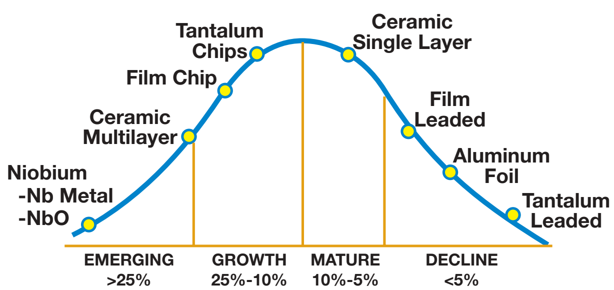



Figure 1. Technology Unit Growth Diagram.

targeting the low voltage (around 10/16V max) high capacitance (> 100µF) space currently occupied by aluminum, ceramic and tantalum capacitors – see Figure 2 below.

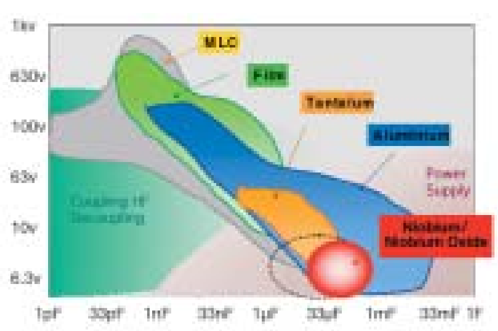



Figure 2. Technology CV Diagram.

## Niobium Oxide and Niobium Metal Powders

Niobium metal appears next to tantalum in the periodic table and it has similar chemical properties. Niobium ore is more abundant in its raw state and is less expensive. This has given the opportunity for tantalum capacitor manufacturers to evaluate niobium as a potential alternative to tantalum metal; however there were two key barriers to niobium usage that have only been overcome recently. Firstly, the diffusion rate of oxygen from the dielectric ($Nb_2O_5$) to niobium metal is higher than tantalum, resulting in direct leakage current (DCL) instability. The second barrier was a lack of high purity niobium powders, able to meet the demanding electrical and mechanical specifications necessary for capacitor manufacture. There are two possible ways to reduce oxygen diffusion and improve DCL stability – either by doping metallic niobium powders with nitrogen or using niobium oxide powder – see Figure 3 below. Niobium oxide (NbO) is a hard ceramic material characterized by high conductivity, a property usually associated with metals. Niobium oxide powder has a similar morphology to that of tantalum and niobium metals can be processed in the same way. This paper compares features of capacitors made from tantalum, niobium metal (nitrogen doped) and niobium oxide powders. The basic material features are summarized in Figure 4.

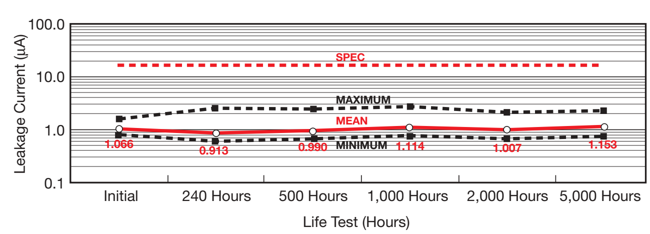



Figure 3. Leakage Current Stability on 85ºC Life for 5,000 hours.

| Parameter | Property | Tantalum | Niobium | Niobium Oxide |
|---|---|---|---|---|
| Powder | Unit Cost | Cap Grade Ta | Cap Grade Nb | Commercial Nb0 |
| Ore Content | Mining Cost | 300 ppm | 3% | 3% |
| Capacitor Usage | Supply Chain | 60% | 10%* | 10%* |
| Density (g/cm$^3$) | Weight, Drop Test | 16.4 | 8.6 | 7.3 |
| Min. Ignition Energy (mJ) | Burning Resistance | 3 | 3 | 600 |
| Burning Rate (mm/s) | Burning Speed | 11.5 | 8 | 1.5 |
| Specific Heat (J/mol/K) | Load Resistance | 25 | 25 | 40 |
| Dielectric Material | Electrical Properties | $Ta_2O_5$ | $Nb_2O_5$ | $Nb_2O_5$ |
| Growth Rate ($10^{-9}$m/V) | Capacitance | 1.7 | 2.5 | 2.5 |
| Dielectric Constant (-) | Capacitance | 27 | 41 | 41 |

* Total share if tantalum ore consumption moved to niobium industry supply chain.

Figure 4. Tantalum, Niobium and Niobium Oxide powder parameters overview table.

## *Availability – Supply Chain*

Niobium and niobium oxide are more abundant in nature than tantalum. These materials are common alloy elements widely used in the production of steel for shipbuilding, pipelines and construction. Usage of niobium for the production of capacitors is dwarfed by these major worldwide industries and thus ensures a long-term stable supply. However, conversion of metallic niobium to capacitor grade niobium (Nb) powder requires the same specialized processing as does capacitor grade tantalum powder, and shares the same supply chain. Additionally, production of capacitor grade niobium metal powder has not yet been scaled up to high volume. By contrast niobium oxide (NbO) technologies have a much wider material supply base and higher volume availability.

# Basic Features of Niobium Oxide Capacitors

An overview of the basic electrical parameters of tantalum, niobium and niobium oxide capacitors is given in Figure 5.

*Basic Electrical Features of NbO capacitors*

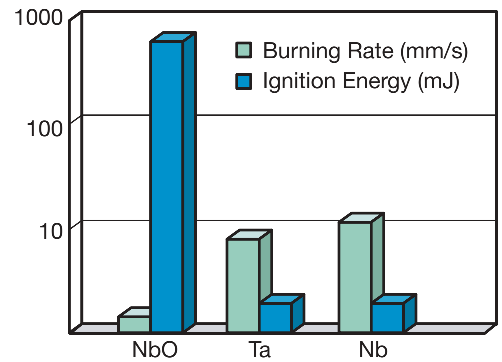
Capacitance: 10 – 470µF
Voltage Range: 4 – 6V
Case Sizes: EIA: A to E case
Temperature Range: -55 to +105°C
DCL: 0.02CV
Basic Reliability: 1%/1000hrs (same as tantalum)

| Technology | Niobium Oxide | Niobium | Tantalum $MnO_2$ |
|---|---|---|---|
| **Anode** | NbO | Nb | Tantalum |
| **Electrode** | $MnO_2$ | $MnO_2$ | $MnO_2$ |
| **Basic Reliability** | 1%/1000 hrs @ 85 =100,000 hrs | 1%/1000 hrs @ 8 =100,000 hrs | 1%/1000 hrs @ 8 =100,000 hrs |
| **Cap Range** | 10 - 100µF | 10 - 1000µf | 0.1 - 1000µf |
| **Cap Tolerance** | 20% (10%) | 20% (10%) | 10% or 20% |
| **Rated Voltage** | 4 - 6 | 4 - 10 | 2.5 - 50 |
| **ESR (D case typical)** | ~100mΩ | ~100mΩ | 35 - 100mΩ |
| **DF** | 6 - 14% | 4 - 16% | 4 - 16% |
| **DCL** | 0.02 CV | 0.01 - 0.04 CV | 0.01 CV |
| **Derating in low imp. Circuits** | 20% | 50% | 50% |
| **Temperature Range** | -55/105ºC (+125ºC dev.) | -55/+125ºC | -55/+125ºC |

Figure 5. Niobium Oxide capacitor features.

## *Resistance to Ignition Failure Mode*

Niobium Oxide has two orders higher ignition energy and two times the specific heat compared to both tantalum and niobium metals – see Figures 6 and 7.



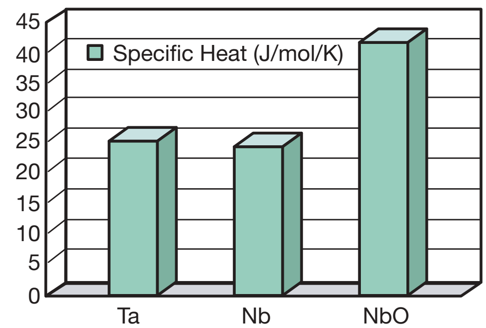




Figure 6, 7. Comparison of Ignition Rate, Ignition Energy and Specific Heat for NbO, Ta and Nb metal powders.

Note: Specific heat [J/mol/K] is the energy needed to heat a unit volume (1mole) by 1Kelvin.

This results in a significant reduction (95%) of the ignition failure mode of niobium oxide capacitors compared to conventional tantalum and niobium metal capacitors. Coupled with the lower electrical stress within the dielectric ($Nb_2O_5$ dielectric grows thicker per applied volt than $Ta_2O_5$ and so operates at lower field strength for a given voltage rating), this also enables a higher ripple current load and reduced voltage derating requirements in low impedance circuits.

Niobium Oxide electrolytic capacitors have a high resistivity short-circuit failure mechanism and their oxide base significantly improves resistance against thermal runaway after dielectric breakdown and also provides a genuine "non-burn" technology when compared to metallic tantalum and niobium types either with or without a polymer electrolyte system.

## Other features

There are more features of niobium oxide capacitors that can be of significant advantage in some specific applications:

### *Lead-free System Ready*

Lead-free assembly systems call for higher reflow temperatures with higher thermo-mechanical stress. Not all capacitor technologies are ready to withstand these rigid conditions. [5]

Aluminum and foil capacitors are most sensitive to thermo-mechanical loads, especially reflow temperature/time soldering profiles that can result in catastrophic electrical failures.

Ceramic capacitors have most resilience to electrical overstress and are thermo-mechanically compatible with Pb-free assembly, but large outline parts can be sensitive to board flexure so manufacturers handling guidelines should always be followed. The general ceramic failure mechanism is low insulation resistance or short circuit.

The new niobium oxide capacitors are of special interest, as they also show very good stability under thermo-mechanical stress and higher temperature peak reflow (Pb-free assembly) conditions, similar to ceramic capacitors but without any sensitivity to mechanical weakness.

### *No Piezo Effect*

High CV formulations of barium titanate (the base ceramic material for most dielectric systems) exhibit a microphonic effect. For example, if one takes a Y5V capacitor and subjects it to a DC bias with a superimposed signal (e.g. 1kHz sine wave), the capacitor will start to "sing". This mechanism is also reversible, which means a 1kHz external signal will cause generation of a 1kHz noise to the electrical signal. Niobium Oxide capacitors exhibit no such microphonic effect despite its ceramic material powder. [3]

### *Low Weight*

Niobium oxide powder is half the density of tantalum powder. This has an effect on total weight of units. Typical E case niobium oxide capacitor is about 25% lighter than the same capacitor made from tantalum powder. The practical usage is in weight sensitive applications such as mobile devices. Lower weight on the same component footprint will also improve PCB drop test strength as another important parameter for some applications.

### *Lower ESR at Higher Temperatures*

Temperature dependence behavior of NbO capacitors is identical to tantalum capacitors. ESR drops with temperature due to improvement of $MnO_2$ (second electrode) conductivity. Thus, filtering features at higher temperature are better than the room temperature 25°C specification.

## Development Roadmap

Figure 8 gives an overview of the ongoing development programs for the niobium oxide capacitor to fulfill all of the markets diverse requirements. These can be sub-divided into four main areas: extension of the maximum temperature rating from 105°C to 125°C, increased product range, i.e. Range Extension and Voltage Extension to both 2.5V and 10V Rated, and lower DCL (equivalent to Tantalum Capacitors). AVX is also currently working on niobium oxide capacitors utilizing our latest generation production technologies to manufacture Low Profile and TACmicrochip™ capacitors. One of the key requirements of the Power Supply sector is Low ESR. AVX is working in several directions towards lower ESR, as shown below.

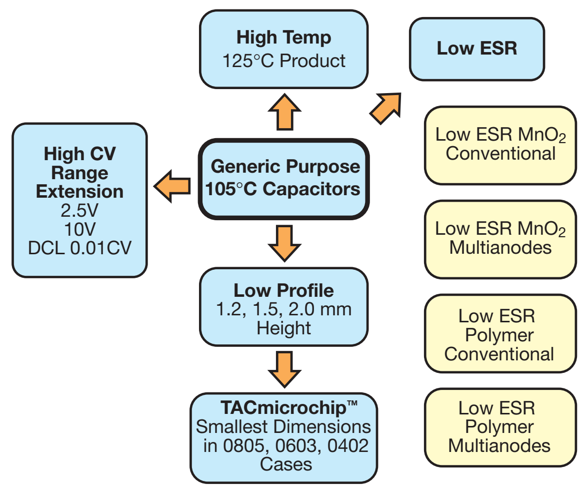



Figure 8. Niobium Oxide Development Road Map.

Within this Development Program there are key Milestones, see Figure 9. This shows the time scales for the launch of new products over the next 1-2 years. All of these developments stem from the underlying stability and reliability of the current Niobium Oxide Capacitor.

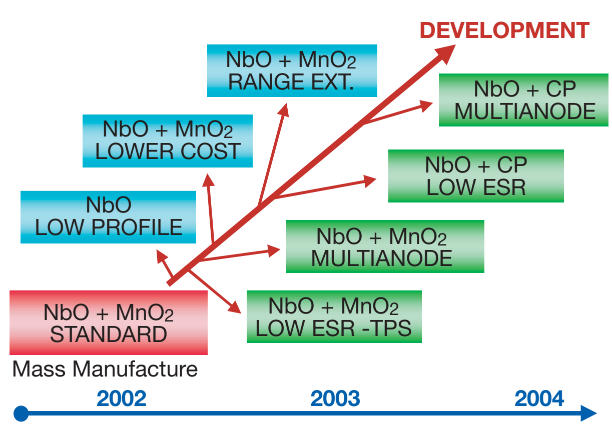



Figure 9. Niobium Oxide Development Milestones.

## Conclusion

Niobium based technology – niobium and niobium oxide capacitors are now entering the high CV capacitor market place. They have a similar capacitance/voltage (CV) range to current tantalum chip and demonstrate ESR characteristics comparable to conventional tantalum ratings. Their parametric stability and less expensive material cost (especially in the case of niobium oxide capacitors), make these technologies promising alternatives to low voltage tantalum and ceramic capacitors, and allow downsizing of aluminum foil capacitors. The reduced burning of NbO also makes this a technology of interest.

Both niobium and niobium oxide dielectrics (as well as tantalum) show no piezo effect that could degrade audio clarity if used in critical audio-video applications.

Tantalum and niobium metal capacitors require 50% minimum derating for low impedance unregulated circuits. Niobium oxide capacitors are able to absorb higher load stress and thus the necessary derating can be reduced to 20% minimum.

The new generation of niobium and niobium oxide capacitors share the same robust casing design and industry standard sizes as current tantalum chip capacitors and are suited low ESR capacitors. However, niobium has the disadvantage of higher cost and relatively higher failure rate.

The key benefits of NbO are long term stable electrical parameters, wide availability of materials, reduced burning and lower cost, which should form the basis for fast design-in cycles in this high growth application area.

## References

[1] niobium release, 293DN series, www.vishay.com
[2] niobium volume production news, www.epcos.com
[3] T. Zednicek, W.A. Millman, J. Gill, "Solution for Increasing Capacitance Demand – High CV Tantalum" CARTS EUROPE 2000, Brussels, Belgium, pp 188-192.
[4] J. Cain, "Comparison of Multilayer Ceramic and Tantalum Capacitors", AVX Technical Publication, AVX Corporation.
[5] T. Zednicek & col., "Leadfree soldering effect to tantalum capacitors", CARTS EUROPE 2001.

## USA

**AVX Myrtle Beach, SC**
**Corporate Offices**
Tel: 843-448-9411
FAX: 843-626-5292

**AVX Northwest, WA**
Tel: 360-699-8746
FAX: 360-699-8751

**AVX North Central, IN**
Tel: 317-848-7153
FAX: 317-844-9314

**AVX Mid/Pacific, MN**
Tel: 952-974-9155
FAX: 952-974-9179

**AVX Southwest, AZ**
Tel: 480-539-1496
FAX: 480-539-1501

**AVX South Central, TX**
Tel: 972-669-1223
FAX: 972-669-2090

**AVX Southeast, NC**
Tel: 919-878-6223
FAX: 919-878-6462

**AVX Canada**
Tel: 905-564-8959
FAX: 905-564-9728

## EUROPE

**AVX Limited, England**
**European Headquarters**
Tel: ++44 (0) 1252 770000
FAX: ++44 (0) 1252 770001

**AVX S.A., France**
Tel: ++33 (1) 69.18.46.00
FAX: ++33 (1) 69.28.73.87

**AVX GmbH, Germany - AVX**
Tel: ++49 (0) 8131 9004-0
FAX: ++49 (0) 8131 9004-44

**AVX GmbH, Germany - Elco**
Tel: ++49 (0) 2741 2990
FAX: ++49 (0) 2741 299133

**AVX srl, Italy**
Tel: ++390 (0)2 614571
FAX: ++390 (0)2 614 2576

**AVX Czech Republic, s.r.o.**
Tel: ++420 (0) 465 358111
FAX: ++420 (0) 465 373010

## ASIA-PACIFIC

**AVX/Kyocera, Singapore**
**Asia-Pacific Headquarters**
Tel: (656) 258-2833
FAX: (656) 350-4880

**AVX/Kyocera, Hong Kong**
Tel: (852) 2-363-3303
FAX: (852) 2-765-8185

**AVX/Kyocera, Korea**
Tel: (82) 2-785-6504
FAX: (82) 2-784-5411

**AVX/Kyocera, Taiwan**
Tel: (886) 2-2696-4636
FAX: (886) 2-2696-4237

**AVX/Kyocera, China**
Tel: (86) 21-6249-0314-16
FAX: (86) 21-6249-0313

**AVX/Kyocera, Malaysia**
Tel: (60) 4-228-1190
FAX: (60) 4-228-1196

**Elco, Japan**
Tel: 045-943-2906/7
FAX: 045-943-2910

**Kyocera, Japan - AVX**
Tel: (81) 75-604-3426
FAX: (81) 75-604-3425

**Kyocera, Japan - KDP**
Tel: (81) 75-604-3424
FAX: (81) 75-604-3425

**Contact:**

A KYOCERA GROUP COMPANY

**http://www.avxcorp.com**

S-NOTR2.5M1002-N