TECHNICAL PAPER

Tantalum and Niobium Technology Roadmap

T. Zednicek and B. Vrana
AVX Czech Republic s.r.o., Dvorakova 328,
563 01 Lanskroun, Czech Republic

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

Chris Reynolds
AVX Corporation
17th Avenue South, Myrtle Beach SC 29575

Abstract:
This paper presents an overview of the key features of emerging capacitor technologies – tantalum, niobium metal and niobium oxide in order to give designers a better understanding of the potential applications and to guide their choice of component solutions for their individual requirements. The second part of the paper is targeted to a new type of solid electrolyte capacitor that has been developed based on niobium oxide powder material. Capacitors made from niobium oxide powder offer the designer many interesting features such as significantly reduced ignition failure mode, better load resistance, reduced cost, etc. The paper gives an overview of the current "state of the art" on this technology and also provides a key development roadmap for short term and future advancements such as low ESR niobium dielectric capacitors.

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Introduction

New technologies based on niobium (Nb) and niobium oxide (NbO) technology have been recently developed targeting the low voltage (~ 6V / 16V max) space currently occupied by aluminum, ceramic and tantalum capacitors. The key benefits that Nb and NbO offer are stable electrical parameters, wide availability of materials, reduced ignition and lower cost, which should form the basis for fast design-in cycles in this high growth application area – see below Figure 1.

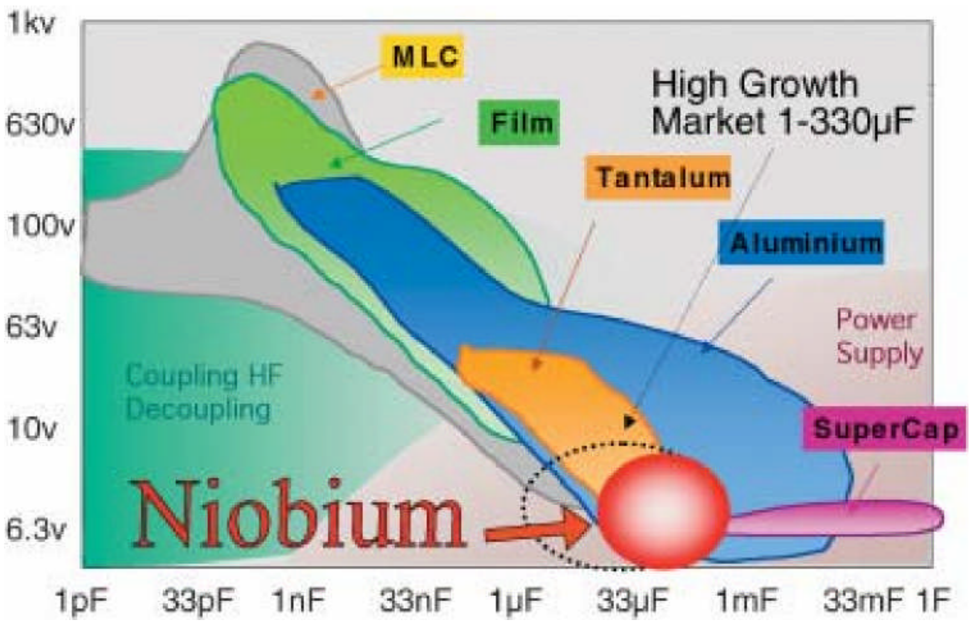


Figure 1. Technology CV Diagram.

Basic Features of Tantalum, Niobium and Niobium Oxide Powers

Niobium metal appears next to tantalum in the periodic table as 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 compared to tantalum, resulting in 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 nitride or using niobium oxide powder. 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 (nitride doped) and niobium oxide powders. The basic material features are summarized in Figure 2:

Parameter	End Value	Tantalum	Niobium	Niobium Oxide
Powder		Ta metal	Nb metal	NbO ceramic
Hardness		medium	medium	high
Ore Content	ore/power cost	300ppm	3%	3%
Non Capacitor Usage	availability	40%	90%*	90%*
Density [g/cc]	weight, drop test, CV	16.4	8.6	7.3
Ignition Energy [mJ]	resistance to burn	2	2	600
Burning Rate [mm/s]	burning speed	11.5	8	1.5
Specific Heat [J/mol/K]	load resistance	25	25	40
Dielectric	electrical properties	Ta_2O_5	Nb_2O_5	Nb_2O_5
Thickness [10^{-9}m/V]	CV	1.7	2.5	2.5
Dielectric Constant (-)	CV	27	41	41

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

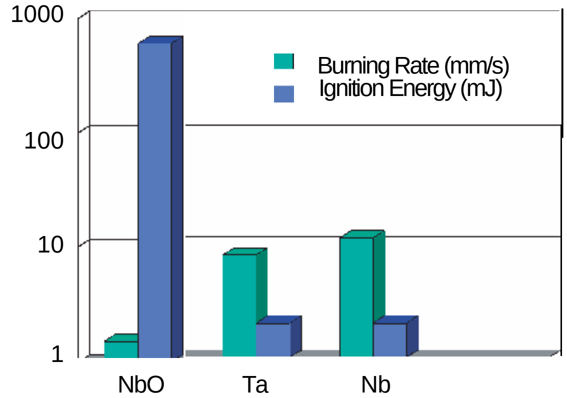
Figure 2. Tantalum, Niobium and Niobium Oxide powder parameters overview table.

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.

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. This results in a significant reduction (95%) of the ignition failure mode compared to conventional tantalum 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 – see Figures 3 and 4.



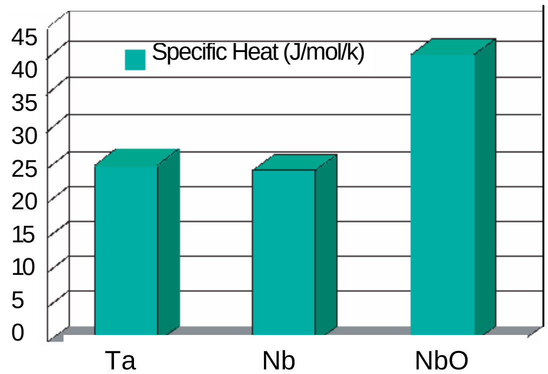


Figure 3, 4. Comparison of Ignition Rate, Ignition Energy and Specific Heat for NbO, Ta and Nb metal powders.

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

Basic Features of Tantalum, Niobium and Niobium Oxide Capacitors

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

Parameter	Tantalum	Niobium	Niobium Oxide
Dielectric	Ta_2O_5	Nb_2O_5	Nb_2O_5
CV	standard	lower-same*	lower-same*
Rated Voltage	2.5 - 50V	4 -16	4 - 6 (10*)
Cap Tolerance	±10%	±10% (20%)#	±20%
DCL	0.01 CV	0.01 - 0.04CV#	0.02CV (0.01*)
ESR (same anode design)	standard	comparable	comparable
DF	standard	same/higher	same/higher
Temperature Range	-55 / +125°C	-55 / +125 (105)#	-55 / +105 (125*)
Derating for low imp. circ.	50%	50%	20%
Basic Reliability	1%/1000 hrs	same	same

Figure 5. Tantalum, Niobium and Niobium Oxide capacitors features.

Derating

For conventional tantalum capacitors, 50% minimum derating is recommended in low impedance circuits such as non-regulated power converters. In other words, a minimum 10V capacitor rating should be used on a 5V power rail. The same applies to niobium metal (Nb) capacitors. However, as noted above, the niobium pentoxide dielectric (Nb_2O_5) operates at much lower field strength than does tantalum pentoxide dielectric, and when used in conjunction with the lower ignition niobium oxide (NbO) anode it will demonstrate a slower overheating rate and higher volumetric specific heat – see Figures 3, 4. Hence a minimum derating of 20% is sufficient; so, for example, a 4V capacitor can be safely used on a 3.3V power rail and a 6.3V rated capacitor on a 5.5V rail.

Filtering – The Key Parameter

One trend common for switch-mode power supply, microprocessor, and digital circuit applications is to achieve reduced noise while filtering higher frequencies. Fast response to transient noise is strongly dependent on both the low ESR and high capacitance characteristics of the filter capacitors used. Low ESR is often considered to be the prime requirement. However, a higher capacitance value also improves filtering, so it is the combination of low ESR with high capacitance in the application that determines performance. (Low inductance is also important, typically a secondary consideration in the 100kHz – 10MHz range, but becoming a significant factor at higher frequencies.) As an example, consider a ceramic chip capacitor (X5R, X7R or Y5V dielectric) that has low ESR – see Figure 8. The capacitance will decrease as DC bias (applied voltage) increases – see Figure 6, and thus reduces a/c noise filtering when used in an application with bias voltage close to its rated voltage.

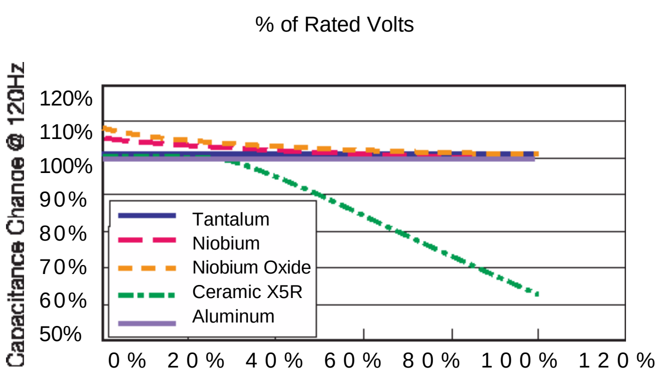
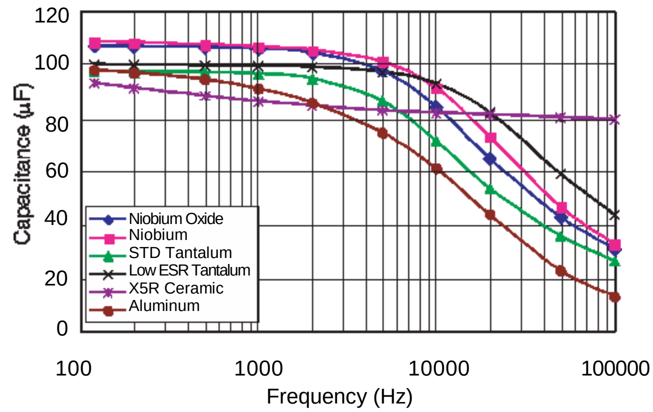


Figure 6. Capacitance vs BIAS of 100µF 6.3V capacitors made by different technologies.



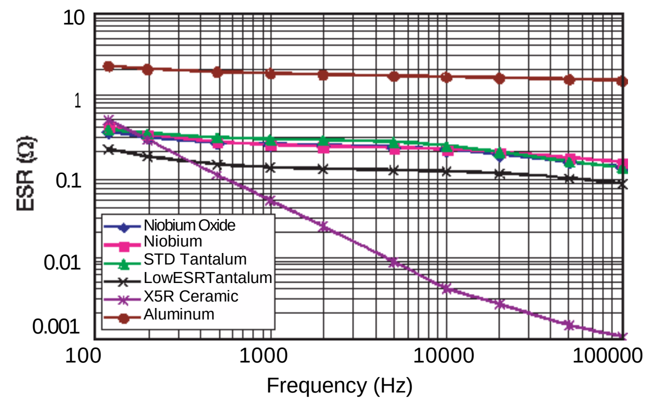


Figure 7, 8. Frequency behavior of Capacitance and ESR on 100µF 6.3V capacitors made by different technologies.

Figures 7 and 8 compare ESR and Capacitance versus frequency for a typical 100µF 6.3V rating made by Niobium Oxide, Niobium, Tantalum, Ceramic X5R and Aluminum foil technologies.

Ceramic X5R capacitors, due to the geometry of their multilayer construction, have a sharp impedance curve at resonance, which gives lowest ESR values and highest capacitance retention at higher frequencies (> 100kHz), although ESR is higher at lower frequencies. Electrolytic capacitors have a more broadband ESR response, with standard foil aluminum capacitors having the highest ESR values. Tantalum chip capacitors show a good broadband response in this frequency range. Low ESR versions of niobium and niobium oxide capacitors have not yet been introduced to the market; but similar values to low ESR tantalum capacitors are currently under development by several manufacturers. [1], [2]. Aluminum polymer capacitors have low ESR values but have limited maximum capacitance and more limited availability.

Noise is another parameter that can degrade filtering, especially in audio/video applications. Ceramic capacitors with barium titanite dielectrics (X5R, X7R, Y5V) do have a small piezoelectric effect that can generate noise in the processed signal in the audio frequency range. This noise is typically low level and will not be a major concern in general applications, however it may be an important consideration in some critical applications such as audio/ video filtering circuits, and in some cases higher frequency applications if harmonics are present. More details are given – see [3], [4].

Filtering-Application Examples

One of the most common capacitor applications is input and output filtering for DC/DC converters. The effect on filtering by using different technologies (tantalum, aluminum, ceramic and niobium capacitors) is compared below in some standard DC/DC applications.

Two parameters sensitive to noise can be used as critical indicators of filtering quality:

Filtering coefficient:	need equation	[1]
Distortion spacing:	info	[2]

where, Upp – peak to peak ripple voltage
Udc – DC voltage level

The Filtering coefficient expresses filtering efficiency as a percentage. A Higher number means better filtering, 100% being the ideal value. The Distortion Spacing is measured in dB and is related to DC voltage to noise ratio.

Application Example: LTC1159 DC/DC

A Linear Technology switching regulator (LTC1159) with 250kHz switching frequency, 10V input and 5V output rail with a 5Ω load was used as a typical application example – see Figure 9.

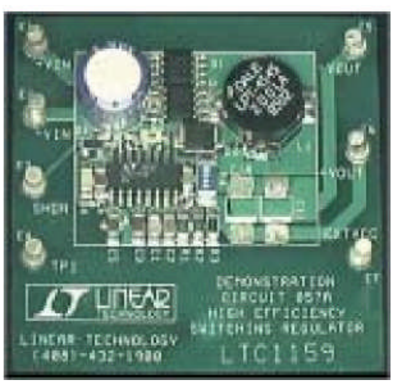


Figure 9. LTC 1159 DC/DC converter.

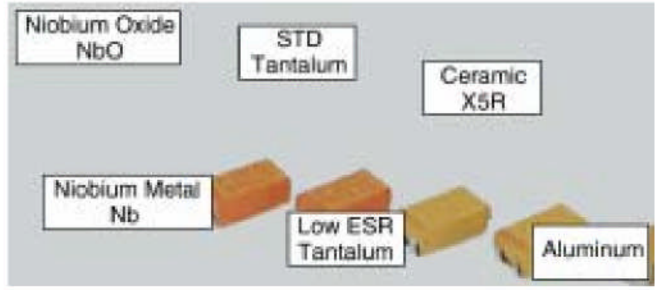
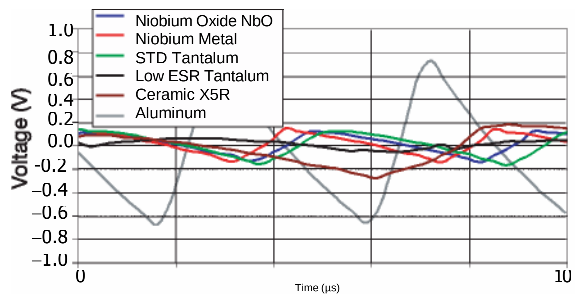


Figure 10. Different capacitors under test.

Single capacitors of Niobium Oxide, Niobium, conventional Tantalum, low ESR Tantalum, Ceramic and Aluminum foil were used as the output capacitor to compare filtering characteristics – see Figure 10.

Oscilloscope recordings were made of output ripple voltage – see Fig. 11. Filtering and Spacing coefficients were calculated by [1], [2] – see Fig. 12.



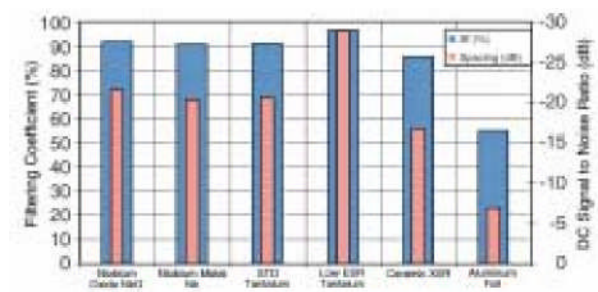


Figure 11, 12. Output ripple voltage and Filtering coefficients comparing different capacitor technologies as the output capacitor.

The best filtering results were obtained using the low ESR tantalum capacitors. Standard tantalum, niobium oxide and niobium metal capacitors reduced ripple voltage to approximately same level. The aluminum foil capacitor showed the worst filtering ability. Changing the bias voltage only affects filtering when a ceramic capacitor is used near its rated voltage (e.g. 6.3V capacitor is used on 5V rail) due to capacitance drop (voltage coefficient). This last result demonstrates that lower ESR (see Figure 4.) was not the critical parameter for output ripple voltage in this case. It is assumed that a higher voltage ceramic capacitor would filter best if used with higher derating, e.g. 6.3V capacitor on a 3.3V DC bias line.

Conclusion

Niobium based technology – utilizing both niobium and niobium oxide capacitors – is now entering the high CV capacitor market place. These devices have a similar capacitance / voltage (CV) range to current tantalum chip technology and demonstrate ESR characteristics comparable to conventional tantalum ratings. Their parametric stability and cheaper material costs (especially in the case of niobium oxide capacitors), make these technologies promising alternatives to low voltage tantalum and ceramic capacitors, and will also allow downsizing of Aluminum foil capacitors. The reduced ignition characteristics of NbO also makes this a technology of interest.

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

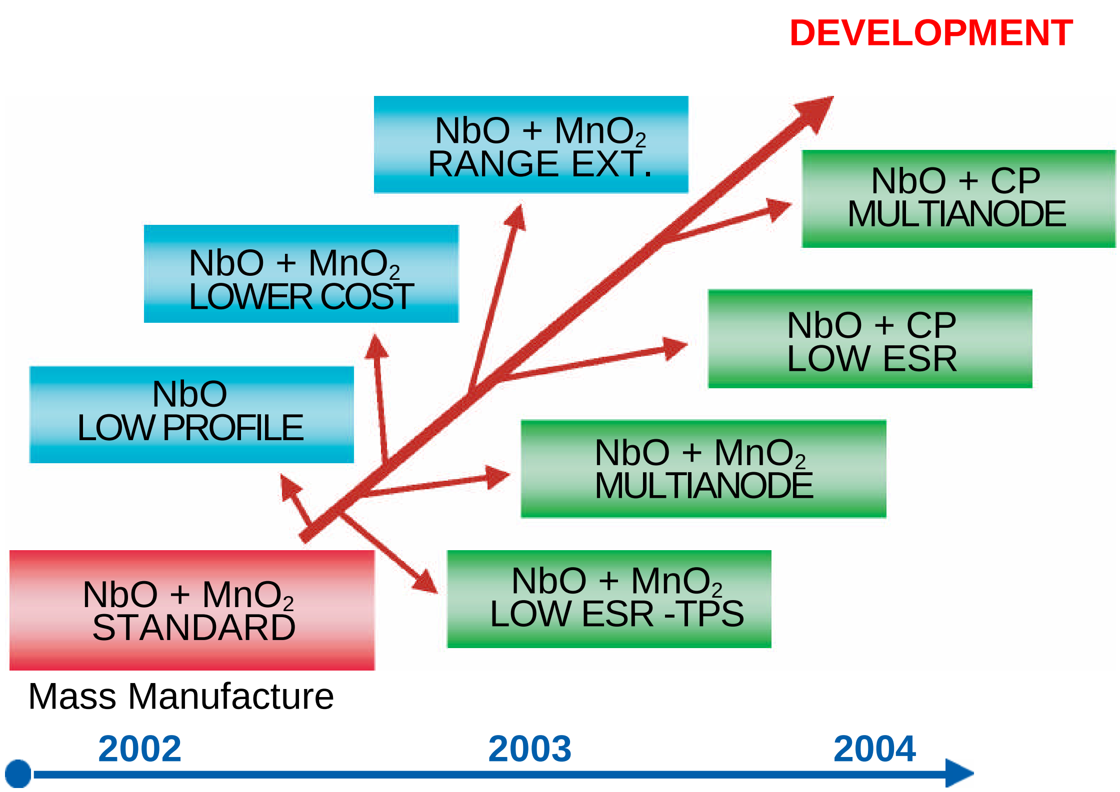
The new generation of niobium and niobium oxide capacitors share the same robust casing design and industry standard sizes as current tantalum chip capacitors and are suited to high speed Pick & Place assembly, Pb-free reflow systems and have no thermal mismatch issues with any substrates.

Future Roadmap

Niobium Oxide is considered to be the preferred product from niobium technology because of its high resistance to ignition failures. As the manufacturing process of niobium oxide capacitors is similar to that of tantalum capacitors, existing equipment may be used to manufacture both tantalum and niobium oxide products. This will enable AVX to expand this technology in a relatively short timescale, with full scale production planned during 2002.

Filtering features are important for power supply and DC/DC converter applications and one of the first development tasks during late 2002 will be the introduction of lower ESR specification products. Multi-anode construction using niobium oxide anodes can also bring benefits in ultra low ESR together with cost saving and reduced ignition.

Low profile series and small case sizes down to 0402 will be the next niobium oxide development focus during late 2002 and first half of 2003, offering cost saving and reduced ignition solutions for height constrained applications such as mobile devices.



Acknowledgement

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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 USA 2000, Brussels, Belgium, pp 188-192.

[4] J. Cain, "Comparison of Multilayer Ceramic and Tantalum Capacitors", AVX Technical Publication, AVX Corporation.

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NORTH AMERICA
Tel: +1 864-967-2150

ASIA
Tel: +65 6286-7555

CENTRAL AMERICA
Tel: +55 11-46881960

EUROPE
Tel: +44 1276-697000

JAPAN
Tel: +81 740-321250

WWW.AVX.COM