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Leakage Current in High-Voltage Defibrillation Capacitors Mediated by Electrolyte Ions

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Implantable defibrillators monitor heart electrical activity to detect fibrillation, which is an episode of uncoordinated, ineffective contractions. Once detected, capacitors are charged to provide a 600-800 V, ~35 J therapeutic pulse to restore a regular heart rhythm. The need for small and highly reliable capacitors in this application generally results in the use of liquid electrolytic capacitors. Two or more capacitors are connected in series to reach the therapy voltage. Due to the unique use condition, these capacitors may be operated close to the potential at which the anodic oxide dielectric was formed.

The magnitude of the potential achievable with these capacitors depends critically on the choice of the electrolytes used for formation of the dielectric (forming electrolyte) and for operation (working electrolyte). Under applied voltage, the interaction of electrolyte and oxide produces leakage current. If the potential is sufficiently high, oxide breakdown can occur. In general, higher voltages require the use of less conductive electrolytes, implying a connection between the concentration of conductive species and the capacitor performance.

Leakage current may include contributions from both ionic current (such as the growth of oxide) and electronic current, the latter being dominant during operation. Electronic current requires a source of electrons. Electrons may be produced from the oxidation of working electrolyte constituents at the oxide/electrolyte interface. It has been previously reported[1] that isotopically labeled acetic acid in tantalum electrolytic capacitors is seen to oxidize, producing carbon dioxide. Carboxylic acids in working electrolytes are therefore likely candidates for supporting leakage current within the capacitor.

The oxidation of carboxylic acid can involve a radical intermediate.[2] This intermediate is stabilized by substitution. If leakage current is limited by the production of electrons from carboxylic acid oxidation, leakage current would be expected to increase with the degree of carboxylate substitution.

To investigate the interaction between electrolyte and leakage current, tantalum electrolytic capacitors were made using a series of electrolytes. Increasingly substituted carboxylic acids were used including acetic acid, propionic acid, isobutyric acid, and pivalic acid. The acids and their associated radicals are shown in Table 1.

Leakage current was measured for each capacitor after holding it at voltage for 5 minutes. Data are shown in Figure 1. Leakage current steadily increases with carboxylate substitution. These results suggest that a significant fraction of leakage current arises from electronic conduction through the oxide supported by oxidation of the carboxylate ion.

References:
1. "A Charge-Transfer Reaction at the Electrified Tantalum-Pentoxide-Electrolyte Interface", Joachim Hossick Schott and Mark E. Viste, Proceedings of the 20th Capacitor and Resistor Symposium, CARTS Europe, Bad Homburg, Germany (2006) (http://ecadigitallibrary.com/pdf/CARTSEUROPE06/1_6%20Hossick-Schott_a.pdf)
2. A. K. Vijh, B. E. Conway, "Electrode Kinetic Aspects of the Kolbe Reaction," *Chemical Reviews*, Vol. 67, No. 6, 1967, pp. 623-664.

Table 1: Acids and associated radical intermediates

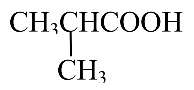
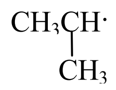
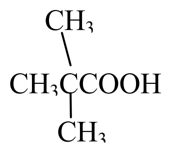
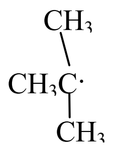
Acid	Structure	Radical
Acetic acid	CH_3COOH	$CH_3\cdot$
Propionic acid	CH_3CH_2COOH	$CH_3CH_2\cdot$
Isobutyric acid	 $CH_3CH(CH_3)COOH$	 $CH_3CH(CH_3)\cdot$
Pivalic acid	 $CH_3C(CH_3)_2COOH$	 $CH_3C(CH_3)_2\cdot$

Figure 1: Leakage current for capacitors made with indicated acids.