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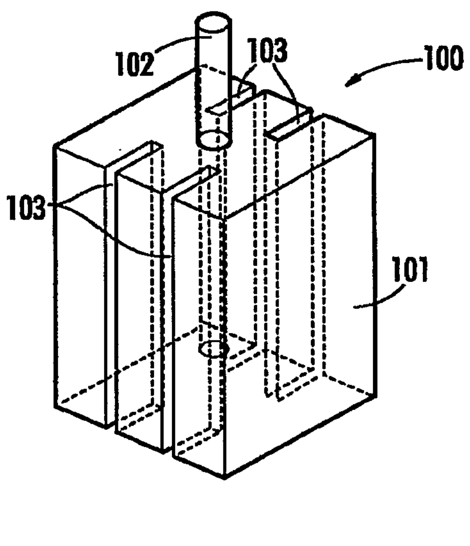
(54) Title: CAPACITIVE ELEMENT COMPRISING AN ANODE WITH FLUTES AND PROCESS FOR FORMING A CAPACITOR



(57) Abstract: An anode (100) with narrow flutes (103) allows for the improved penetration of cathode solutions into the anode body and reduces the redistribution which occurs as the solutions are converted to the solid cathode material.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

TITLE

IMPROVED FLUTED ANODE WITH IMPROVED CAPACITANCE AND CAPACITOR COMPRISING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is related to U.S. Patent Appl. No. 11/431,385 filed May 10, 2006 which is now U.S. Patent No. 7,154,742 issued December 26, 2006.

FIELD OF THE INVENTION

[0002] The present invention is directed to an improved anode with narrow flutes and improved capacitance, capacitance recovery, dissipation factor and improved formation of the cathode layer in the flute.

BACKGROUND OF THE INVENTION

[0003] There is an ongoing need to improve the electrical characteristics of capacitors. Two long term trends in the electronics industry are the on-going miniaturization and reduced cost of the components. For solid electrolytic capacitors increased volumetric efficiency and reduced cost are achieved primarily through the use of higher specific surface area powders of the valve metals used to form the anode body. As the specific surface area of the anode body increases, the pore diameters decrease which presents challenges in the manufacturing process.

[0004] The anode of a typical solid electrolytic capacitor consists of a porous anode body, with a lead extending beyond the anode body and connected to the positive mounting termination of the capacitor. The anode is formed by first pressing a valve metal powder into a pellet. Valve metals include Al, Ta, Nb, Ti, Zr, Hf, W, and mixtures, alloys or suboxides of these metals. The anode is sintered to form fused connections between the individual powder particles.

[0005] The dielectric is formed on the internal and external surfaces of the porous anode through an anodic oxidation process by application of voltage to the anode while immersed in an electrolyte solution. The thickness of the dielectric film is proportional to the applied voltage.

[0006] The cathode of a solid electrolytic capacitor is typically either manganese dioxide or an intrinsically conductive polymer. In either case the internal surfaces of the dielectric are coated with the cathode material by first dipping the anode body in a solution(s) that is subsequently converted to the solid cathode. The dipping process is termed impregnation. In the case of a manganese dioxide cathode the anodes are dipped in manganese nitrate solutions which are subsequently converted to manganese dioxide in a thermal decomposition process.

This process is commonly called conversion. Intrinsically conductive polymers are formed on the internal surfaces of the dielectric by dipping the anodes in a solution of the monomer and a solution of an oxidizer, either in a single co-mixed solution or as separate solutions in an alternate dip process. Once the monomer and oxidizer impregnate the anode body the polymerization reaction is allowed to occur so that the intrinsically conductive polymer coats the internal dielectric surfaces. The process by which the oxidizer and monomer are allowed to react is commonly referred to as polymerization.

[0007] The capacitance of a solid electrolytic capacitor is governed by the general equation of capacitance:

$$C=kA/d$$

where C=capacitance;

k=dielectric constant;

A=surface area of the anode/cathode plates; and

d=distance between the anode and cathode plates or dielectric thickness.

[0008] Since the distance between the anode and cathode plate is proportional to the voltage used to form the dielectric in the anodic oxidation process, the formation voltage (V_f) can be substituted for distance (d) in the general equation for resistance. Furthermore, since the dielectric constant is a material property of the dielectric it can be seen that the multiplicative product of capacitance and formation voltage is proportional to the surface area of the anode. This product is commonly referred to in the industry as CV. The specific surface area of commercial valve metal powders used to manufacture solid electrolytic capacitors is expressed as the product of capacitance times formation voltage divided by the powder weight. This measure of specific surface area of a valve metal powder is commonly referred to as the charge of the powder and it is often abbreviated as CV/g.

[0009] In order to drive the on-going need for miniaturization of electronic components and assemblies, valve metal manufacturers have developed ever higher CV/g powders over the last 40 years as indicated in Figure 1. As the CV/g has increased, the diameter of the pores has decreased. Coating the internal dielectric surfaces with the solid cathode is very difficult for the high CV/g powders available today due to the decreased pore size. Incomplete coating of the internal dielectric surface with the solid cathode results in a loss of capacitance in the finished device. The loss of capacitance due to the incomplete cathode coverage is expressed as capacitance recovery and is defined by Equation 1.

$$\text{Capacitance recovery} = 100 \times (\text{dry capacitance}/\text{wet capacitance})$$

Equation 1

[0010] Wet capacitance is determined by the amount of Ta in the anode, the specific surface area of the Ta (CV/g) and the anodization voltage. The equation for calculating wet capacitance from these anode characteristics is calculated in accordance with equation 2.

Wet capacitance = (Ta volume x press density x CV/g)/(formation voltage)

Equation 2

[0011] Dry capacitance is the capacitance measured after application of the solid electrolyte when the anode is in a dry state.

[0012] The buildup and uniformity of the solid electrolyte inside the pores of the anode impacts several of the electrical characteristics of the finished device which effect the performance of the capacitor in an electric circuit. Poor or nonuniform buildup causes the resistance of solid electrolyte inside the pores to increase, resulting in increases in equivalent series resistance (ESR) and dissipation factor (DF), and a loss in capacitance at higher frequencies (capacitance roll off). DF is the parameter most often used to measure this characteristic of the solid electrolyte.

[0013] Another means of reducing the size of the anode is to increase the anode density. Thus for a given CV/g powder the CV/cc is higher as the anode density is increased. However, as the anode density increases the pore diameters decrease and complete coating of the dielectric surfaces is difficult.

[0014] The ability to coat the internal dielectric surfaces is also governed by the size of the anode. For example 150,000 CV/g powders are currently used in commercially available capacitors with anode bodies less than 0.015 cubic centimeters wherein the smallest dimension is approximately 1 mm. However, for anodes greater than approximately 0.05 cubic centimeters, where the smallest dimension is approximately 3.3 mm, the practical limit for CV/g powders in use today is 70,000 CV/g.

[0015] Manufacturers of solid electrolytic capacitors have been improving the processes for coating the dielectric surfaces for years. Factors manipulated to improve the impregnation process include solution concentration, dip times, dip speeds, surface tension, and vacuum impregnation. Despite these improvements capacitance recover is less than 50% for large case size anodes pressed from powders with CV/g exceeding 60,000. For capacitors employing manganese dioxide as the cathode, this is largely due to the redistribution of the manganese dioxide during the conversion process. This redistribution occurs in part due to the evolution of gasses which occurs during the reaction:

$Mn(NO_3)_2$-> MnO_2 + $2NO_2(g)$

[0016] As these gases escape from the internal body of the anode they carry unreacted manganese nitrate to the outer portions of the anode body. This results in poor coverage of the dielectric surfaces close to the center of the anode and poor capacitance recovery. Similarly as the solvents in the monomer and/or oxidizer solution(s) evaporate prior to, or during, polymerization the evolved gases cause a redistribution of the polymer away from the center of the anode body.

[0017] Another important trend in the capacitor industry is the drive to components with low ESR at high frequencies (100k Hz and higher). In order to reduce ESR, component manufacturers develop means of reducing the resistance of the various elements of the capacitor. Typically the largest contribution to the ESR of the component is due to the resistance of the internal and external cathode layers. The resistance of these elements follow the general equation of resistance as reproduced in Equation 3.

Resistance = resistivity x path length/cross sectional area

Equation 3

[0018] Fluted anodes comprising a furrow or groove on the otherwise monolithic capacitor body as described, for example, in U.S. Pat. Nos. 6,191,936, 5,949,639 and 3,345,545 reduce the path length through the internal cathode layer and increase the cross-sectional area for current to flow through the external cathode layer. Capacitors utilizing fluted anodes as illustrated in Fig. 1 enjoy much success and this technique is still utilized in current capacitors. However, the groove cut in the anode reduces the CV of the anode, resulting in lower capacitance of the device.

[0019] U.S. Patent No. 6,191,936 to Webber et al. discloses a capacitor with flutes of 0.254 to 0.508 mm. The authors describe the benefit of the flutes to be lower ESR, but that the drawback is lower capacitance. Flute dimensions impact capacitance because the flutes reduce the internal surface area of the anode. Webber et al. claim that by limiting the flute dimensions to 0.254 to 0.508 mm in both width and depth this drawback of reduced capacitance is minimized, while still allowing for the benefits of flutes as described in the prior art, such as U.S. Pat. No. 3,345,545, to be realized.

[0020] There has been an ongoing desire to improve impregnation of the anode body thereby allowing for improved capacitance and the ability to take full advantage of higher CV/g powders without sacrifices in equivalent series resistance, dissipation factor or capacitance roll off.

SUMMARY OF THE INVENTION

[0021] It is an object of the invention to provide an improved fluted anode, and capacitor comprising the anode.

[0022] It is another object of the present invention to provide a capacitor with higher capacitance.

[0023] It is yet another object of the present invention to improve the capacitance recovery of the finished capacitor.

[0024] A further object of this invention is to improve the uniformity of the cathode coating on the internal dielectric surfaces for high CV/cc anodes.

[0025] It is an object of this invention to provide a more uniform coverage of the internal dielectric surfaces with the solid electrolyte.

[0026] A particular advantage is the ability to provide improved cathode coverage on the interior of the walls of the flute.

[0027] It is an object of this invention to provide more complete coverage of the internal dielectric surfaces with the solid electrolyte.

[0028] It is yet another object of this invention to reduce the DF of solid electrolytic capacitors.

[0029] These and other advantages, as will be realized, are provided in an anode with narrow flutes which are no more than 0.25 mm wide at the widest point.

[0030] These and other advantages, as will be realized, are provided in an improved capacitor. The capacitor has an anode with flutes wherein each flute has a width of at least 0.06 mm and no more than 0.25 mm. An anode termination is in electrical contact with the anode. A cathode is coated on the dielectric. A cathode termination is in electrical contact with the cathode.

[0031] Yet another embodiment is provided in an improved capacitor. The capacitor has a tantalum anode formed from tantalum powder with a powder charge of at least 50,000 CV/g. The tantalum anode has flutes wherein each flute has a width of no more than 0.3 mm and a depth of 0.75 mm to 1.50 mm. An anode termination is in electrical contact with the anode. A dielectric is coated on the anode and a cathode is coated on the dielectric. A cathode termination is in electrical contact with the cathode.

DESCRIPTION OF DRAWINGS

[0032] Fig. 1 is a plot of historical changes in CV/g and average pore diameter.

[0033] Fig. 2 is a top perspective view of an anode of the present invention.

[0034] Fig. 3 illustrates the distribution of manganese dioxide for a conventional anode.

[0035] Fig. 4 illustrates the distribution of manganese dioxide for an anode of the present invention.

[0036] Fig. 5 graphically illustrates dry capacitance as a function of flute depth for anodes with various flute widths.

[0037] Fig. 6 depicts cap recovery versus flute depth for anodes of various flute widths.

[0038] Fig. 7 plots dry capacitance versus flute width for 1.01 mm flute depth.

[0039] Fig. 8 is a plot of DF versus flute depth anodes of various flute widths.

[0040] Fig. 9 illustrates an anode of the present invention.

[0041] Fig. 10 illustrates an anode of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0042] The present invention will be described with reference to the various figures forming an integral part of the specification. Throughout the various drawings similar elements will be numbered accordingly.

[0043] Through diligent research a limitation of the ability to coat the internal surfaces of the anode body has been found to reside in the redistribution of the solid cathode that occurs during the reaction to form the cathode. The redistribution of materials toward the outside of the anode results in the loss of capacitance. By employing very narrow flutes in the anode, the external surfaces of the anode can be brought close to the center of the anode. This results in improved capacitance recovery without the loss of capacitance typical of previously envisioned fluted anodes. The end result is higher capacitance, improved capacitance recovery, and lower cost (through the need for less valve metal powder). In addition to these benefits other electrical measures of the capacitors performance, DF, ESR, capacitance roll off and leakage improve due to the more uniform distribution of the solid cathode.

[0044] An anode of the present invention is illustrated in perspective view in Fig. 2. The anode generally represented at 100, comprises a radially compressed anode body, 101, and an anode lead, 102, integral thereto. The anode lead may be welded to the anode body. In a preferred embodiment the anode lead is inserted into the anode powder and secured therein by pressing the powder to form the anode body and securing the anode lead therein by compression. Additional anode leads may be included and the anode lead may have a round, oval or rectangular cross-sectional shape.

[0045] The anode body, 101, comprises a series of flutes, 103. Each flute has a width of at least 0.06 mm to no more than 0.3 mm and, in some embodiments, a depth of at least 0.5 mm to no more than 1.5 mm. More preferably the flute depth is at least 0.75 mm to no more than 1.25 mm. More preferably, the flute width is at least 0.10 mm to no more than 0.25 mm.

Even more preferably the flute width is more than 0.20 mm to no more than 0.25 mm. A flute width of less than 0.06 mm approaches the results of an unfluted anode and therefore provides no benefit with high CV/g powders. A flute width of more than 0.3 mm is detrimental due to a dry capacitance which is inferior to unfluted anodes. It is preferable that the flute extend the length of the anode body.

[0046] The cathode buildup on the interior walls of the flutes tend to decrease as the flute width becomes more narrow. Inadequate cathode coverage of the interior walls of the flute allows the carbon and silver layers, which are applied after the cathode layer, to penetrate through the cathode layer and contact the dielectric. Carbon or silver in contact with the dielectric causes high leakage, included short circuits, and low yields in manufacturing. One approach to circumvent this problem is to completely fill the flute with the cathode layer. Steps taken to completely fill the flute with cathode increase the cathode buildup on external anode surfaces. This increases the size of the anode, reducing the volumetric efficiency which the narrow flutes are intended to minimize. In order to completely fill the flutes without causing excessive buildup on the external surfaces of the anode flute depths of more than 0.20 mm to no more than 0.25 mm are particularly preferred.

[0047] A particularly preferred embodiment is illustrated in Fig. 9. In Fig. 9 the anode, 201, comprising an anode wire, 202, is wider at the mouth of the flute and becomes narrower as the flute penetrates inside the body of the anode. Thus, the flute when viewed at right angles to the length of the flute may be V shaped with linearly converging flutes, 203. Alternatively the flute may be curved to more closely resemble a portion of a sine wave when viewed at right angles to the length of the flute as illustrated in Fig. 10. In Fig. 10, the flutes, 204, comprise radially converging flutes. Radially converging flutes converge non-linearly. However, these shapes limit the depth of a flute. When converging flutes are used the widest portion is preferably at the mouth of the flute. As demonstrated in Figures 6 and 8 capacitance recovery and DF improve with flute depth. In order to balance the desire for high capacitance, capacitance recovery, manufacturing yield, while minimizing DF and leakage flute widths of greater than 0.2 mm but less than 0.25 mm are desired.

[0048] The anode is formed by pressing a powder. The anode powder is preferably tantalum with a powder charge of at least 50,000 CV/g. More preferably, the anode powder has a powder charge of at least 70,000 CV/g and even more preferably the anode powder has a powder charge of at least 100,000 CV/g. Below about 50,000 CV/g the present invention provides minimal advantages since the porosity of the powder allows for adequate formation of the manganese dioxide layer. The upper limit of useable powder charge for the present invention is limited by the current unavailability of powder with a powder charge of above about 200,000 CV/g. Throughout the specification the CV/g can be converted to CV/cc using a density of approximately 6 g/cc.

EXAMPLES

Example 1

[0049] Two sets of anodes were pressed using 62,000 CV/g powder. The anode dimensions were 3.25 x 3.25 x 4.83 mm. The density of the anodes after pressing was 6.0 g/cc. The first set of comparative anodes employed a conventional anode with no flutes. The inventive group was pressed with four flutes of dimensions 0.20 mm wide by about 1.0 mm deep. The anodes were vacuum sintered to form porous anodes suitable for manufacturing solid electrolytic capacitors. After an anodization step to form the dielectric, both groups of anodes were processed through a series of 13 manganese nitrate dip/conversion cycles together. The anodes were then fractured to reveal the manganese dioxide distribution. Pictures were taken with an optical microscope to demonstrate the differences in manganese dioxide distribution between these two anode designs. Figure 3 is a photomicrograph of the MnO_2 distribution in the conventional anode. Outside the rectangular box the comparative anodes exhibit a shading which is characteristic of heavy manganese dioxide buildup. This heavy buildup makes it even more difficult to penetrate to the center of the anode during subsequent impregnation/conversion cycles. Figure 4 is a photomicrograph depicting the MnO_2 distribution in an anode with 0.2 mm wide flutes. Between the rectangular box and the oval the anodes with very narrow flutes exhibit a shading that is characteristic of modest manganese oxide buildup. The comparative anodes exhibit a shading characteristic of the dielectric, indicating that there is very little manganese oxide buildup. Inside the oval box the comparative anodes clearly have little, if any manganese dioxide coating the dielectric surfaces while the anodes with very narrow flutes exhibit characteristic of an improved manganese dioxide coating.

[0050] Both sets of anodes were processed together through an additional set of manganese nitrate dips. After application of a carbon and silver layer the electrical characteristics of the capacitors were measured.

[0051] This data is provided in table 1 below.

Table 1.

Group	Dry Capacitance (μF)	Capacitance Recovery (%)	Dissipation Factor (DF)	ESR (milliohms)	Leakage (μA)
comparative	382	76%	9.32	86	42
inventive	414	90%	5.52	67	18

Example 2

[0052] Anodes were pressed using 62,000 CV/g powder. The anode dimensions were 3.25 x 3.25 x 4.83 mm. The density of the anodes after pressing was 6.0 g/cc. The first set of anodes employed a conventional anode (no flutes). In order to demonstrate the effect of flute width and depth on the electrical characteristics of a solid electrolytic capacitor several additional groups were pressed. These groups were pressed using 62,000 CV/g powder and external anode dimensions of 3.25 x 3.25 x 4.83 mm. The density of the anodes after pressing was 6.0 g/cc. Flute width was varied between 0.2 mm and 0.66 mm. Flute depth was varied between 0.51 mm and 1.27 mm. After sintering, the anodes were anodized to 38 volts to form the dielectric. The Ta volume was calculated based on the external dimensions of the anode (3.25 x 3.25 x 4.83 mm) minus the dimensions of the flutes (e.g. 4 x 0.56 x 1.0 mm). Wet capacitance was calculated from the Ta volume, press density, powder charge, and formation voltage as indicated in equation 2. The anode lots were processed through a sequence of 21 manganese nitrate dip and conversion cycles as is common in the industry. Following application of a carbon and silver layer the electrical characteristics of the capacitors were measured. The cap recovery was calculated from the ratio of the dry capacitance to the wet capacitance (x 100). The data is in Table 2.

Table 2.

Flute Width (mm)	Flute Depth (mm)	Ta Vol. (mm^3)	Wet Cap (µF)	Dry Cap (µF)	Cap Recovery (%)	Solid DF (%)
0.00	0.00	51.01	499.4	391.2	78.3	10.9
0.20	1.02	47.03	460.4	413.0	89.7	5.3
0.56	0.51	45.53	445.7	372.8	83.6	8.4
0.56	0.76	42.79	418.9	359.0	85.7	7.7
0.56	1.02	40.05	392.1	346.4	88.4	5.7
0.56	1.27	37.31	365.3	330.2	90.4	4.6
0.66	0.51	44.54	436.0	361.4	82.9	10.4
0.66	0.76	41.3	404.3	350.9	86.8	8.2
0.66	1.02	38.06	372.6	336.6	90.3	5.0
0.66	1.27	34.82	340.9	294.5	86.4	3.8

In Figure 5 a plot of dry capacitance versus flute depth reveals that the capacitance is dropping as the flute depth increases for anodes with 0.56 and 0.66 mm flutes. For a given flute depth the dry capacitance is lower for the 0.66 mm flute width than the 0.56 flute width. These trends were expected due to the loss of Ta powder for larger flutes. Surprisingly, the dry capacitance of the anodes pressed with 0.20 mm x 1.02 mm flutes was higher than that of a conventional anode without flutes.

[0053] In Figure 6 a plot of capacitance recovery versus flute depth reveals that capacitance recovery increased with flute depth. This correlation between capacitance recovery and flute dimensions was previously unknown and not anticipated. Capacitance recovery did not depend strongly on flute width. The variations in the data for anodes with equal flute depths appear to be largely due to random variation present in any experiment.

[0054] Figure 7 plots dry capacitance versus flute width for 1.01 mm flute depth. The data indicate that for flute widths below approximately 0.30 mm the dry capacitance is higher for the fluted anode than the conventional anode.

[0055] Dissipation factor (DF) is another measure of the quality of the impregnation process. DF versus flute depth is plotted in Figure 8. It shows that DF decreased as the flute depth was increased, but like capacitance recovery, was independent of flute width. The DF for all of the fluted anode groups was better than that of the conventional anode, but wide flutes were not needed to obtain the benefits in DF.

[0056] The invention has been described with particular emphasis on the preferred embodiments without limit thereto. The metes and bounds of the invention are set forth in the claims appended hereto.

Claimed is:

1. A capacitive element comprising:

an anode comprising one or more flutes wherein each flute has a width of at least 0.06 mm to no more than 0.25 mm;

an anode termination in electrical contact with said anode;

a dielectric coated on said anode;

a cathode coated on said dielectric; and

a cathode termination in electrical contact with said cathode.

2. The capacitive element of claim 1 wherein said flute has a width of no more than 0.20 mm.

3. The capacitive element of claim 1 wherein said flute has a width of more than 0.20 mm.

4. The capacitive element of claim 1 wherein said anode comprises a pressed powder wherein said pressed powder has a powder charge of at least 50,000 CV/g.

5. The capacitive element of claim 4 wherein said pressed powder has a powder charge of at least 70,000 CV/g.

6. The capacitive element of claim 5 wherein said pressed powder has a powder charge of at least 100,000 CV/g.

7. The capacitive element of claim 1 wherein said anode comprises at least one element selected from aluminum, tantalum, niobium, titanium, zirconium, hafnium, tungsten, and mixtures, alloys or suboxides thereof.

8. The capacitive element of claim 7 wherein said powder comprises tantalum.

9. The capacitive element of claim 1 wherein said flute has a width of no more than 0.1 mm.

10. The capacitive element of claim 1 wherein said flute has a depth of at least 0.50 mm.

11. The capacitive element of claim 10 wherein said flute has a depth of at least 0.50 mm to no more than 1.5 mm.

12. The capacitive element of claim 11 wherein said flute has a depth of at least 0.75 mm to no more than 1.25 mm.

13. The capacitive element of claim 1 wherein said flutes are converging.

14. The capacitive element of claim 13 wherein said flutes are linearly converging.

15. The capacitive element of claim 13 wherein said flutes are radially converging.

16. A process for forming a capacitor comprising:

pressing a powder into an anode comprising flutes with a width of at least 0.06 mm to no more than 0.25 mm;

providing an anode termination in electrical contact with said anode;

forming a dielectric on said anode;

forming a cathode on said dielectric; and

forming a cathode termination in electrical contact with said cathode.

17. The process for forming a capacitor of claim 16 wherein said anode comprises a pressed powder wherein said pressed powder has a powder charge of at least 50,000 CV/g.

18. The process for forming a capacitor of claim 17 wherein said pressed powder has a powder charge of at least 70,000 CV/g.

19. The process for forming a capacitor of claim 18 wherein said pressed powder has a powder charge of at least 100,000 CV/g.

20. The process for forming a capacitor of claim 16 wherein said anode comprises at least one element selected from aluminum, tantalum, niobium, titanium, zirconium, hafnium, tungsten, and mixtures, alloys or suboxides thereof.

21. The process for forming a capacitor of claim 20 wherein said powder comprises tantalum.

22. The process for forming a capacitor of claim 16 wherein said flutes have a width of no more than 0.2 mm.

23. The process for forming a capacitor of claim 16 wherein said flutes have a width of more than 0.2 mm.

24. The process for forming a capacitor of claim 16 wherein said flute has a width of no more than 0.1 mm.

25. The process for forming a capacitor of claim 16 wherein said flutes have a depth of at least 0.50 mm.

26. The process for forming a capacitor of claim 25 wherein said flutes have a depth of at least 0.50 mm to no more than 1.5 mm.

27. The process for forming a capacitor of claim 26 wherein said flutes have a depth of at least 0.75 mm to no more than 1.25 mm.

28. The process for forming a capacitor of claim 16 wherein said flutes are converging.

29. The process for forming a capacitor of claim 28 wherein said flutes are linearly converging.

30. The process for forming a capacitor of claim 28 wherein said flutes are radially converging.

31. A process for forming a capacitor comprising:

pressing a powder into an anode comprising flutes with a width of at least 0.06 mm to no more than 0.3 mm;

providing an anode termination in electrical contact with said anode;

forming a dielectric on said anode; and

forming a cathode termination in electrical contact with said cathode wherein said flutes have a depth of at least 0.75 mm to no more than 1.25 mm.

32. A capacitive element comprising:

a tantalum anode formed from tantalum powder with a powder charge of at least 50,000 CV/g wherein said tantalum anode comprises flutes wherein each flute has a width of no more than 0.25 mm and a depth of 0.50 mm to 1.50 mm;

an anode termination in electrical contact with said anode;

a dielectric coated on said anode;

a cathode coated on said dielectric; and

a cathode lead in electrical contact with said cathode lead.

33. The capacitive element of claim 32 wherein said tantalum powder has a powder charge of at least 70,000 CV/g.

34. The capacitive element of claim 33 wherein said tantalum powder has a powder charge of at least 100,000 CV/g.

35. The capacitive element of claim 32 wherein said flute has a width of no more than 0.2 mm.

36. The capacitive element of claim 32 wherein said flute has a width of more than 0.2 mm.

37. The capacitive element of claim 32 wherein said flute has a depth of at least 0.75 mm to no more than 1.25 mm.

38. The capacitive element of claim 32 wherein said flutes have a width of at least 0.06 mm.

39. The capacitive element of claim 32 wherein said flutes have a width of no more than 0.1 mm.

40. A capacitive element comprising:

an anode comprising one or more flutes wherein each flute has a width of at least 0.06 mm to no more than 0.3 mm;

an anode termination in electrical contact with said anode;

a dielectric coated on said anode;

a cathode coated on said dielectric;

a cathode termination in electrical contact with said cathode wherein said flute has a depth of at least 0.75 mm to no more than 1.25 mm.

41. A capacitive element comprising:

an anode comprising one or more flutes wherein each flute has a width of at least 0.06 mm to no more than 0.25 mm;

an anode termination in electrical contact with said anode;

a dielectric coated on said anode; and

a cathode coated on said dielectric.

42. A capacitive element comprising:

an anode comprising one or more converging flutes wherein each flute has a maximum width of more than 0.2 mm to no more than 0.25 mm;

an anode termination in electrical contact with said anode;

a dielectric coated on said anode;

a cathode coated on said dielectric; and

a cathode termination in electrical contact with said cathode.

43. The capacitive element of claim 42 wherein said converging flutes are linear converging flutes.

44. The capacitive element of claim 42 wherein said converging flutes are radially converging flutes.

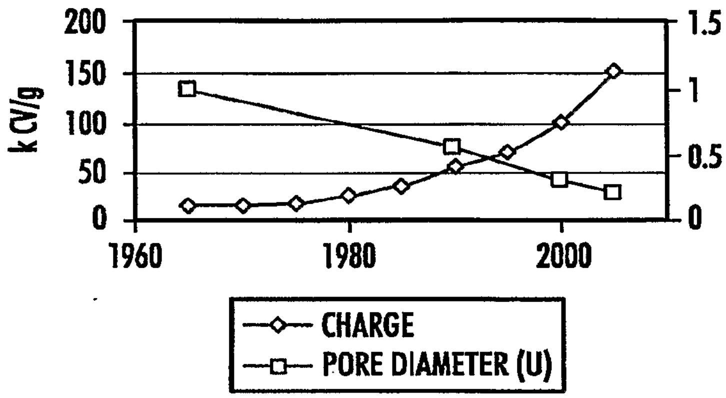

200
150
100
50
0
k CV/g
1.5
1
0.5
0
1960
1980
2000
CHARGE
PORE DIAMETER (U)

FIG.1

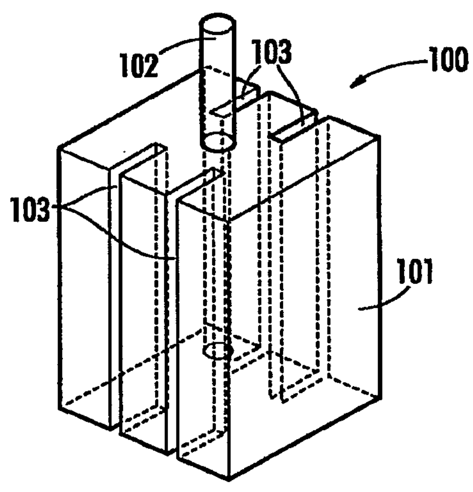

102
103
100
103
101

FIG.2

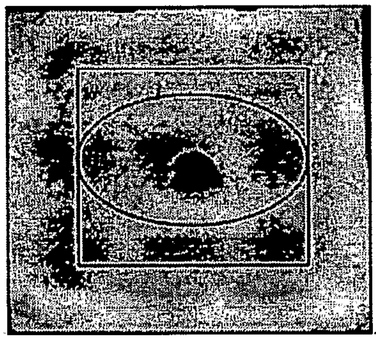


FIG.3
PRIOR ART

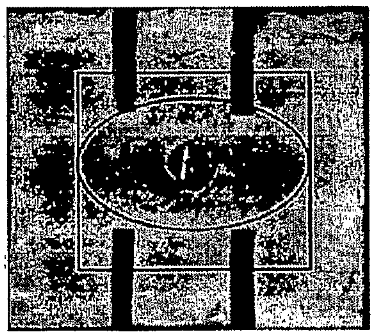


FIG.4

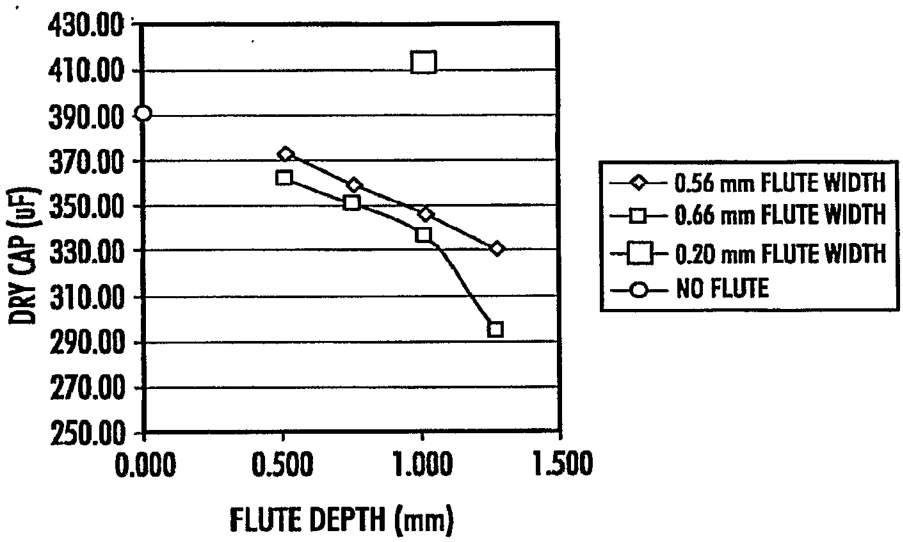

430.00
410.00
390.00
370.00
350.00
330.00
310.00
290.00
270.00
250.00
DRY CAP (uF)
0.000
0.500
1.000
1.500
FLUTE DEPTH (mm)
0.56 mm FLUTE WIDTH
0.66 mm FLUTE WIDTH
0.20 mm FLUTE WIDTH
NO FLUTE

FIG.5

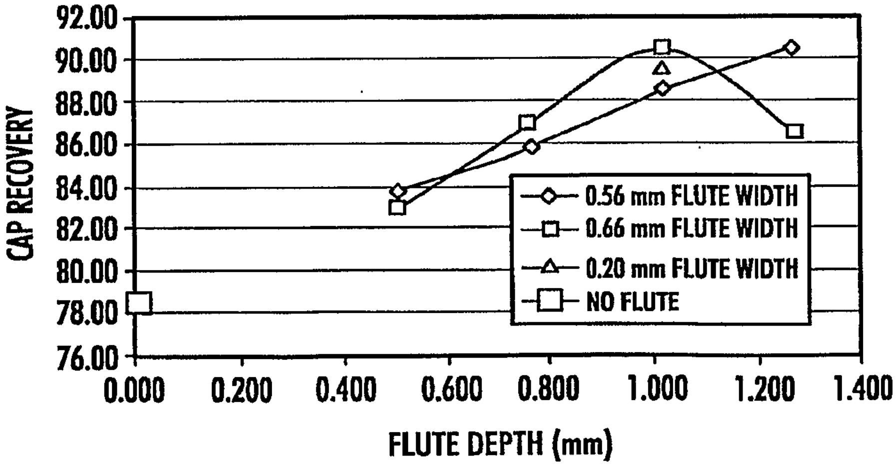
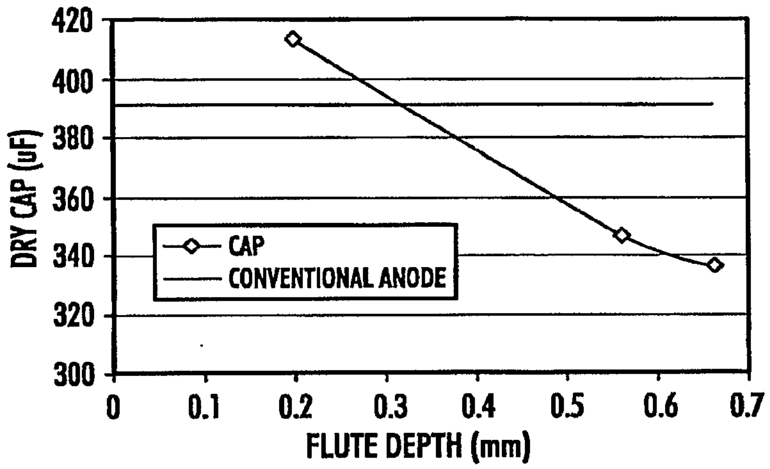
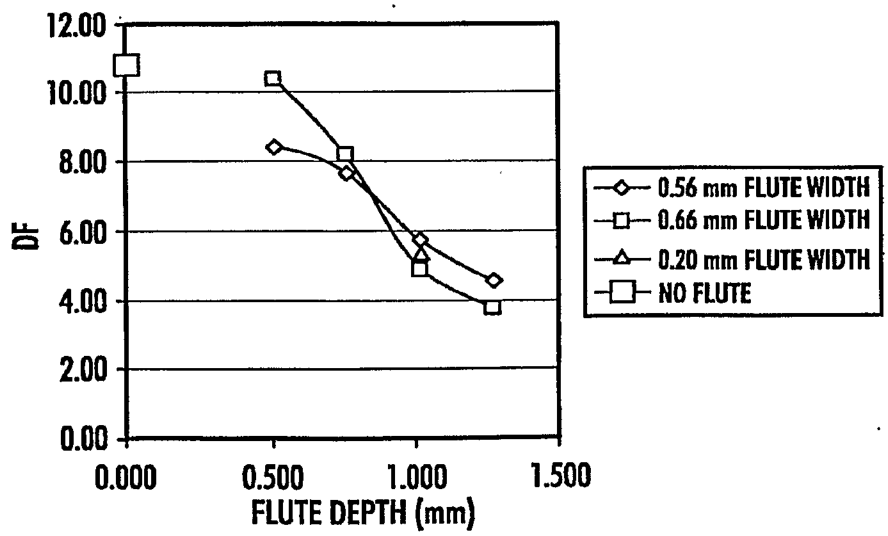

92.00
90.00
88.00
86.00
84.00
82.00
80.00
78.00
76.00
CAP RECOVERY
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
FLUTE DEPTH (mm)
0.56 mm FLUTE WIDTH
0.66 mm FLUTE WIDTH
0.20 mm FLUTE WIDTH
NO FLUTE

FIG.6



420
400
380
360
340
320
300
DRY CAP (uF)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
FLUTE DEPTH (mm)
CAP
CONVENTIONAL ANODE

FIG. 7



12.00
10.00
8.00
6.00
4.00
2.00
0.00
DF
0.000
0.500
1.000
1.500
FLUTE DEPTH (mm)
0.56 mm FLUTE WIDTH
0.66 mm FLUTE WIDTH
0.20 mm FLUTE WIDTH
NO FLUTE

FIG. 8

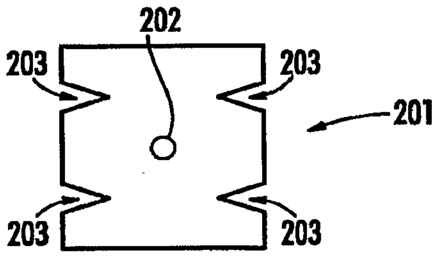


FIG. 9

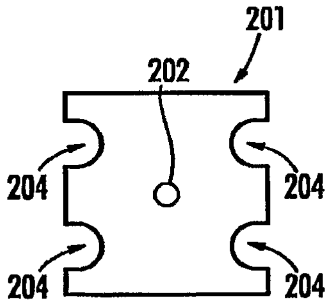


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/007507

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01G9/04 H01G9/048 H01G9/15

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 191 936 B1 (WEBBER DEAN A [US] ET AL) 20 February 2001 (2001-02-20) cited in the application	1,16,31, 32,40-42
Y	the whole document	15,30,44
Y	US 3 345 545 A (BOURGAULT PIERRE L ET AL) 3 October 1967 (1967-10-03) cited in the application the whole document	15,30,44
A	US 2005/122663 A1 (POLTORAK JEFFREY P [US]) 9 June 2005 (2005-06-09) the whole document	1-44
A	WO 2004/049361 A (MEDTRONIC INC [US]) 10 June 2004 (2004-06-10) the whole document	1-44

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 August 2007	14/08/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lescop, Emmanuelle

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2007/007507

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US 2005122663	A1	09-06-2005	AT	362642	T	15-06-2007
			AU	2004298010	A1	23-06-2005
			CA	2517901	A1	23-06-2005
			CN	1757084	A	05-04-2006
			EP	1692709	A1	23-08-2006
			JP	2006524907	T	02-11-2006
			KR	20060018843	A	02-03-2006
			MX	PA05011685	A	23-01-2006
			TW	246098	B	21-12-2005
			US	2007143977	A1	28-06-2007
			WO	2005057598	A1	23-06-2005
WO 2004049361	A	10-06-2004	CA	2507028	A1	10-06-2004
			EP	1568052	A1	31-08-2005
			US	2004134874	A1	15-07-2004