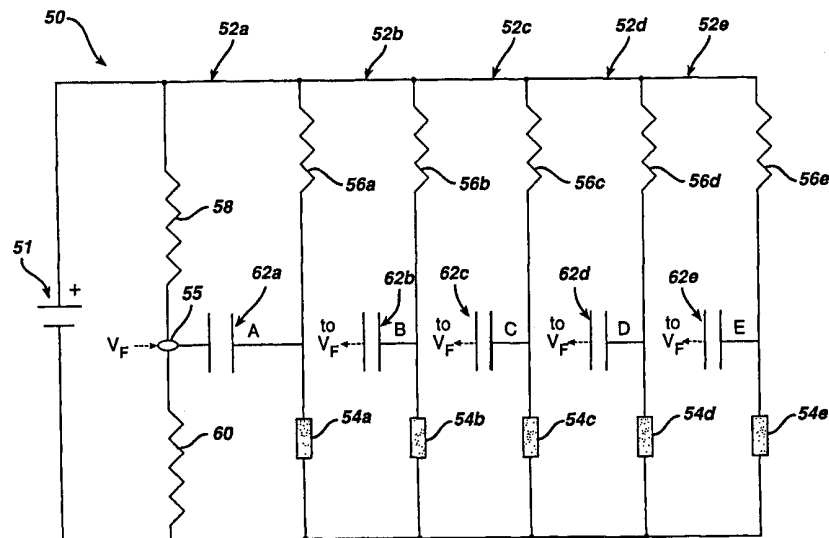




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification <sup>7</sup> : G01R 31/36, H01M 10/48, G02F 1/1365, G09G 3/36</p>	<p>A1</p>	<p>(11) International Publication Number: <b>WO 00/63712</b> (43) International Publication Date: 26 October 2000 (26.10.00)</p>
<p>(21) International Application Number: PCT/US00/09726 (22) International Filing Date: 12 April 2000 (12.04.00) (30) Priority Data: 09/293,288 16 April 1999 (16.04.99) US (63) Related by Continuation (CON) or Continuation-in-Part (CIP) to Earlier Application US 09/293,288 (CON) Filed on 16 April 1999 (16.04.99) (71) Applicant (for all designated States except US): THE GILLETTE COMPANY [US/US]; Prudential Tower Building, Boston, MA 02199 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): LYNCH, Anne, T. [US/US]; 108 Hoover Road, Needham, MA 02494 (US). KACPROWICZ, Mark [US/US]; 9 Eisenhower Avenue, Natick, MA 01760 (US). HEWES, Jeffrey, S. [US/US]; 121 Rockland Street, Holliston, MA 01746 (US). (74) Agents: HANDELMAN, Joseph, H.; Ladas &amp; Parry, 26 West 61st Street, New York, NY 10023 (US) et al.</p>	<p>(81) Designated States: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p><b>Published</b> With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>	

## (54) Title: GAUGE EFFECT BATTERY TESTER



## (57) Abstract

A battery includes a cell having an outer circumference and a battery tester. The battery tester can be of different types. One type a segmented display tester includes a first voltage divider and a plurality of parallel battery tester elements including a voltage controlled display having a first terminal coupled to the first voltage divider and a second voltage divider coupled in parallel with the first voltage divider and coupled to a second terminal of the voltage controlled display. The second voltage divider also includes a non-linear device. A second type of battery tester is also disclosed. This type is a variable type and has a first voltage divider including a non-linear device coupled to a plurality of resistance elements and a voltage controlled display having a first terminal coupled to the first voltage divider and a plurality of second terminals coupled to the plurality of resistance elements.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

GAUGE EFFECT BATTERY TESTER

This invention relates to battery testers that can be incorporated on battery cells.

Known types of battery testers that are placed on batteries are so called "thermochromic" types. In a thermochromic battery tester there can be two electrodes that are connected by a consumer manually depressing a switch. Once the switch is depressed the consumer has connected an anode of the battery to a cathode of the battery cell through the thermochromic tester. The thermochromic tester includes a silver conductor that has a variable width so that the resistance of the conductor also varies along its width. As current travels through the silver conductor, the current generates heat that changes the color of a thermochromic ink display that is over the silver conductor. The thermochromic ink display is arranged as a gauge to indication relative capacity of the battery. The higher the current the more heat is generated and the more the gauge will change to indicate that the battery is good.

Sometimes the switch can be hard for people to depress and it becomes difficult to tell whether the tester worked or not or whether the battery is good or bad. This can be confusing to a consumer. Depressing the switch makes a direct relatively high conductance connection between the anode and cathode of the cell which can draw significant power and reduce battery lifetime.

According to an aspect of the invention, a battery tester disposed on a battery includes a display that continuously indicates the state of charge of the battery.

According to a further aspect of the invention, a battery tester, includes a first voltage divider and a plurality of parallel battery tester elements. Each element includes a voltage controlled display having a first terminal coupled to the first voltage divider and a second voltage divider coupled in parallel with the first voltage divider and coupled to a second terminal of the voltage controlled display, with the second voltage divider including a non-linear device.

According to a further aspect of the invention, a battery tester includes a first voltage divider including a non-linear device and a plurality of resistance elements. A voltage controlled display having a first terminal is coupled

to the first voltage divider and a plurality of second terminals of the display are coupled to the plurality of resistance elements.

According to a further aspect of the invention, a battery tester, includes a voltage controlled display, a first voltage divider having a terminal  
5 coupled to a terminal of the voltage controlled display and a second voltage divider having a terminal couple to a second terminal of the voltage controlled display. The second voltage divider includes a switch device coupled to the voltage controller display such that when activated causes current to flow through the second voltage divider to provide a potential difference across the voltage controlled  
10 display.

A major advantage of the tester compared to other testers is that a consumer can merely look at the tester on the battery to determine whether the battery is good or not. This tester eliminates the need to hold the battery and depress a switch to engage the battery tester. This tester provides a gauge effect to  
15 enable the consumer to judge the relative amount of capacity left in the battery. The tester may be more efficient than prior testers depending on how many times a consumer presses the switch on the prior tester. Over the lifetime of a battery this tester could either use less current or be comparable to prior approaches.

FIG. 1 is a cross-sectional view of an M-I-M diode structure.  
20 FIG. 1A is a blowup view taken along line 1A-1A of a portion of  
FIG. 1.

FIG. 2 is a cross-sectional view of an alternative M-I-M diode structure.  
FIG. 2A is a blowup view taken along line 2A-2A of a portion of  
25 FIG. 2.

FIG. 3 is a cross-sectional view of another alternative M-I-M diode structure.  
FIG. 4 is a flow chart of a process to manufacture the device of  
FIG. 1.

30 FIGS. 5A-5D are plots of voltage vs. current showing typical switching characteristics of M-I-M diode devices of FIGS. 1-4.

FIG. 6 is a schematic diagram of a multiple non-linear element

segmented display battery tester.

FIG. 7 is a schematic diagram of a multiple resistor, variable display battery tester.

FIG. 8 is a diagrammatical, perspective view of a construction example for a multiple non-linear element battery tester of FIG. 6.

FIG. 9 is a diagrammatical view of a construction example for the multiple non-linear element battery tester of FIG. 6.

FIG. 10 is a diagrammatical view of a construction example for the multiple resistor battery tester of FIG. 7.

FIG. 11 is a perspective view of a battery cell having a segmented display battery tester disposed about a circumference of the battery.

FIG. 12 is a perspective view of a battery cell having a variable display battery tester disposed about a circumference of the battery.

FIG. 13 is a diagrammatical view of an alternative arrangement for a battery having a segmented battery tester display.

FIG. 14 is a diagrammatical view of a battery operated device having a battery compartment.

FIG. 15 is a schematic view of a on/off battery tester incorporating a voltage controlled display.

Referring now to FIG. 1, a metal-insulator-metal diode 10 is shown. The metal-insulator-metal diode 10 includes a first electrode 12, e.g., a copper foil substrate or another conductive material such as carbon or gold or other conductive materials such as chromium, tungsten, molybdenum, or other conductive materials such as metal particles dispersed in a polymer binder such as a conductive ink. The metal-insulator-metal diode 10 further includes a composite metal-insulator layer 14 comprised of metal particles 20 suspended in a dielectric binding layer 22. As shown in FIG. 1A, the metal particles 20 have an intrinsic oxide layer 20a that covers the surface of the particles 20. One preferred metal is tantalum that readily forms an intrinsic, stable and generally uniform intrinsic oxide layer 20a. Other metals can be used such as niobium. These other metals should form oxides that are self-limiting, stable, and having a suitable dielectric constant for the application. One reason that tantalum is preferred is that the intrinsic oxide layer forms readily

on tantalum upon its exposure to air.

Disposed on the composite metal-insulating layer 14 is a second electrode 16 also comprised of e.g., copper or another conductive material such as a carbon, chromium, tungsten, molybdenum, or gold or other conductive materials.

5 The second electrode is preferably disposed directly on the layer 12 to be in contact with the intrinsic oxide layer 20a on the particles 20. The second electrode also can be a composite layer including the conductive materials and a binder. By varying the conductivity of the electrode layer 16, the electrical characteristics of the device 10 can be changed. Specifically, the I-V characteristic curve can be made sharper  
10 to obtain a steeper on/off characteristic. That is, the higher the electrical conductivity, the sharper the curve.

As will be described below in FIGS. 5A-5D, the M-I-M device has a symmetrical current-voltage (I-V) characteristic curve exhibiting diode-like properties. The device also can be made to have lower switching voltages than  
15 other approaches, e.g., less than 10 volts and more specifically less than 1 volt to about 0.5 volts but with the same symmetrical properties. By varying the ratio of the tantalum to the binder and also the thickness of the tantalum-binder layer enables shifting of the I-V characteristic curve for the same material up or down within a range of plus/minus 50% or more.

20 The switching voltage of the device 10 can be more consistent from device to device. This may occur due in part to the more consistent oxide layer thickness and quality of the intrinsically formed oxide. The thickness of the tantalum oxide layer 20a does not vary widely compared to thermal annealing or anodized oxide layers. It is believed that the intrinsic layer 20a also has a  
25 substantially uniform thickness from tantalum particle 20 to tantalum particle 20 that is on the order of monolayers of thickness. Characteristics of the tantalum particles are that the powder has a particle size in a range less than 0.5 microns up to about 10's of microns. The printed layer 14 can have a thickness less than 0.5 mils up to 8-10 mils. Other particle sizes and thicknesses could be used herein.

30 Referring now to FIG. 2, another embodiment 10' of the diode includes a layer 14' comprising inert particles 24 (as shown in FIG. 2A) of another dielectric material such as particles 24 of titanium dioxide  $TiO_2$  or magnesium

- 5 -

carbonate  $MgCO_3$  dispersed within the polymer binder 22 and the tantalum particles 20 having an oxide layer 20a. In this embodiment, a portion (e.g., 0% to 75%) of the tantalum particles 20 are replaced with inert dielectric material particles 24 such as the titanium dioxide or magnesium carbonate. The tantalum particles 20 can optionally have an annealed oxide or other type of oxide layer disposed about the tantalum although, the intrinsic oxide layer 20a alone is preferred.

The addition of dielectric particles of e.g., titanium dioxide solids to the polymer binder 22 and the tantalum particles 20 can improve printing of the layer 14', enabling use of lower amounts of tantalum particles while still maintaining a high solids content that would exhibit good diode properties. This would be particularly desirable with very thin layers of the metal/insulating material layer to avoid shorting of the two electrodes 12 and 16 through the layer 14'. Including an inert material reduces the probability of shorting and provides a more consistent film/coating.

Moreover, at sufficiently low concentrations of tantalum, devices may be provided with higher switching voltages. It is anticipated that rather than using the oxide layer around the tantalum particles to act as the insulator, i.e., the potential barrier that electrons need to exceed in order to cause conduction, the barrier would be governed by the dielectric properties of the inert material, e.g., the titanium dioxide and the binder at the lower concentrations of tantalum.

Referring now to FIG. 3, another embodiment 10" of the diode has the first electrode 12 and the metal-insulating layer 14 or 14' on the first electrode. This structure 10" may give similar diode properties when a connection 28 is made to the metal-insulating layer 14 or 14'. By eliminating the second electrode, the device 10" can have fewer layers, changing the fabrication process without substantially altering the characteristics of the metal insulator layer.

Referring now to FIG. 4, the device of FIG. 1 can be prepared as follows: The process 30 includes mixing 32 tantalum powder that is 99.97% pure, having the intrinsic oxide layer and having a particle size less than e.g., 5 microns, with a polymer binder such as Acheson, Electrodag No. 23DD146A, or Acheson SS24686, a more thixotropic material. Both polymer binders are available from Acheson, Port Huron, MI. Other binders can be used with the tantalum to form a

tantalum ink. The binders should be electrically insulating, stable with tantalum or the other metal used and preferably have a relatively high e.g., 15% to 35% or so solids content. The tantalum can be in a range of 100% to 39% of the total weight of the binder. Other ranges could be used. The tantalum particles and binder are  
5 mixed well to produce the tantalum ink. The tantalum ink is printed 34 on the first electrode e.g., a copper foil substrate or on other conductive material. The layer is printed, for example, by either draw down bars, screen printing, flexo or gravure printing techniques. The layer is dried 36, e.g., in an oven at 120°C for 15-20 minutes. A second conductive layer such as chromium in the form of chromium  
10 particles mixed in a binder material is printed 38 on the tantalum binder layer. This chromium layer is also dried 40 at e.g., at 120°C for 15-20 minutes producing the device 10. Thereafter, the device 10 can be tested 42.

Alternative conductive layers or metals such as copper, tungsten, molybdenum, carbon and so forth can be used for the first and/or second electrode.  
15 The conductivity of this layer can be varied by changing relative concentrations of conductive material to binder. Exemplary ranges for conductive material are 30% to 39%. By varying the conductivity of this layer, the shape of the current-voltage characteristic curve can be varied, making it a little sharper producing a diode having a steeper on/off response.

20 Processing is simplified because the tantalum particles used have an intrinsic oxide layer 20a. There is no need to thermally anneal or otherwise thermally preprocess the tantalum powder. The intrinsic oxide coating is very consistent in thickness and quality. This tends to produce very consistent metal-insulator layer materials and hence diodes with switching voltages having  
25 relatively low standard deviations over a series of diodes.

Another advantage is that since there is no need to thermally anneal the tantalum powder, the properties of the ink can be adjusted to achieve various diode properties to fit different applications. Ink formulation may be an easier process to control than thermal processing of the tantalum.

30 This device could also be referred to as a varistor, i.e., a thin printed varistor. This M-I-M structure is good for applications that need a non-linear element that operates at low voltages and perhaps low current that can be printed

rather than using semiconductor deposition techniques.

Referring now to FIGS. 5A-5D plots of voltage vs. current showing typical switching characteristics of M-I-M diode devices of FIGS. 1-5 are shown. As shown in FIG. 5A, a current voltage characteristic curve 44 for a M-I-M diode  
5 device exhibits a switching voltage at 100 na. (nano-amperes) of approximately 1.8 volts, with an on/off ratio that is calculated to be about 33. The current voltage characteristic curve 44 was obtained using a Hewlett Packard semiconductor analyzer, Model No. 4155B.

This device used a tantalum layer that was prepared by mixing 5  
10 grams of tantalum particles obtained from Alfa Aesar, Ward Hill, MA. having a particle diameter of less than 2 microns, with 20 grams of Electrodag 23DD146A polymer having a 25% solid versus 75% volatile compound composition. The ink was coated onto a conductive surface of copper foil using a 15 mil cutout i.e., to produce a layer having a wet thickness of 15 mils. The sample was dried in an  
15 oven at 120°C for 20 minutes. The ink for the second layer of the diode was prepared by mixing 5 grams of chromium powder with a particle size of less than 5 microns as received from Alfa Aesar with 4 grams of Electrodag 23DD146A and was coated on top of the tantalum ink layer using a 5 mil cutout. This coating was dried for 20 minutes at 120°C.

20 As shown in FIG. 5B, the M-I-M diodes can exhibit different switching voltages based upon different "P:B" ratios, that is, different ratios of metal (e.g., tantalum) particles to binder. As shown in FIG. 5B, for the same thickness of 15 mils, with P:B ratios of 5, 2, and 1, devices exhibit switching voltages of approximately 9 volts (curve 45a), 5.3 volts (curve 45b) and 3.8 volts (curve 45c) at  
25 100 nano amperes.

As also shown in FIG. 5C, varying the wet thickness of the tantalum layer can also produce varying switching voltages. With a tantalum layer having a tantalum to binder ratio (P:B) of 8:1, a M-I-M diode having a 15 mil thick tantalum layer would exhibit a switching voltage of approximately 9 volts (curve 46a), a 10  
30 mil thick layer would provide a M-I-M diode with a switching voltage of approximately 7.8 volts (curve 46b), and a 5 mil thick layer would provide a M-I-M diode with a switching voltage of approximately 4.6 volts (curve 46b). Each of the

switching voltages are measured at 100 nano amperes.

Referring now to FIG. 5D, addition of magnesium carbonate to the tantalum layer can produce M-I-M diodes that have consistently high on/off ratios with minimal impact on switching voltage. As shown in FIG. 5D, as the amount of magnesium carbonate is increased, the switching voltage characteristic becomes steeper. The curve 46a shows the switching characteristic for a 100% tantalum layer having a P:B ratio of 1:1 that exhibits a switching voltage of 1.8 volts. Curves 47b-47d illustrate that as the amount of magnesium carbonate increases, the switching characteristic becomes steeper therefore indicating a better on/off ratio.

Referring now to FIG. 6, a multiple, non-linear element battery tester 50 is shown connected to a battery 51. The multiple, non-linear element battery tester 50 is comprised of a plurality of individual, non-linear element battery testers 52a-52e coupled to provide a parallel circuit. Each of the individual, non-linear element battery tester circuits 52a-52e include a non-linear element such as a M-I-M diode 54a-54e, respectively, and a film resistor 56a-56e respectively. The battery tester 50 includes a voltage divider provided by two resistors, 58 and 60 coupled in parallel with the plurality of individual non-linear element battery testers 52a-52e. Each of the individual non-linear element battery testers 52a-52e includes a corresponding one of a plurality of display devices 62a-62e disposed between an electrode 55 (potential  $V_p$ ), and a common connection of the respective parallel circuits 52a-52e of the non-linear elements, i.e., M-I-M diodes 54a-54e and the film resistor 56a-56e.

The display devices 62a-62e are of a ultra-low current, low voltage, voltage controlled display type. One type of display devices 62a-62e are an electrophoretic display device such as described in "All Printed Bistable Reflective Displays: Printable Electrophoretic Ink and All Printed Metal-Insulator-Metal Diodes" Massachusetts Institute of Technology, June, 1998 and provided by E-INK, Inc. Cambridge, Ma, that are modified to include low switching voltage devices as described above in FIGS. 1-5D.

This type of display is based on so called "electronic inks", e.g., electrophoretic materials that change their properties e.g., color based on an applied voltage. Using electrophoretic materials such as electronic ink, a flat panel display

can be printed on a substrate material. These displays draw very little current and hence dissipate very little power. Any voltage sensitive material could be used as the display. Another material that has been described in "The Reinvention of Paper", Scientific American, Sept., 1996, called Gyricon which is also voltage  
5 sensitive. The display needs to operate at voltages that are within the range of the voltage of battery.

The non-linear devices 54a-54e can be the M-I-M diode 10 described above in conjunction with FIGS. 1-5A-5D.

The multiple, non-linear element battery tester 50 has five different  
10 diodes, in five parallel paths. If the diodes are constructed to switch at a different voltage, the displays would change state at different voltages producing a segmentation of the display or a gauge effect that would indicate charge status of the battery.

The multiple, non-linear element battery tester 50 has one terminal of  
15 each of the displays 62a-62e coupled to a common voltage potential labeled as  $V_f$ . The voltage potential  $V_f$  is derived from a point between the two resistors, 58,60, and if resistors 58 and 60 are equal, provides  $V_f$  at one-half of the voltage of the cell. The different parallel segments 52a-52e have a value of voltage respectively, at points A-E where the magnitude of the voltage is set by the diodes 54a-54e and  
20 the resistor elements 56a-56e. The different parallel segments 52a-52e can be set to have monotonically increasing or decreasing values of voltage at points A-E. For example, for a 9 volt battery, one diode 54a could be selected to switch at 8 volts, diode 54b could be selected to switch at 7 volts, diode 54c could be selected to switch at 6 volts, and so on, so that as the voltage of the battery drops, different  
25 segments of the displays 62a-62e turn off.

The diodes 54a-54e can be set to switch at different voltages that would either turn "on" or turn "off" the display, i.e., change from one color to another color depending on how the display is connected to the circuit. The number of segments is only limited by how well the diodes can differentiate different  
30 voltages. In the 9 volt example, a one volt difference was used. But if the diodes are fabricated to produce exactly 1/10 of a volt difference the battery tester can have 1/10 of a volt switching difference and the battery tester can be expanded out to 15

or 60 segments or more segments.

The current drawn from the battery can be selected to depend on the values of resistance of the voltage divider of resistors 58 and 60. The display devices 62a-62e draw very little current.

5                    Since diodes 54a-54e are non-linear, at some point as diodes 54a-54e switch they will cause the voltage at electrode 55 to become negative with respect to the voltage of respective ones of the electrode coupled to points A-E. This would cause corresponding flips or changes in the polarity on the displays 62a-62e, causing the displays 62a-62e to change color indicating that the battery is losing  
10 charge. When the last one of the displays e.g., 62e changes color it could indicate that the battery 51 is no longer within some defined specification.

Referring now to FIG. 7, an alternate embodiment 50' of a multiple, non-linear element battery tester 50 is shown connected to a battery 51. In this battery tester 50', segmentation i.e., a gauge effect, is provided by using different  
15 resistors with a common, segmented display device 78. The battery tester 50' includes a parallel circuit. On one side of the parallel circuit is a non-linear element, e.g., a M-I-M diode 72 and resistor 74. On the other side, rather than just having the two resistor elements to split the current, as the battery tester 50 of FIG. 1, the battery tester 50' includes a plurality of resistors e.g., five, 76a-76e.  
20 The plurality of resistors 76a-76e are coupled to corresponding electrodes 76a-76d of a display 78 that has a second electrode 80 coupled at the connection of the non-linear element 72 with the resistor 74 which is at a potential E. The voltage at any point A-D along the display 78 is equal to the sum of the resistance up to that point divided by the total resistance, as shown below for Equations 1-4.

- 11 -

$$V_a = V_{\text{battery}} \frac{R_1}{R_1 + R_2 + R_3 + R_4 + R_5} \quad \text{Equation 1}$$

$$V_b = V_{\text{battery}} \frac{R_1 + R_2}{R_1 + R_2 + R_3 + R_4 + R_5} \quad \text{Equation 2}$$

$$V_c = V_{\text{battery}} \frac{R_1 + R_2 + R_3}{R_1 + R_2 + R_3 + R_4 + R_5} \quad \text{Equation 3}$$

$$V_d = V_{\text{battery}} \frac{R_1 + R_2 + R_3 + R_4}{R_1 + R_2 + R_3 + R_4 + R_5} \quad \text{Equation 4}$$

The voltage  $V_E$  at point E is relatively constant throughout the life of the cell and the voltages  $V_A$ ,  $V_B$ ,  $V_C$  and  $V_D$  will vary with respect to the voltage  $V_E$  at point E. There will be different points at which the values of the voltages at points A, B, C and D are positive with respect to point E or negative. When there is a polarity change there is a corresponding change color of the display. The difference in the values of resistors 76a-76e can be easily varied by printing different widths of conductive material.

Preferably, all of the resistors 76a-76e are printed with a transparent conductive material such as ITO (indium tin oxide) and suspended in a polymer binder material. The conductivity of the printed layers can be varied by changing the amount of ITO dispersed in the polymer binder with low levels of ITO producing films of high resistance. A circuit with an overall resistance of 15 meg-ohms between anode and cathode would produce a current draw of 100 nano-amps (na). This relatively low current draw would have an impact on cell capacity of only about ½ percent.

Referring now to FIGS. 8 and 9, an example of the battery tester (FIG. 6) is shown. A transparent conductor 94, e.g., a material such as an ITO (indium tin oxide) ink or a transparent coating used for electrostatic dissipation is printed on the cell or label of the battery 51. Examples of the material of the transparent conductor, include an electrostatic coating. The transparent conductor 94 need not carry a high current because the displays 62a-62e (FIG. 1) are voltage sensitive displays. The transparent conductor is merely a current carrying material.

The transparent conductor 94 is attached to resistors 58,60 which attach to the anode or the cathode, so the transparent conductor 94 is attached between the anode and the cathode. The attachment of resistors 58,60 to the anode and the cathode of battery 51 can be provided by glueing, crimping or other arrangements.

5                 Resistors 58-60 may be formed from strips of material having different widths or thicknesses to provide different resistances. On top of the transparent conductor 94, the display is printed. This display could be the electrophoretic ink display mentioned above or it could be a Gyricon based display or any other voltage sensitive material that produces a change in color by varying  
10 an applied voltage.

                  The display includes an electrophoretic ink material 96 that is printed on the transparent conductor 94. On top of the electrophoretic ink material 96, a first conductor 98 of the display is printed. This conductor 98 couples one side of the display to one of the poles of the battery, either the anode or the cathode,  
15 depending on how the display is to be initially switched. This conductor 98 is also printed in segments and is coupled to resistors 56a-56d (FIG. 6, only four used in this example). If the conductor 98 is printed as one solid conductor, the conductor would carry a uniform voltage. Printing the conductor in sections gives a segmentation, e.g., gauge effect.

20                 The diodes 54a-54d (FIG. 6, only four use in this example) are printed by depositing a tantalum layer segments 100 having tantalum particles with an intrinsic oxide coating in a dielectric binder as described above. The intrinsic oxide has a sufficient thickness to provide M-I-M diodes. In order to vary the characteristics of the parallel paths, these segments can be at different thicknesses to  
25 give different diode properties. This provides a different switching voltage for each diode.

                  A second electrode 102 such as a chromium layer is printed on top of the tantalum layer. The second electrode 102 is surrounded by an optional dielectric coating 104 to insure that short circuits are avoided. A second conductor  
30 106 is printed on top of the second electrode 102 to connect all the chromium layers together. The second conductor 106 is connected to the opposite pole of the battery from the first conductor 94, either anode or cathode depending on which pole the

first conductor 98.

Referring now to FIG. 10, an example of the multiple resistor battery tester 50' is shown. The battery tester 50' is laid-out very similar to the battery tester 50. A transparent conductor 110 is printed in different sections 110a-110d to provide segmentation i.e., the battery charge gauge. The transparent conductor 110 is printed to include a wedge-shaped conductor portion 110e to produce resistors 76a-76e. The wedge-shape conductor portion 110e has a resistance characteristic that varies along the conductor length so that at the narrower end it has a higher resistance while at the wider end it has a lower resistance. The conductor portion 110e could also be a single width where the resistance at any point in the conductor would depend on how far that point was from one pole of the battery. Other arrangements are possible.

The wedge-shaped conductor portion 110e is connected to both the anode and the cathode of battery 51 such as by glueing or crimping or other arrangements. On top of the transparent conductor 110 is printed the display material 112, e.g., the E-Ink or Gyricon or other voltage sensitive material. Over the display material 112 another conductor 114 is printed. One end of the conductor 114 is connected via resistor 115 to one of the poles of the cells, either the anode or the cathode. On top of that conductor, a tantalum oxide/tantalum metal layer 116 is printed and on top of tantalum oxide/tantalum metal layer 116, the second electrode 118 e.g., a chromium layer is printed. The second electrode 118 is connected to the opposite pole of the cell.

Since the battery tester 50 or 50' is a printed device, the non-linear device can be provided with carbon ink based electrodes as described above. The resistors can also be carbon-based with a dielectric filler to reduce the conductivity of the resistors making them more resistive. Ideally the entire battery tester 50 should have a very high total resistance, e.g., on the order of 15 meg-ohms. For a 1.5 volt cell that would provide a tester 50 or 50' that draws 100 nano-amps which is a low enough current level to have a minimum impact on the lifetime of the battery. For example, for a "double A" cell with a 7 year lifetime, a 100 nano ampere draw would consume only about 0.5 percent of the battery's capacity.

Typical thicknesses for the layers in the battery testers can be as

follows: The transparent conductor could have a thickness between 0.1 to 0.2 mils; the display medium 1.0 mil; the electrode layers 0.1-0.2 mils; tantalum layer for the M-I-M diode 0.5-1.0 mils and various dielectric layers 0.2-0.5 mils. Other thicknesses could alternatively be used.

5 Referring now to FIG. 11, a battery 51' having a battery tester 150 with a segmented display is shown. The battery tester 150 includes a first plurality of segments 154a-154g disposed in a second plurality of columns 156a-158g along the length of the battery 51'. The battery tester 150 can be provided by using one tester that is disposed around the battery 51'. In the battery tester 150, the battery  
10 tester 150 is turned sideways around the battery 51'. The battery tester 150 is arranged such that successive ones of the segments 154a-154g turn on or off at different voltage levels to give an indication of the power remaining in the battery 51'.

Thus, as an example, for a given condition of the battery 51', the  
15 battery tester 150 can have all segments 154a and 154b in all columns 156a-156g turn on to indicate that the battery has spent "two sevenths" (2/7) of its useful life. The battery tester 150 is incorporated over the entire circumference of the battery 51'. Therefore, a consumer does not have to hold the battery in one orientation to look at the display, since the display is visible from any orientation.

20 Referring now to FIG. 12, a battery 51" including a battery tester 162 with a variable display is shown. The battery tester 162 is comprised of individual battery testers 164 that are printed in columns 166a-166g that are disposed around the circumference of the battery 51". Thus, unlike the battery tester 150 (FIG. 11), i.e., a tester that is expanded all around the cell, the battery tester 162 is comprised  
25 of a series of battery testers 164 arranged in vertical columns 166a-166g along the height of the battery 51".

Referring to FIG. 13, an alternative arrangement 170 for a battery 51' having a segmented battery tester display 172 is shown. The segmented battery tester display 172 includes a plurality of segments 174a-174d disposed in a plurality  
30 of rows 176a-176d, in a band around an upper portion of the battery 51'. The segmented battery tester display 172 can be provided by using one segmented tester that is disposed around the battery 51'. In the segmented battery tester display 172,

the segmented battery tester display 172 is turned sideways around the battery 51'. The segmented battery tester display 172 is arranged such that successive ones of the segments 174a-174d turn off at different voltage levels to give an indication of the power remaining in the battery 51'. This arrangement could be used to replace  
5 a gold band found around an upper circumference portion of batteries from Duracell® Gillette, Inc. Boston Ma. As the battery capacity is consumed, the gold band could change to a different color or disappear to indicate remaining capacity.

Referring now to FIG. 14, an electronic device 180 includes a body 182 having a battery compartment 184 with a door 186. A battery, as shown can be  
10 placed in the battery compartment. The door 186 has a transparent window 188, through which a consumer can see the battery 51' or 11" and read the display of the battery tester 150 or 162 for those testers that can be considered as passive testers, i.e., those that do not require any action on the part of the consumer to activate 62 (FIG. 6) or 78 (FIG. 7). The electronic device can be any type of consumer device  
15 including without limitation, a calculator, cellular telephone, toy, radio and so forth. The transparent window could be part of the door or indeed could be the entire door.

Alternatively, the battery tester 150 (FIG. 6) or the battery tester 162 (FIG. 7) can be implemented with active battery testers i.e., those that require some  
20 consumer action such as manually closing a switch to electrically connect the tester to the battery electrode(s). In order to allow for inspection within the battery compartment of an electronic device, the compartment can be provided with an external lever or linkage (not shown) that would permit the user to test the battery having a manual type of tester.

While the battery tester displays 150 and 162 were described as being  
25 disposed around the entire circumference, other arrangements are possible. For example, they could be disposed in quadrants or even about 2/3 to 3/4 about the entire circumference of a battery. Moreover, to accommodate other information on the label they do not have to extend over the entire or substantially entire length or  
30 circumference of the battery, but could be a portion of the length or circumference.

Moreover, other types of tester could be used. For example, rather than using a tester that gives a gauge effect, a tester that merely gives a good or bad

- 16 -

indication could also be used, as will now be described.

Referring now to FIG. 15, a good/bad indicator battery tester 200 is coupled to a battery 51. The battery tester 200 includes a parallel circuit including a display device 206 disposed between two electrodes 202,204 that are in parallel. Electrode 202 is connected to the circuit 200 at a voltage divider provided by two resistors, 208 and 210. Electrode 204 is connected to the other side of the parallel circuit. The other side of the parallel circuit has a non-linear element, i.e., a switch 212 and a third resistor 214. The display device 206 is an ultra-low current, voltage controlled type of display. The non-linear device 212 is a M-I-M diode as described above.

The voltage potential at terminal 202 will always have, half of the battery cell voltage across it if the value of resistor 208 equals the value of resistor 210. The potential of the electrode 204 is determined by voltage across the non-linear element 212 and resistor 214. The voltage at terminal 202 will start at a known value depending on the values of resistors 208, 210 and 214. As current is drawn from the battery due to use or leakage, the voltage of electrode 202 will vary with respect to the voltage at electrode 204. Since element 212 is non-linear, at some point it will switch causing the voltage at electrode 202 to become negative with respect to the voltage of electrode 214. When the non-linear element switches, this would flip the polarity on the display causing the display to change color indicating that the battery is no longer within some defined specification. The display can be wired into the circuit so that either color of the display can indicate that the battery is no longer within some defined specification. In either event the battery tester works on the principle that the display exhibits a change in color when there is a change in the status i.e., good to bad of the battery cells.

Since the battery tester 200 is a printed device, the non-linear device can be provided with carbon ink based electrodes, as described in the above pending application. The resistors can also be carbon based and include a filler to reduce the conductivity of the resistors to make them more resistive. Ideally the entire battery tester 200 should have a very high total resistance, e.g., on the order of 15 meg-ohms. For a 1.5 volt cell that would provide a tester 200 that draws 100 nano-amps (na) of current which is a low enough current level to have a minimum impact

- 17 -

on the lifetime of the battery. For example, a "double A" cell with a 7 year lifetime, a 100 na draw would consume only about 0.5 percent of the battery's capacity.

5 It is to be understood that while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims.

C L A I M S

1. A battery tester disposed on a battery comprising:  
a display that continuously indicates the state of charge of the battery.
2. The battery tester of claim 1, wherein the battery tester further  
5 comprises:  
at least one non-linear device to control switching of a state of the  
display.
3. The battery tester of claim 2, wherein the battery tester further  
comprises:  
10 a plurality of non-linear devices to control switching of segments of  
the display.
4. The battery tester of claim 1, wherein the battery tester further  
comprises:  
a non-linear device; and  
15 a plurality of resistors to control switching of a state of segments of  
the display.
5. A battery tester, comprises:  
a first voltage divider; and  
a plurality of parallel battery tester elements, each element  
20 comprising:  
a voltage controlled display having a first terminal coupled to the  
first voltage divider; and  
a second voltage divider coupled in parallel with the first voltage  
divider and coupled to a second terminal of the voltage controlled display, with the  
25 second voltage divider comprising:  
a non-linear device.
6. The battery tester of claim 5, wherein the voltage controlled display  
is an electrophoretic display.
7. The battery tester of claim 5, wherein the non-linear device is a  
30 metal-insulator-metal diode.
8. The battery tester of claim 5, wherein the first voltage divider  
includes a pair of resistors having the same resistance.

9. The battery tester of claim 5, wherein the second voltage divider includes a resistor coupled in series with the non-linear device.

10. The battery tester of claim 5, wherein the tester in operation is always on.

5 11. The battery tester of claim 5, wherein a voltage potential at the first terminal of the display in each battery tester element is about half of a battery cell voltage and a potential at the second terminal of the display in each battery tester element is determined by voltage across the non-linear element and resistor.

10 12. The battery tester of claim 11, wherein as current is drawn from a battery due to use or leakage, the voltage of one of the terminals of the display in each battery tester element will vary with respect to the voltage at the other terminal of the display in each battery tester element.

15 13. The battery tester of claim 12, wherein the M-I-M diode will switch states causing the voltage at one of the terminal of the display in each battery tester element to become negative with respect to the voltage at the other terminal of the display in said battery tester element, to cause a change in color of the display to indicate that the battery has lost a predetermined amount of capacity.

20 14. The battery tester of claim 5, wherein the non-linear device will switch states causing the voltage at one of the terminal of the display in each battery tester element to become negative with respect to the voltage at the other terminal of the display in said battery tester element, to cause a change in color of the display to indicate that the battery has lost a predetermined amount of capacity.

25 15. The battery tester of claim 14, wherein as current is drawn from a battery due to use or leakage, the voltage of one of the terminals of the display in battery tester element will vary with respect to the voltage at the other terminal of the display in battery tester element.

30 16. A battery comprising:  
a cell having an outer circumference; and  
a battery tester, comprises:  
a first voltage divider; and  
a plurality of parallel battery tester elements, each element comprising:

- 20 -

a voltage controlled display having a first terminal coupled to the first voltage divider: and

a second voltage divider coupled in parallel with the first voltage divider and coupled to a second terminal of the voltage controlled display, with the  
5 second voltage divider comprising:  
a non-linear device.

17. The battery of claim 16, wherein the display in each battery tester element is an electrophoretic display.

18. The battery of claim 16, wherein the non-linear device in each battery  
10 tester element is a metal-insulator-metal diode.

19. The battery of claim 16, wherein the first voltage divider of the tester includes a pair of resistors having the same resistance.

20. The battery of claim 16, wherein each second voltage divider of each battery tester element includes a resistor coupled in series with the non-linear  
15 device.

21. The battery of claim 16, wherein the tester in operation is always on.

22. The battery of claim 10, wherein a voltage potential at the first terminal of the display in each tester element is about half of a battery cell voltage and a potential at the second terminal of the display in each tester element is  
20 determined by voltage across the non-linear element and resistor.

23. The battery of claim 22, wherein as current is drawn from a battery due to use or leakage, the voltage of one of the terminals of the display in each tester element will vary with respect to the voltage at the other terminal of the display.

25 24. The battery of claim 23, wherein the non-linear device will switch states causing the voltage at one of the terminal of the display in each tester element to become negative with respect to the voltage at the other terminal of the display in each tester element to cause a change in color of the display to indicate that the battery has lost a predefined amount of capacity.

30 25. The battery of claim 23, wherein the non-linear device is a transistor.

26. A battery tester, comprises:  
a first voltage divider including a non-linear device;

- 21 -

a plurality of resistance elements; and  
a voltage controlled display having a first terminal coupled to the first voltage divider and a plurality of second terminals coupled to the plurality of resistance elements.

5 27. The battery tester of claim 26, wherein the voltage controlled display is an electrophoretic display.

28. The battery tester of claim 26, wherein the non-linear device is a metal-insulator-metal diode.

29. The battery tester of claim 26, wherein the first voltage divider  
10 includes resistor coupled to the non-linear device.

30. The battery tester of claim 26, wherein the tester in operation is always on.

31. The battery tester of claim 26, wherein a voltage potential at the first terminal of the display is about half of a battery cell voltage and a potential at the  
15 plurality of second terminals of the display is determined by voltage across corresponding ones of the plurality of the resistor elements.

32. The battery tester of claim 31, wherein as current is drawn from a battery due to use or leakage, the voltage of one of the terminals of the display will vary with respect to the voltage at the plurality of second terminals of the display.

20 33. The battery tester of claim 32, wherein the non-linear device will switch states causing the voltage at one of the second electrodes of the display to become negative with respect to the voltage at the first terminal of the display to cause a change in color of the display to indicate that the battery has lost a predetermined amount of capacity.

25 34. A battery tester, comprises:  
a voltage controlled display;  
a first voltage divider having a terminal coupled to a terminal of the voltage controlled display; and

a second voltage divider having a terminal couple to a second  
30 terminal of the voltage controlled display, with the second voltage divider comprising:

a switch device coupled to the voltage controller display such that

when activated causes current to flow through the second voltage divider to provide a potential difference across the voltage controlled display.

35. The battery tester of claim 34, wherein the display is an electrophoretic display.

5 36. The battery tester of claim 34, wherein the switch device is a manually activated switch.

37. A method of fabricating a battery tester on a battery comprises forming a first voltage divider over a sidewall of the battery; and forming a plurality of parallel battery tester elements including a voltage controlled display having a first terminal coupled to the first voltage divider; and

10

forming a second voltage divider coupled in parallel with the first voltage divider and coupled to a second terminal of the voltage controlled display, with the second voltage divider including a non-linear device to control changing of an indication of battery capacity in the display.

15

38. The method of claim 37, wherein forming a first voltage divider comprises:

printing a material having a resistivity characteristic over the sidewall of the battery.

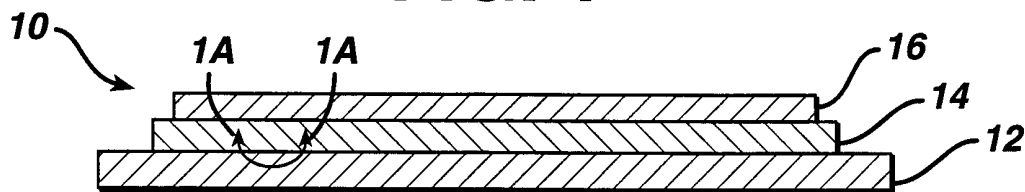
20 39. The method of claim 37, wherein forming tester elements comprises: disposing a conductive layer over the resistive material; and providing a electrophoretic material over the conductive material; providing a second conductor over the electrophoretic material.

40. The method of claim 37, wherein forming a second voltage divider having an non-linear element comprises:

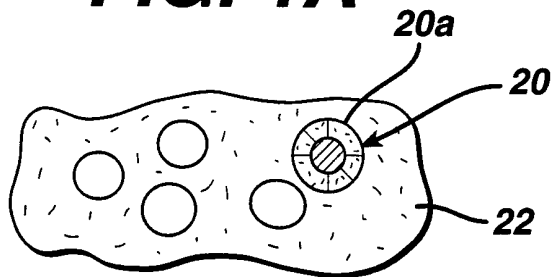
25

forming a metal-insulator-metal diode over the sidewall of the battery.

**FIG. 1**



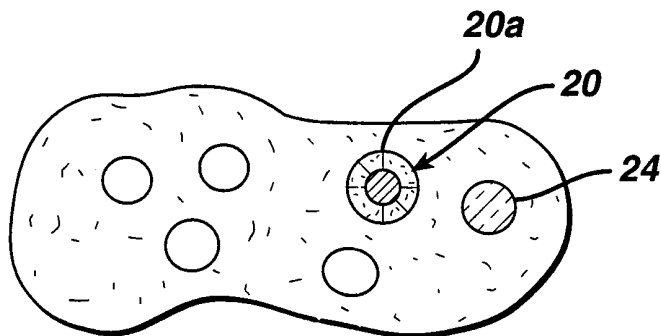
**FIG. 1A**



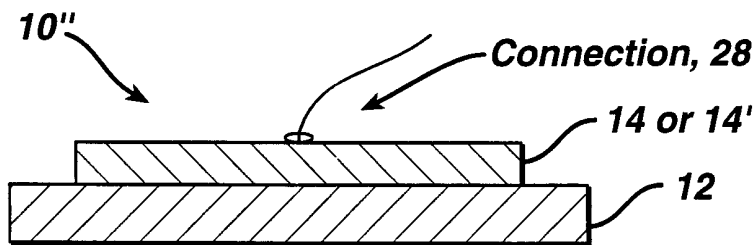
**FIG. 2**



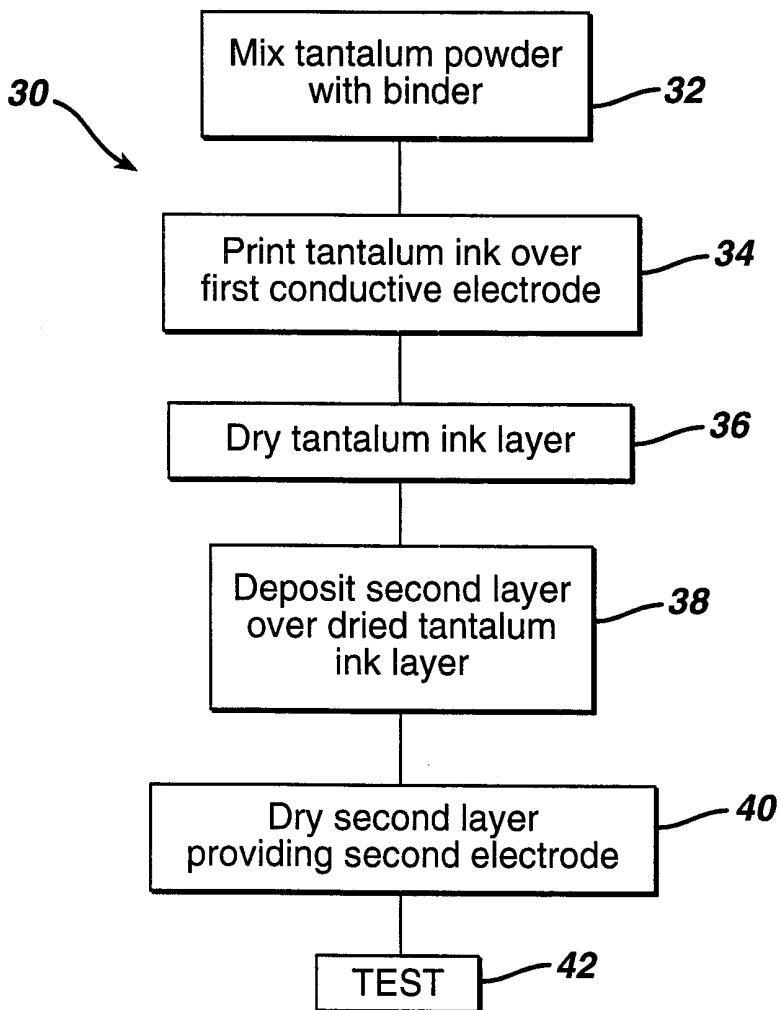
**FIG. 2A**



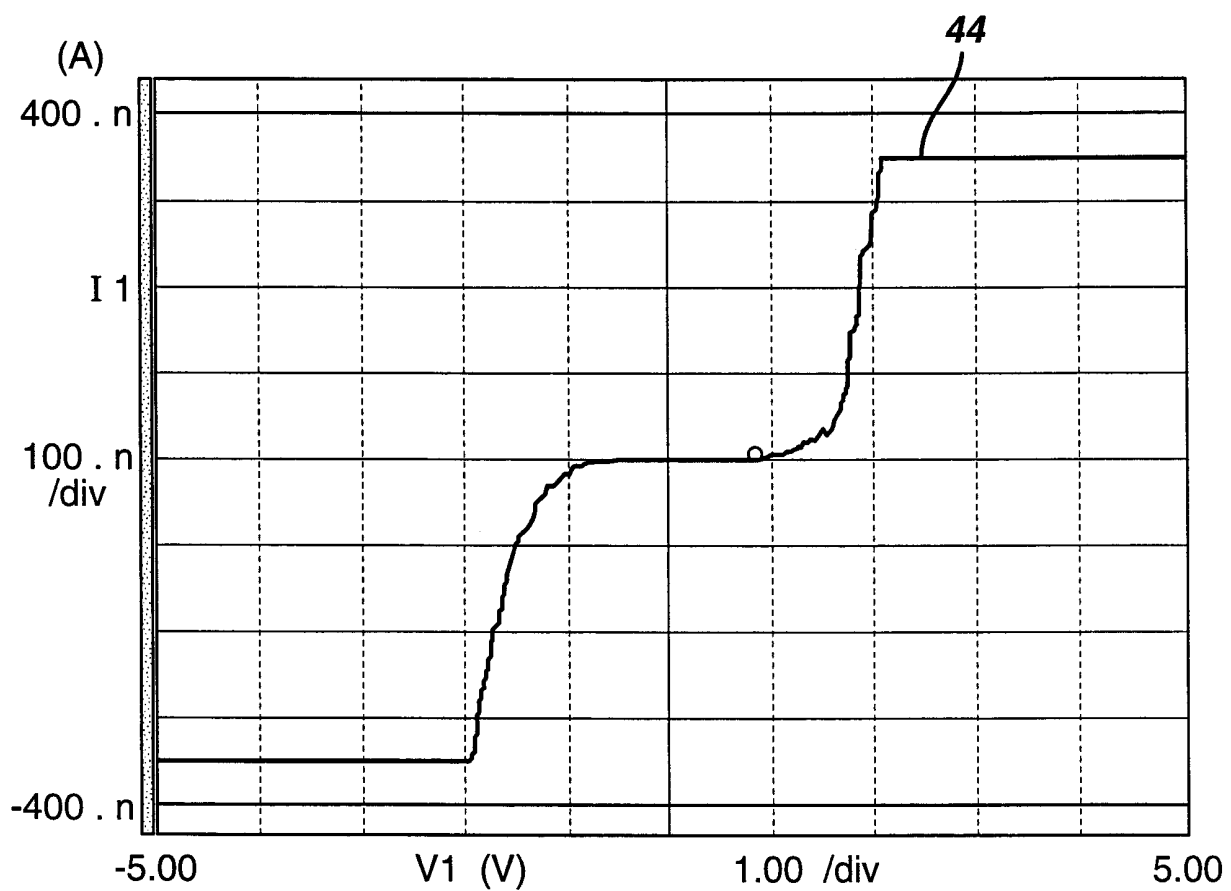
**FIG. 3**



**FIG. 4**

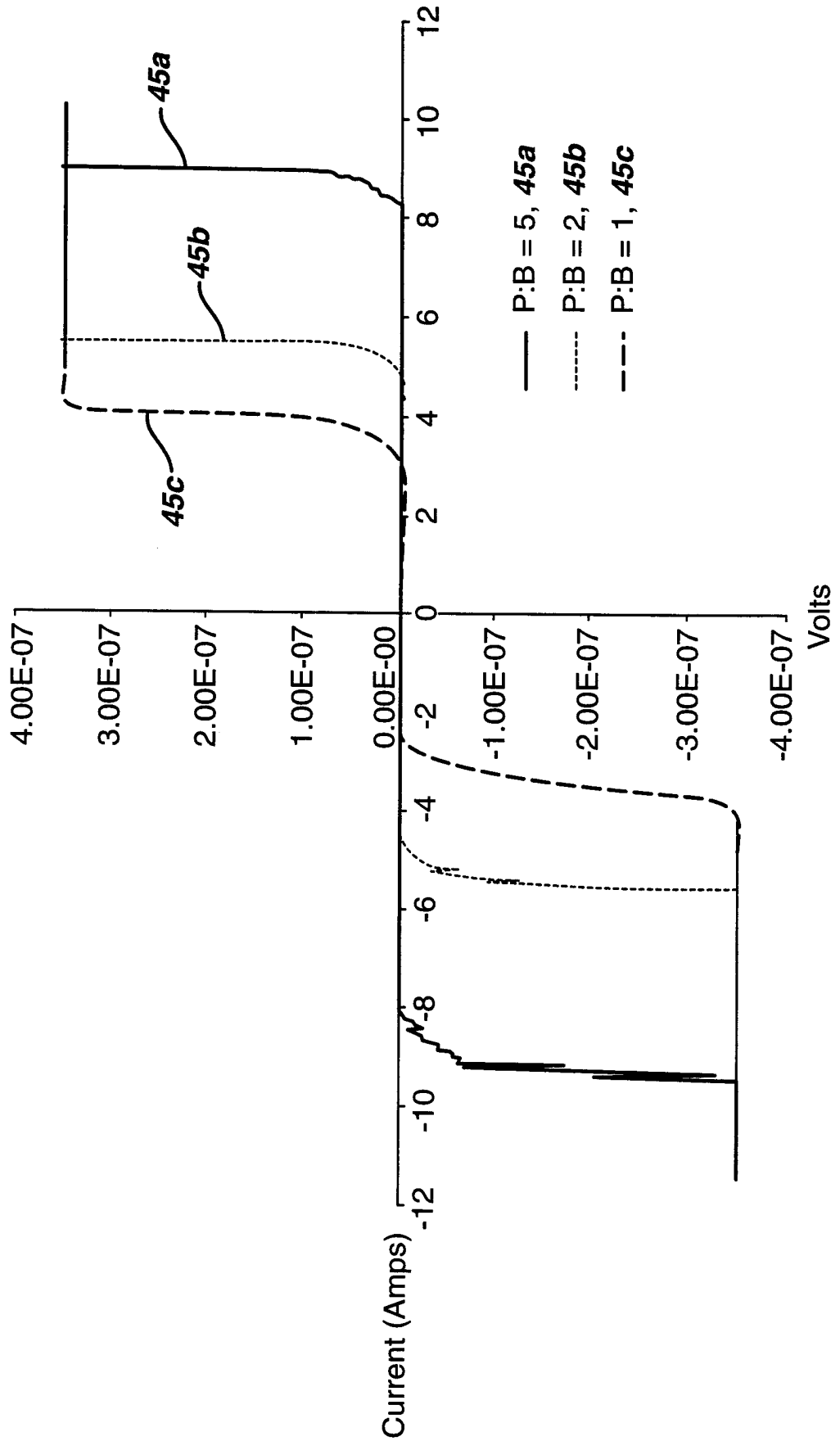


**FIG. 5A**



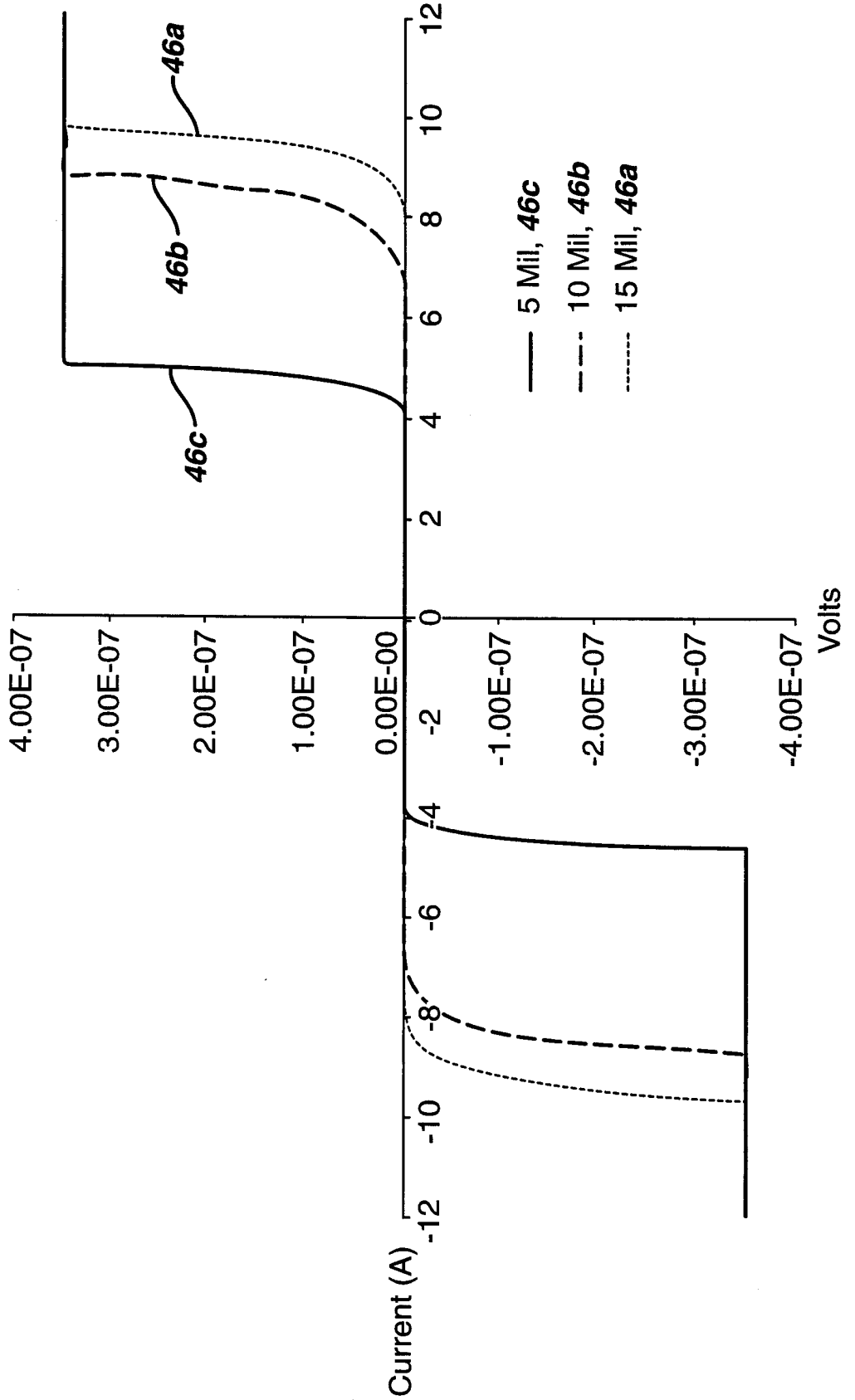
**FIG. 5B**

MIM Varistors Printed with Different P:B Ratios  
Wet Thickness = 15 MIL



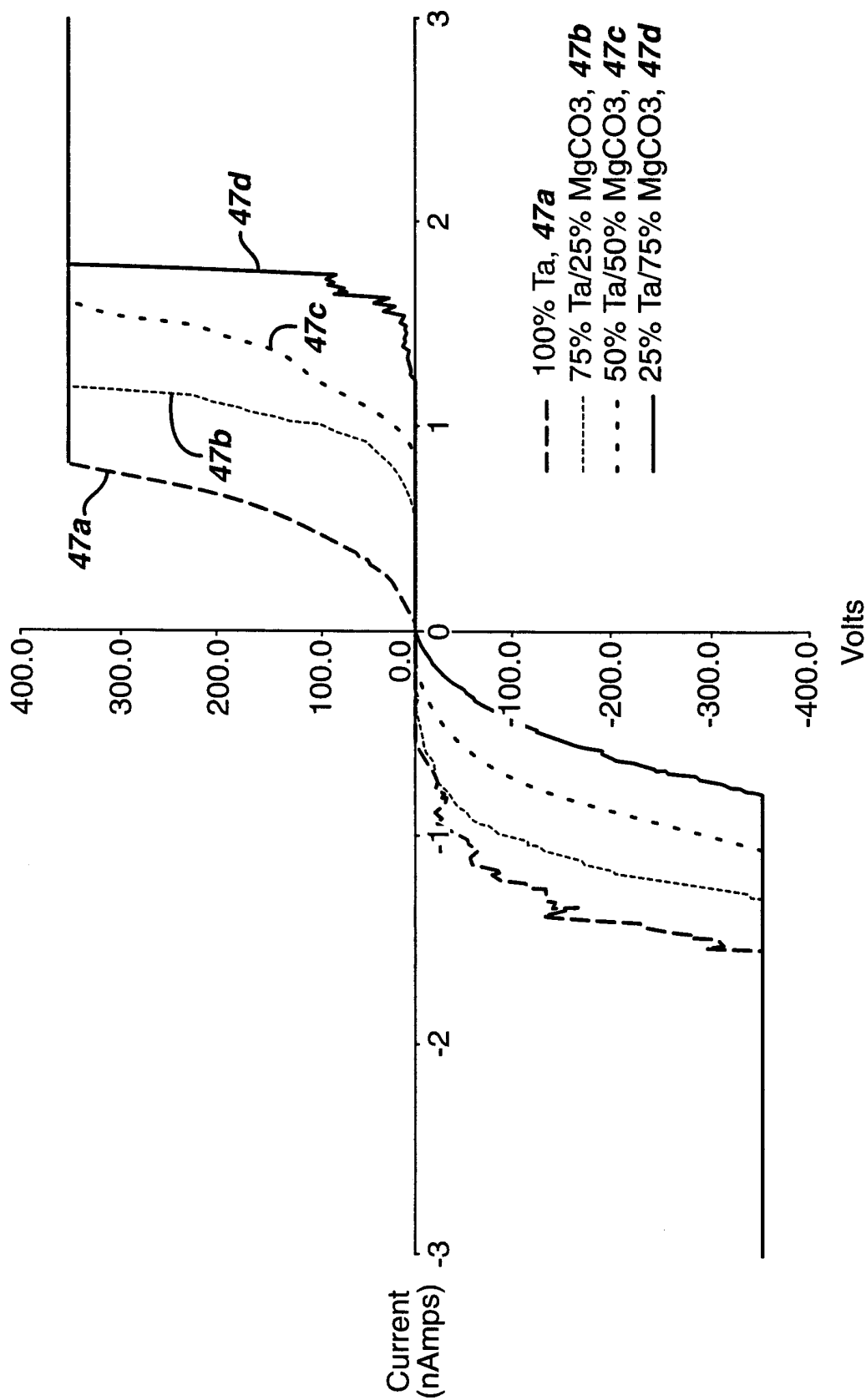
**FIG. 5C**

MIM Varistors Printed at Different Thickness  
Ink: Untreated tantalum mixed with binder in an 8:1 ratio

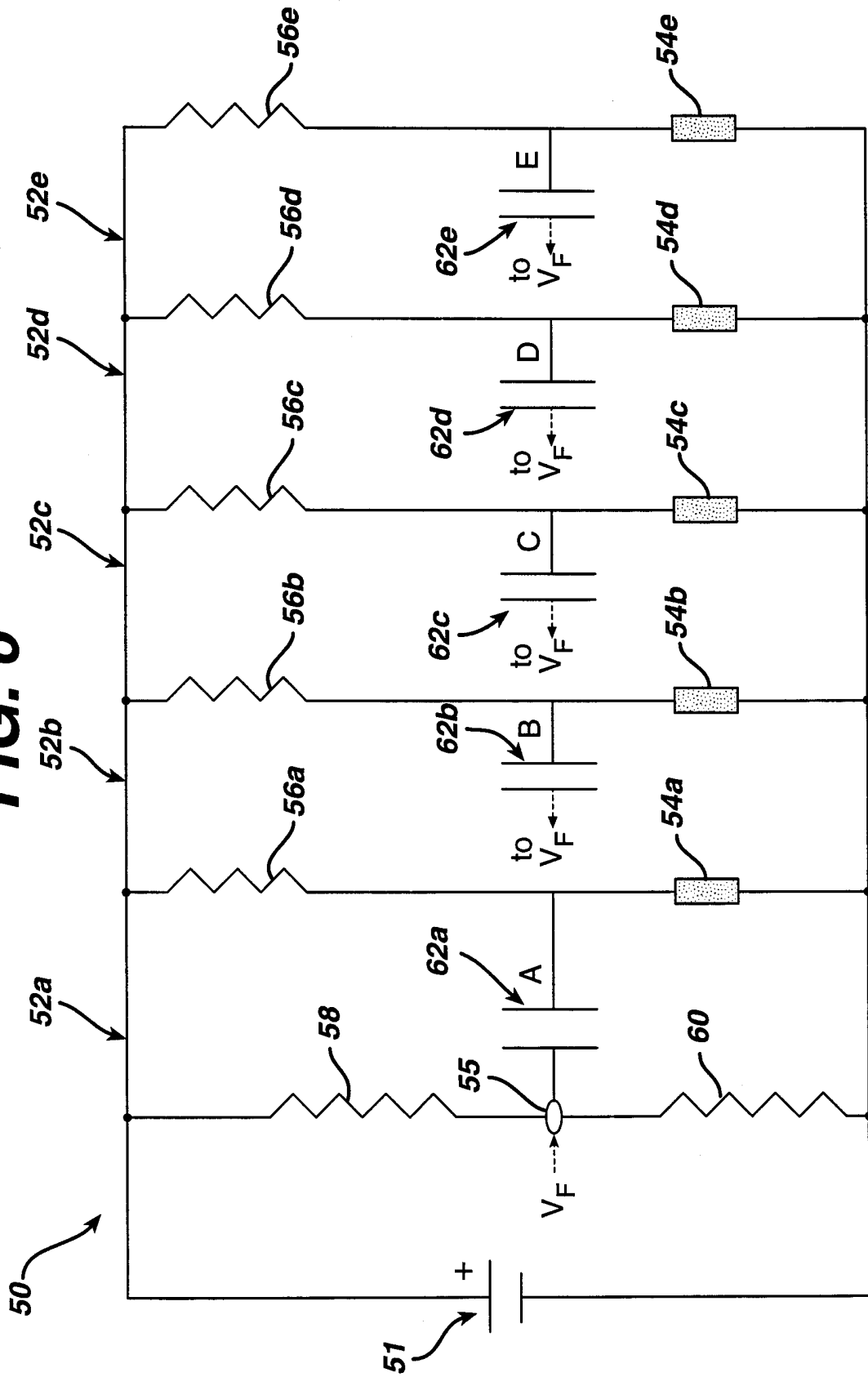


**FIG. 5D**

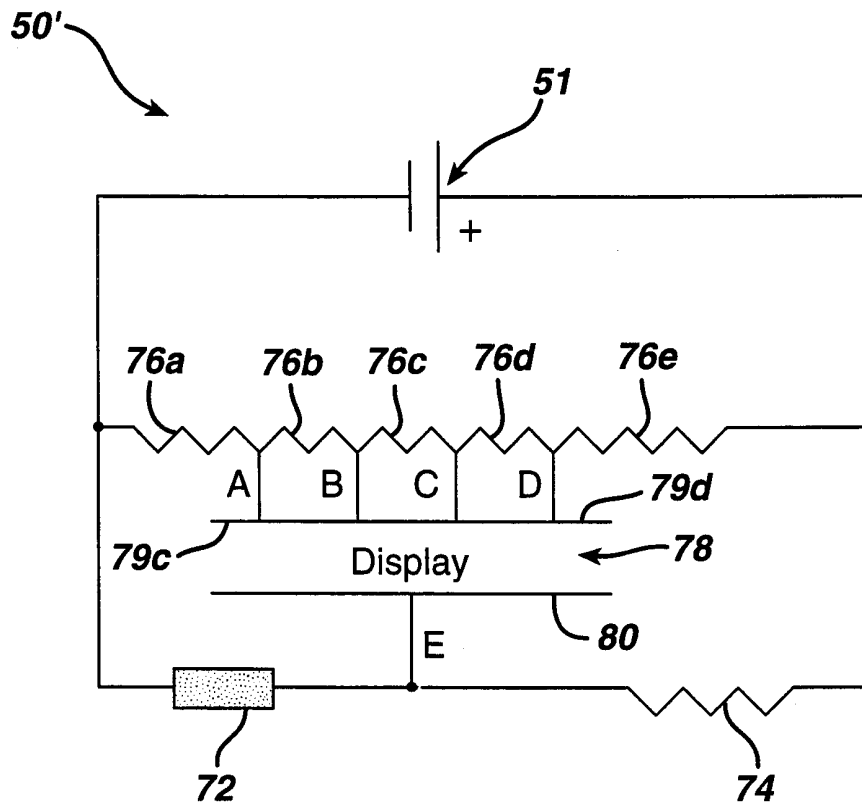
Addition of MgCO<sub>3</sub> to Varistor



**FIG. 6**

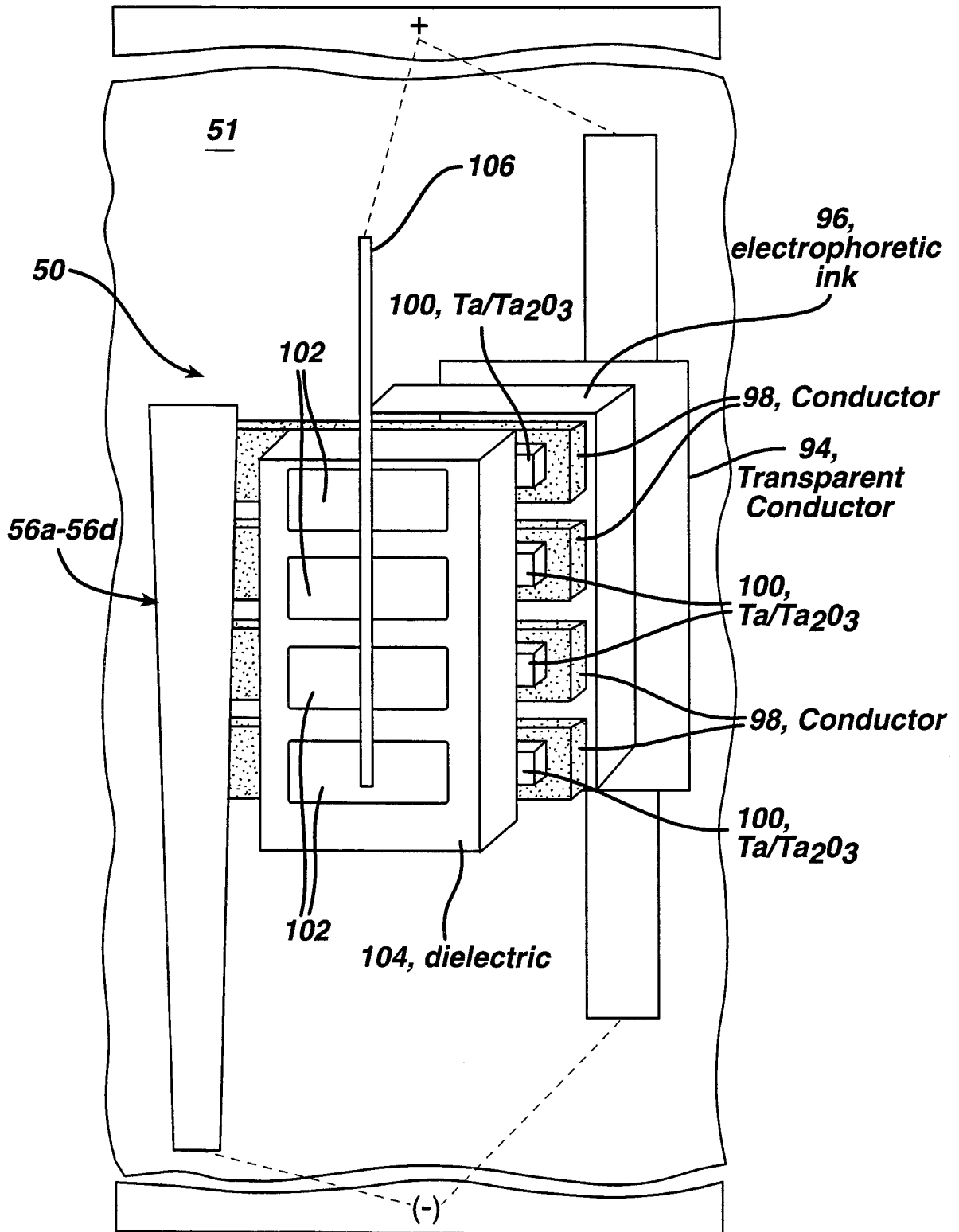


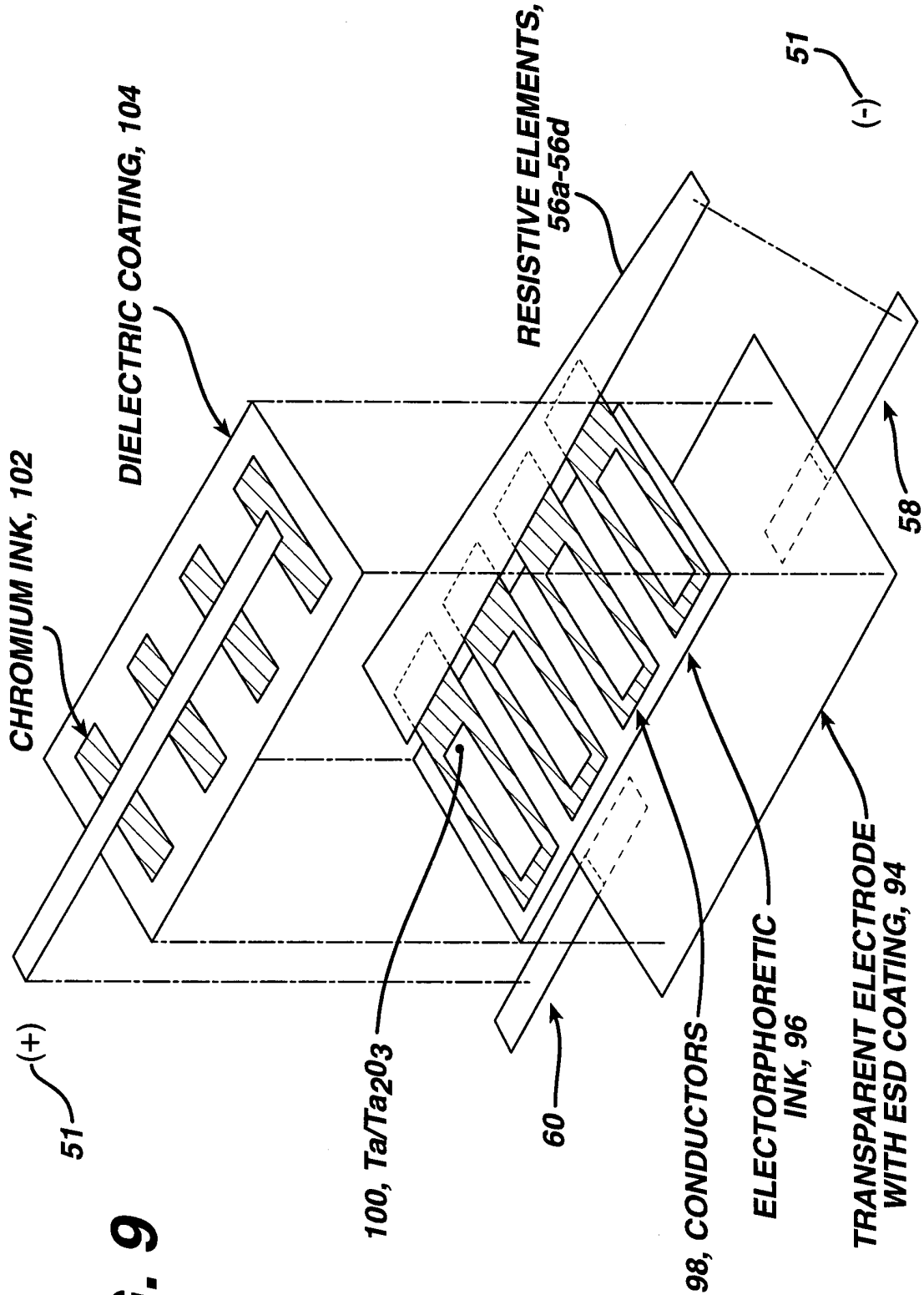
**FIG. 7**



9/15

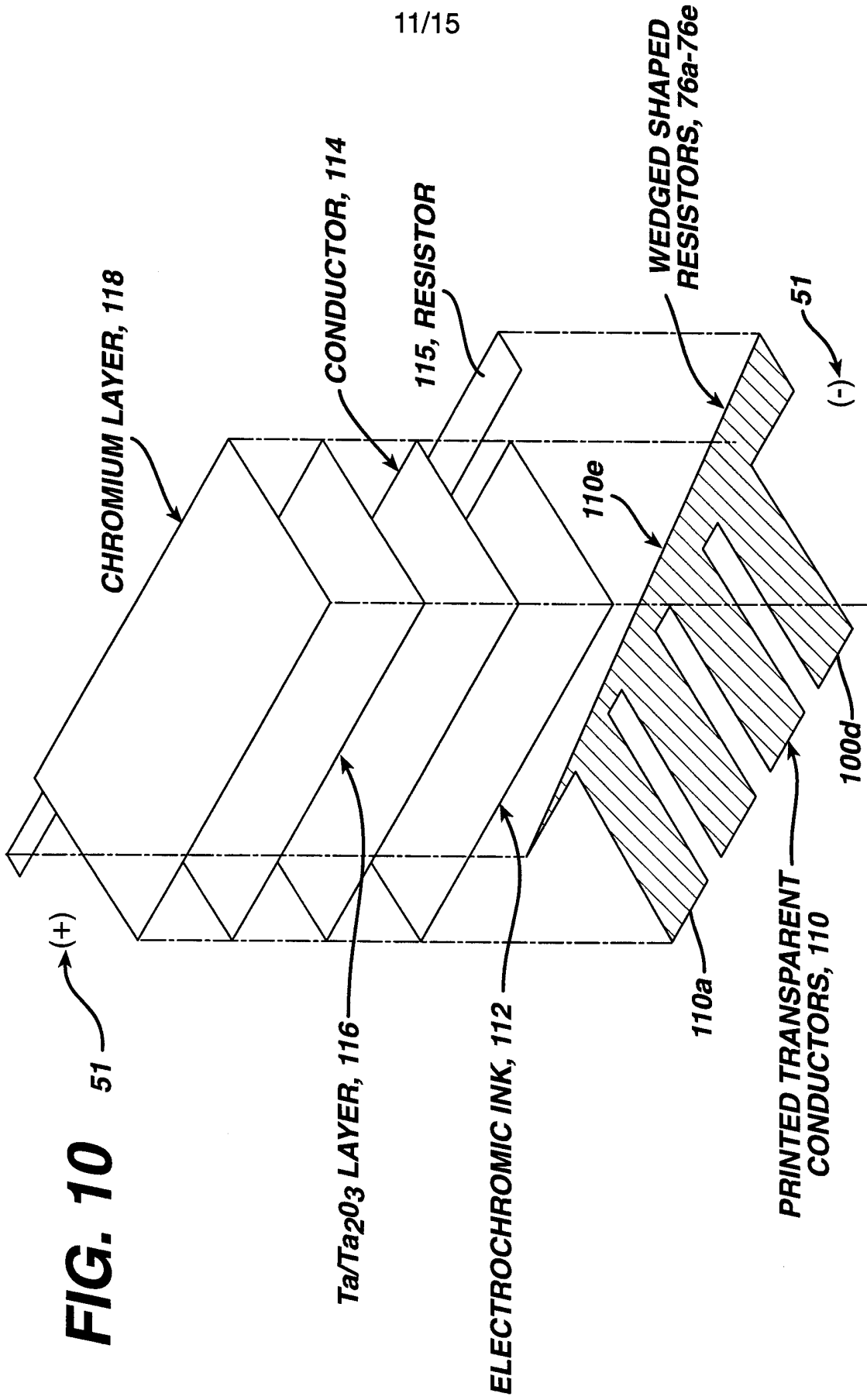
**FIG. 8**





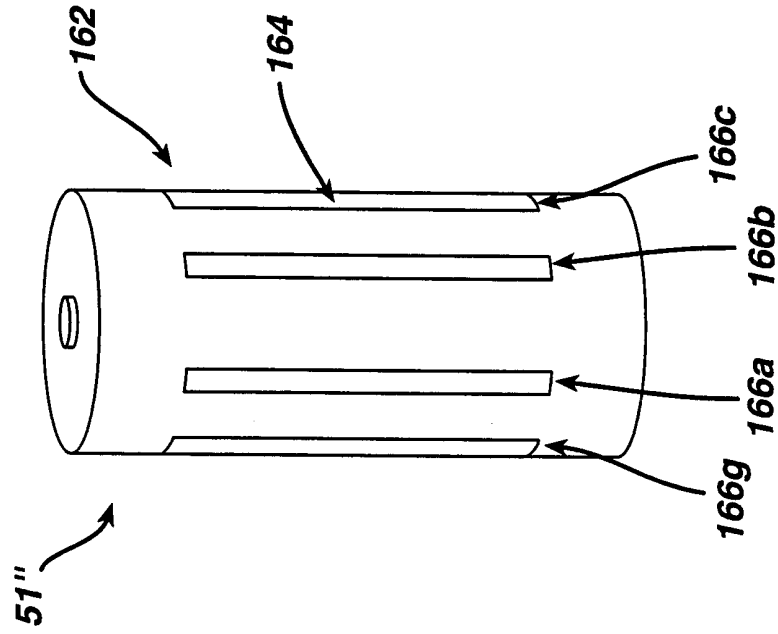
**FIG. 9**

11/15

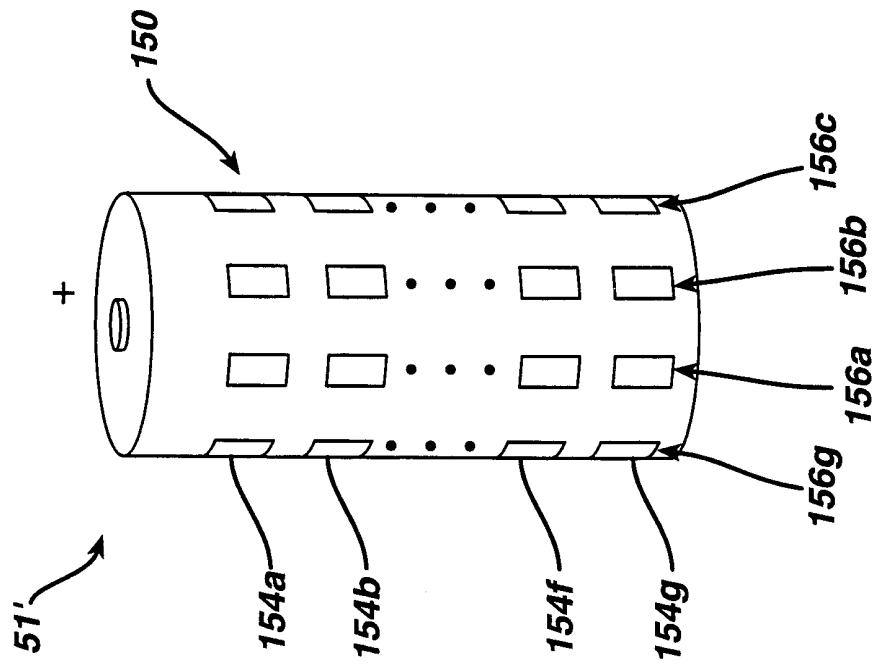


**FIG. 10**

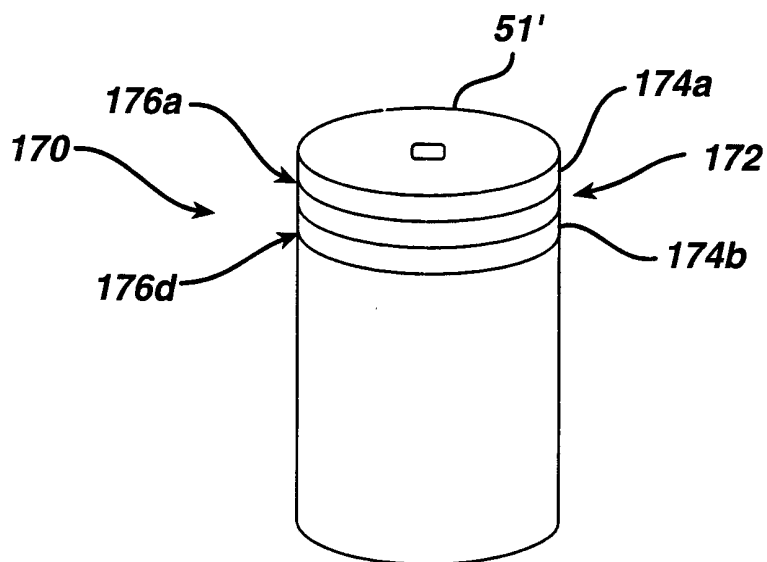
**FIG. 12**



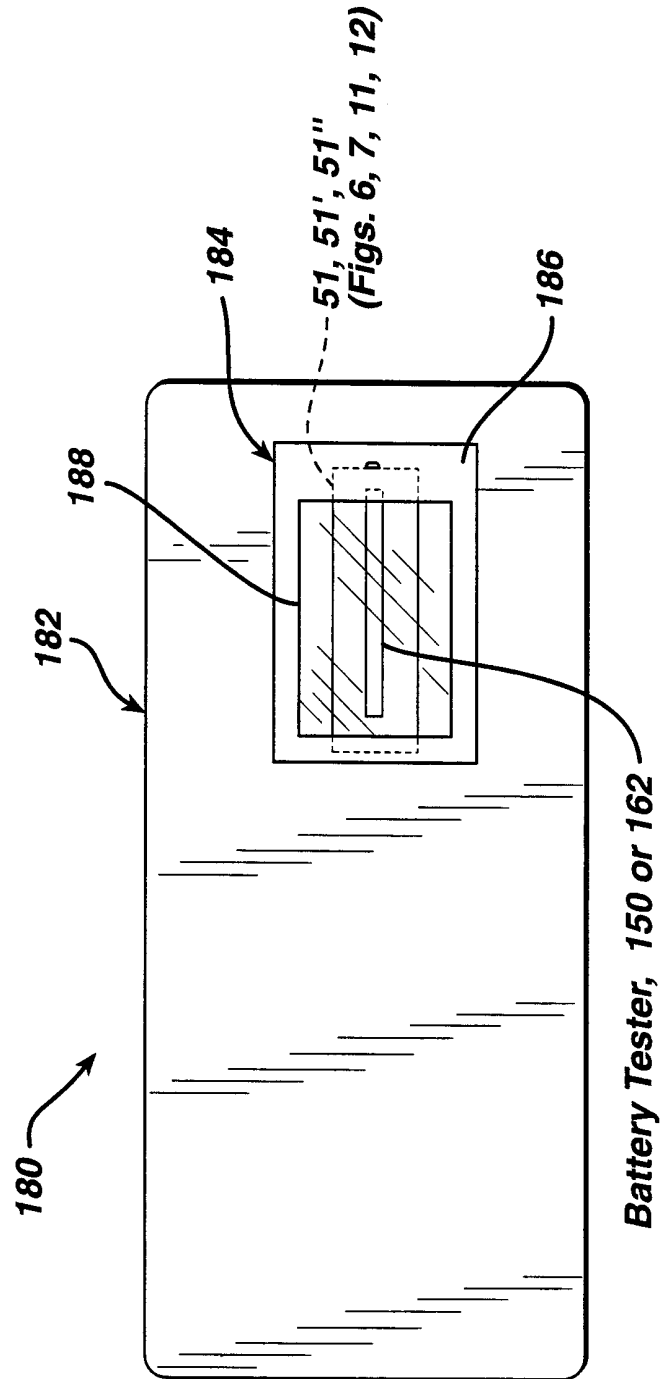
**FIG. 11**



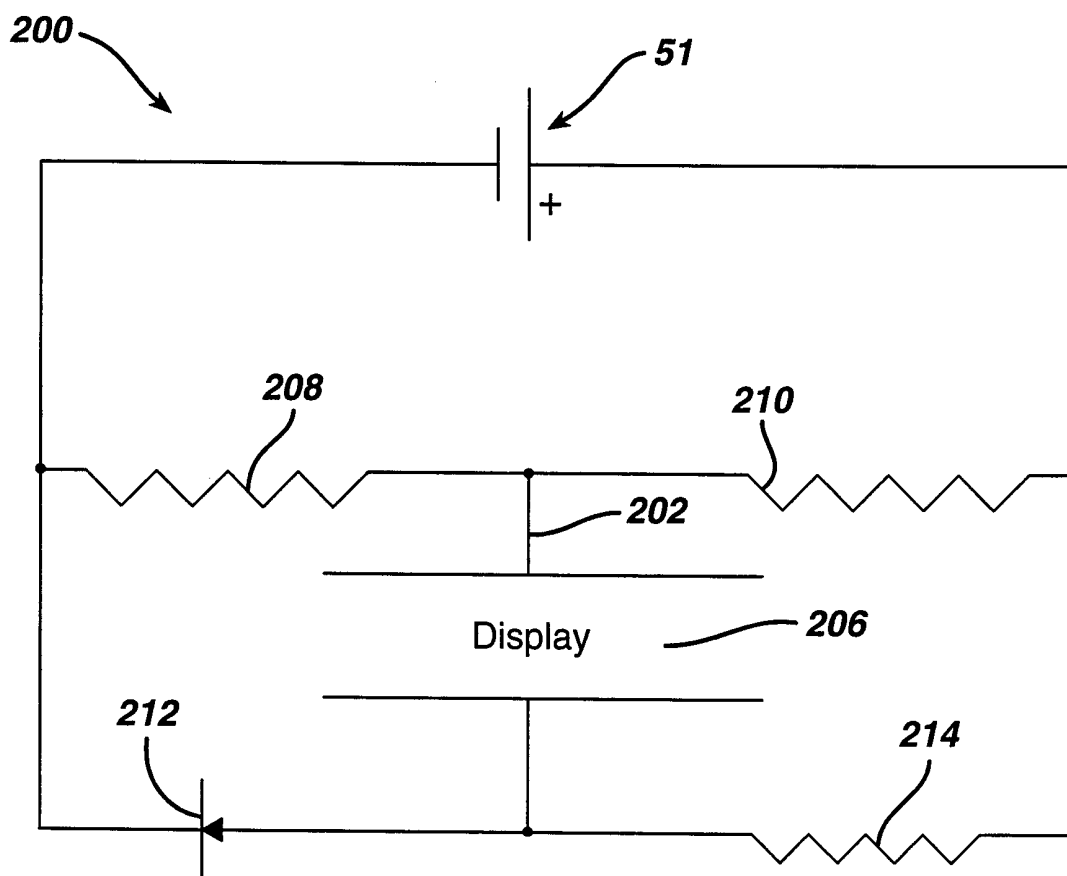
**FIG. 13**



**FIG. 14**



**FIG. 15**





## INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 00/09726

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 010, no. 380 (P-528), 19 December 1986 (1986-12-19) & JP 61 169781 A (CANON INC), 31 July 1986 (1986-07-31)	5, 8, 9, 11, 12, 14, 15, 34, 36
A	abstract	3, 16, 19, 20, 22-24
X	EP 0 501 609 A (MITSUBISHI ELECTRIC CORP) 2 September 1992 (1992-09-02)	1
A	column 3, line 48 -column 7, line 39; claims 1-13	6
E	WO 00 26761 A (E INK CORP) 11 May 2000 (2000-05-11) page 4, line 26 -page 5, line 11 page 11, line 17 -page 14, line 30 page 18, line 8 -page 20, line 6 page 24, line 5-28; claims 1-21	1-3, 5-25
A	DATABASE INSPEC 'Online! INSTITUTE OF ELECTRICAL ENGINEERS, STEVENAGE, GB; PARK J ET AL: "All printed bistable reflective displays: Printable electrophoretic ink and all printed metal-insulator-metal diodes" Database accession no. 6408835 XP000934069 abstract & FLAT-PANEL DISPLAY MATERIALS - 1998. SYMPOSIUM, FLAT-PANEL DISPLAY MATERIALS - 1998. SYMPOSIUM, SAN FRANCISCO, CA, USA, 13-17 APRIL 1998, pages 211-217, 1998, Warrendale, PA, USA, Mater. Res. Soc, USA ISBN: 1-55899-414-9	5-7, 17, 18, 25, 37-40
A	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 01, 29 January 1999 (1999-01-29) & JP 10 268798 A (SANYO ELECTRIC CO LTD), 9 October 1998 (1998-10-09) abstract	5-7, 37-40
A	PATENT ABSTRACTS OF JAPAN vol. 005, no. 154 (P-082), 29 September 1981 (1981-09-29) & JP 56 087021 A (MATSUSHITA ELECTRIC IND CO LTD), 15 July 1981 (1981-07-15) abstract	5, 16, 25
	-/--	

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 00/09726

**C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT**

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 11360 A (EVEREADY BATTERY INC) 27 March 1997 (1997-03-27)	1
A	page 18, line 1 -page 23, line 30; claims 1-20	4,26,34, 37
A	----	
A	US 5 428 370 A (KNAPP ALAN G ET AL) 27 June 1995 (1995-06-27) column 1, line 26-40 column 7, line 4 -column 8, line 51 column 11, line 42 -column 14, line 24	5-7, 37-40
A	----	
A	PATENT ABSTRACTS OF JAPAN vol. 013, no. 471 (P-949), 25 October 1989 (1989-10-25) & JP 01 185462 A (MATSUSHITA ELECTRIC IND CO LTD), 25 July 1989 (1989-07-25) abstract	34,36
	-----	

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 00/09726

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9905745 A	04-02-1999	AU 9129398 A EP 1000443 A	16-02-1999 17-05-2000
JP 08203567 A	09-08-1996	NONE	
JP 61169781 A	31-07-1986	NONE	
EP 0501609 A	02-09-1992	JP 4262277 A DE 69211032 D DE 69211032 T US 5256500 A	17-09-1992 04-07-1996 02-10-1996 26-10-1993
WO 0026761 A	11-05-2000	AU 1811300 A	22-05-2000
JP 10268798 A	09-10-1998	NONE	
JP 56087021 A	15-07-1981	NONE	
WO 9711360 A	27-03-1997	US 5654640 A AU 6968496 A	05-08-1997 09-04-1997
US 5428370 A	27-06-1995	DE 69216700 D DE 69216700 T EP 0523797 A JP 8022022 A	27-02-1997 10-07-1997 20-01-1993 23-01-1996
JP 01185462 A	25-07-1989	NONE	