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[Continued on next page]

(54) Title: A HUMIDITY SENSOR DEVICE

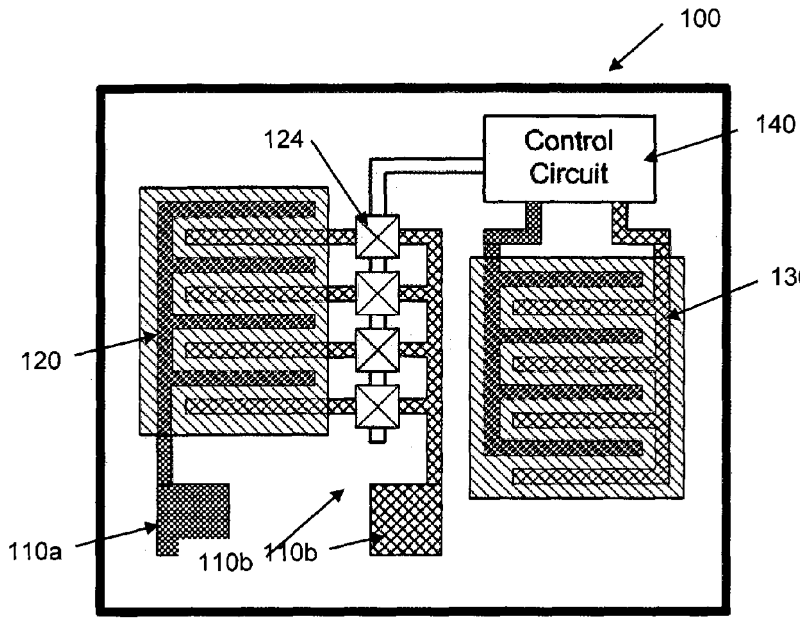

FIG. 3

(57) **Abstract**: The present invention relates to a humidity sensor device. The humidity sensor device (100) comprises of at least two contact pads (110), a sensing capacitor (120), a reference capacitor (130), and a control circuit (140). The sensing capacitor (120) is an interdigital capacitor and it is divided into at least two sub- capacitors (120a, 120b, 120c, 120n). The control unit (140) determines the number of sub capacitors (120a, 120b, 120c, 120n) to be connected to the contact pads (110) by measuring the capacitance value of the reference capacitor (130) and controlling the switches (124) of the sensing capacitor (120) based on the variation in sensing material thickness of the reference capacitor (130).

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Declarations under Rule 4.17:

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— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

A HUMIDITY SENSOR DEVICE

FIELD OF INVENTION

The present invention relates to a sensor device and more particularly to a capacitive humidity sensor device.

BACKGROUND OF THE INVENTION

A capacitive humidity sensor device is used for sensing humidity in an environment. The capacitive humidity sensor device (**10**) comprises of interdigital electrodes (**11**) deposited on an isolator material (**12**) and covered by a sensing material (**13**) such as Polyimide. **FIGS. 1** show a vertical sectional view and a top view of a typical capacitive humidity sensor device (**10**).

A change in humidity of an environment changes the permittivity of the sensing material (**13**) and thus, causing a change in capacitance value of the humidity sensor device (**10**). The capacitance value of the humidity sensor device (**10**) is determined by the thickness of the sensing material used (***t***), width of the interdigital fingers (***w***), space between adjacent interdigital fingers (***s***), number of interdigital fingers (***N***) and the permittivity of the sensing material used (ε_r) which itself is a function of temperature (***T***) and the relative humidity of the environment (***RH***).

The interdigital electrodes (**11**) of the capacitive humidity sensor device (**10**) are typically fabricated by using advanced lithography technique. The fabrication tolerance on the width of the interdigital fingers (***w***) and the space in between the interdigital fingers (***s***) is very small; however, since the sensing material (**13**) is typically deposited using spin coating technique, the variation on the thickness of the sensing material used (***t***) is large. As a result, the sensing material (**13**) has generally a smaller thickness at the center (**13a**) than the edge (**13b**) of a wafer as shown in **FIG. 2** or vice versa. The variation in the thickness of the sensing material (**13**) causes varying response capacitance value from one wafer to another wafer and/or from one sensor device to another sensor device.

Hence, each capacitive humidity sensor device (**10**) needs to be calibrated before it can be used. In this regard, the capacitive humidity sensor device (**10**) is typically calibrated in few known temperature and relative humidity points, compensated by a readout circuit or by referring to a reference capacitor. Examples of such capacitive humidity sensor are provided by US Patent Nos. 7,222,531 and 7,032,448.

US Patent No. 7,222,531 relates to a capacitive humidity sensor for detecting a humidity change which includes a first sensor element having a first capacitance, a second sensor element having a second capacitance and connected in series with the first sensor element, and a humidity sensitive layer having a dielectric constant, which changes in accordance with humidity. The first and the second capacitances change with respect to the humidity change at a different rate. The humidity is detected using the different capacitances of the first and the second sensor elements. The humidity sensitive layer is formed to each sensor element so that each sensor element can be effectively protected.

US Patent No. 7,032,448 relates to a capacitive humidity sensor which includes a detection portion and a reference portion. The detection portion includes detection electrodes and a moisture sensitive film. The reference portion includes reference electrodes and a moisture permeation film as a capacitance adjusting film. The capacitive humidity sensor detects humidity by converting a capacitance difference between a capacitance of the detection electrodes and a capacitance of the reference electrodes to an electric signal by using a capacitance-voltage conversion circuit. The moisture permeation film reduces offset voltage of the capacitive humidity sensor.

Therefore, there is a need to provide a capacitive humidity sensor device capable of self-calibrating without having to provide a relative humidity environment.

SUMMARY OF INVENTION

The present invention relates to a humidity sensor device (**100**). The humidity sensor device (**100**) comprises of at least two contact pads (**110**), a sensing capacitor (**120**), and a reference capacitor (**130**). The sensing capacitor (**120**) further comprises an interdigital electrodes (**121**) fabricated on a substrate (**150**) and a layer of humidity sensitive material (**122**) covering on top of the interdigital electrodes

(**121**), and wherein the sensing capacitor (**120**) is divided into at least two sub-capacitors (**120a**, **120b**, **120c**, **120n**), and wherein one terminal of each sub-capacitor (**120a**, **120b**, **120c**, **120n**) is connected to one of the at least two contact pads (**110a**), and wherein another terminal of each sub-capacitor (**120a**, **120b**, **120c**, **120n**) is connected to one of the at least two contact pads (**110b**) through a switch (**124**). The reference capacitor (**130**) further comprises an interdigital electrodes (**131**) fabricated on a substrate (**150**), a layer of humidity sensitive material (**132**) covering on top of the interdigital electrodes (**131**), and a package sealant (**133**) provided on the humidity sensitive layer (**132**), and wherein the reference capacitor (**130**) is connected to the control unit (**140**). The humidity sensor device (**100**) further comprises a control circuit (**140**), and wherein the control unit (**140**) provides a signal to close or open the switches (**124**) of the sensing capacitor (**120**) by determining the variation in sensing material thickness of the reference capacitor (**130**).

Preferably, an isolation layer which is made of oxide material is provided in between the substrate (**150**) and the capacitors (**120**, **130**).

Preferably, the humidity sensitive material (**121**, **132**) is made of polyimide.

Preferably, the package sealant (**133**) is made out of plastic, glob-top or the like.

A method of calibrating a humidity sensor device (**100**) is also provided in the present invention. The method comprises the steps of initializing the sensor device (**100**), measuring capacitance value of a reference capacitor (**130**) by a control unit (**140**), comparing the measured capacitance value of a reference capacitor (**130**) with a predetermined expected capacitance value, determining the number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) to be enabled, and closing and/or opening a plurality of switches (**124**) to connect the determined number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) to be enabled to the contact pads (**110**).

Preferably, if the measured capacitance value of the reference capacitor (**130**) is equivalent to the predetermined expected capacitance value, the control unit (**140**) enables a predetermined number of the sub-capacitors (**120a**, **120b**, **120c**, **120n**).

Preferably, if the measured capacitance value of the reference capacitor (**130**) is larger or lesser than the predetermined expected capacitance value, the control unit (**140**) determines the number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) by predetermining the expected capacitance value of the sensing capacitor (**120**), and calculating the number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) to be enabled by using the variation in the thickness of the sensing material of the reference capacitor (**130**).

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

FIG. 1a shows a vertical sectional view of a typical humidity sensor device (**10**).

FIG. 1b shows a top view of a typical humidity sensor device (**10**).

FIG. 2 shows a vertical sectional view of a plurality of humidity sensor devices (**10**) fabricated on a wafer.

FIG. 3 shows architecture of a humidity sensor device (**100**) in accordance with an embodiment of the present invention.

FIG. 4 shows an equivalent schematic diagram of the humidity sensor device (**100**) of **FIG. 3**.

FIG. 5 shows a vertical sectional view of a sensing capacitor (**120**) and a reference capacitor (**130**) of the humidity sensor device (**100**) of **FIG. 3**.

FIG. 6 shows a flowchart of a calibration process of the humidity sensor device (**100**) of **FIG. 3**.

FIG. 7 shows a graph of a simulated response of the humidity sensor device (**100**) of **FIG. 3**.

DESCRIPTION OF THE PREFFERED EMBODIMENT

A preferred embodiment of the present invention will be described herein below with reference to the accompanying drawings. In the following description, well known functions or constructions are not described in detail since they would obscure the description with unnecessary detail.

Referring now to **FIG. 3**, there is shown a humidity sensor device (**100**) in accordance with an embodiment of the present invention. Generally, the humidity sensor device (**100**) comprises of at least two contact pads (**110**), a sensing capacitor (**120**), a reference capacitor (**130**) and a control unit (**140**). Preferably, the sensing capacitor (**120**) and the reference capacitor (**130**) are fabricated on the same substrate (**150**) and in proximity to each other. Thus, the sensing capacitor (**120**) and the reference capacitor (**130**) have similar variation of the thickness of the sensing material (***t***), the width (***w***) and spacing (***s***) of the interdigital electrodes when fabricated. Moreover, an isolation layer is preferably provided in between substrate (**150**) and the capacitors (**120**, **130**). The isolation layer is suitably made of oxide material. **FIG. 4** shows an equivalent schematic diagram of the humidity sensor device (**100**) to provide a better understanding of the interconnection between the contact pads (**110**), the sensing capacitor (**120**), the reference capacitor (**130**) and the control unit (**140**).

The two contact pads (**110**) allow connectivity to an external sensing circuit to measure the capacitance value based on the changes in humidity of an environment. The contact pads (**110**) are suitably made out of any conductive material such as aluminium, copper, alloy and the like.

The sensing capacitor (**120**) is an interdigital capacitor which is used for sensing humidity in an environment. The sensing capacitor (**120**) comprises an interdigital electrodes (**121**) fabricated on a substrate (**150**) and a layer of humidity sensitive material (**122**) covering on top of the interdigital electrodes (**121**) as shown in **FIG. 5**. Preferably, the humidity sensitive material (**121**) is made of polyimide. The sensing capacitor (**120**) is divided into a plurality of sub-capacitors (**120a**, **120b**, **120c**, **120n**). One terminal of each sub-capacitor (**120a**, **120b**, **120c**, **120n**) is connected to a contact pad (**110a**) for connection to an external sensing circuit. Another terminal of each sub-capacitor (**120a**, **120b**, **120c**, **120n**) is connected to another contact pad (**110b**) through a switch (**124**). Each switch (**124**) is controlled by the control unit (**140**). When the switch (**124**) is closed, the sub-capacitor (**120a**, **120b**, **120c**, **120n**) completes a connection to an external sensing circuit. Thus, when more than one switch (**124**) is closed, the sub-capacitors (**120a**, **120b**, **120c**, **120n**) are connected in parallel to one another.

The reference capacitor (**130**) is an interdigital capacitor and provides a reference capacitance value for the sensing capacitor (**120**). The capacitance value of the reference capacitor (**130**) does not change with respect to a change in humidity. The reference capacitor (**130**) comprises of an interdigital electrodes (**131**) fabricated on a substrate (**150**), a layer of humidity sensitive material (**132**) covering on top of the interdigital electrodes (**131**), and a package sealant (**133**) provided on the humidity sensitive layer (**132**) as shown in **FIG. 5**. Preferably, the humidity sensitive material (**132**) is polyimide and the package sealant (**133**) is made out of plastic, glob-top or the like. The reference capacitor (**130**) is fabricated in proximity to the sensing capacitor (**120**) and it is connected to the control unit (**140**).

The control unit (**140**) provides a signal to close or open the switches (**124**) connected to the sub-capacitors (**120a**, **120b**, **120c**, **120n**). The control unit (**140**) decides to close or open the switches (**124**) by referring to the reference capacitor (**130**).

Referring now to **FIG. 6**, there is provided a flowchart of calibrating the humidity sensor device (**100**) of **FIG. 3**. Initially, as in step **201**, the sensor device (**100**) is powered up and initialized. Thereon, as in step **202**, the control unit (**140**) measures the capacitance value of the reference capacitor (**130**) as the reference capacitance value (C_{ref}). In step **203**, the control unit (**140**) compares the reference capacitance value (C_{ref}) with a predetermined expected capacitance value (C_{exp}). The predetermined expected capacitance value (C_{exp}) is calculated based on the design parameters of the reference capacitor (**130**) using the formula below:

$$C_{exp} = f\,(N_{exp}, T_{exp}, t_{exp}, w_{exp}, s_{exp}, \varepsilon_{exp})$$

wherein f is a function notation, N_{exp} is number of interdigital fingers of the reference capacitor, T_{exp} is temperature, t_{exp} is the thickness of the sensing material of the reference capacitor, w_{exp} is width of the interdigital fingers of the reference capacitor,

s_{exp} is space between adjacent interdigital fingers of the reference capacitor and ε_{exp} is permittivity of the sensing material of the reference capacitor. By comparing C_{ref} and C_{exp}, the variation in the thickness of the sensing material of the reference capacitor (t_{ref}) can be determined.

In decision **204**, the control unit (**140**) determines whether the reference capacitance value (C_{ref}) is equivalent, larger or lesser than the predefined expected capacitance value (C_{exp}).

If the measured C_{ref} is equivalent to C_{exp}, then the control unit enables a predetermined number of the sub-capacitors (**120a**, **120b**, **120c**, **120n**) by using the switches (**124**) as in step **205**. This indicates that there is no variation in sensing material thickness of the humidity sensor device (**100**).

If the measured C_{ref} is larger or lesser than C_{exp}, this indicates that there is a variation in sensing material thickness when fabricated. Thus, as in step **206**, the control unit (**140**) determines the number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) by predetermining the expected capacitance value of the sensing capacitor (**120**), and calculating the number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) to be enabled by using the variation in the thickness of the sensing material of the reference capacitor (t_{ref}) in the formula below:

$$N_s = f\,(C_s, RH_{ref}, T_s, t_{ref}, w_s, s_s, \varepsilon_s)$$

wherein f is a function notation, RH_{ref} is a relative humidity of the environment of the reference capacitor (**120**), C_s is the predetermined capacitance value of the sensing capacitor (**120**), T_s is temperature, t_{ref} is the thickness of the sensing material of the reference capacitor (**130**), w_s is width of the interdigital fingers of the sensing capacitor (**120**), s_s is space between adjacent interdigital fingers of the sensing capacitor (**120**) and ε_s is permittivity of the sensing material of the sensing capacitor (**120**). Thereon, the control unit (**140**) closes and opens the switches (**124**) to enable only N_s sub-capacitors (**120a**, **120b**, **120c**, **120n**) connected to the contact pads (**110**) as in step **207**.

In order to simulate the capacitive humidity sensor device (**100**) of **FIG. 3**, the capacitive humidity sensor (**110**) was modelled using coplanar stripline (CPS) model

(Erli Chen et.al., 1997) with 200 interdigital fingers (N_s=N_{ref}=200) having 5um width (w_{exp}=5um) and 5um spacing (s_{exp}=5um) in between the fingers. Moreover, a polyimide material was used as the sensing material (**122**) with a target thickness of 3um (t_{exp}=3um). Therefore, the relative permittivity of the sensing material used is expected to vary between 3.2 and 4 with a relative humidity change from 0% to 100% (Laconte et.al. 2003).

As a result of the simulation, **FIG. 7** shows a graph of the response of the humidity sensor device (**100**). The dashed line (**310**) of the graph indicates the expected response of the sensor device while the solid line (**320**) of the graph indicates the response of the uncompensated sensor device when there is 10% variation in the thickness of the sensing material (**122**) which results in (t_{ref} = 3.3um). The response of the compensated capacitance using the sensor device (**100**) of **FIG. 3** is indicated by the dotted line (**330**). The graph reveals that if the control unit (**140**) compensates the sensor device (**100**) by decreasing the number of fingers from 200 to 196 (N_s=196), the response of the compensated sensor device (**330**) becomes closer to the expected result (**310**).

While embodiments of the invention have been illustrated and described, it is not intended that these embodiments illustrated and describe all possible forms of the invention. Rather, the words used in the specifications are words of description rather than limitation and various changes may be made without departing from the scope of the invention.

REFERENCES

1. Erli Chen and Stephen Y. Chou, "Characteristics of Coplanar Transmission Lines on Multilayer Substrates: Modeling and Experiments", *IEEE Transactions on Microwave Theory and Techniques*, vol. 45 no. 6, pp. 939-945, 1997.

2. J. Laconte, V. Wilmart, D. Flandre and J.P. Raskin, "High-Sensitivity Capacitive Humidity Sensor Using 3-Layer Patterned Polyimide Sensing Film", *Proceedings of IEEE Sensors*, vol. 1, pp. 372-377, 2003.

CLAIMS

1. A humidity sensor device (**100**) comprising:
    a) at least two contact pads (**110**),
    b) a sensing capacitor (**120**), and
    c) a reference capacitor (**130**);

characterized in that:

the sensing capacitor (**120**) further comprising an interdigital electrodes (**121**) fabricated on a substrate (**150**) and a layer of humidity sensitive material (**122**) covering on top of the interdigital electrodes (**121**), and wherein the sensing capacitor (**120**) is divided into at least two sub-capacitors (**120a**, **120b**, **120c**, **120n**), and wherein one terminal of each sub-capacitor (**120a**, **120b**, **120c**, **120n**) is connected to one of the at least two contact pads (**110a**), and wherein another terminal of each sub-capacitor (**120a**, **120b**, **120c**, **120n**) is connected to one of the at least two contact pads (**110b**) through a switch (**124**);

the reference capacitor (**130**) further comprising an interdigital electrodes (**131**) fabricated on a substrate (**150**), a layer of humidity sensitive material (**132**) covering on top of the interdigital electrodes (**131**), and a package sealant (**133**) provided on the humidity sensitive layer (**132**), and wherein the reference capacitor (**130**) is connected to the control unit (**140**); and

the humidity sensor device (**100**) further comprising a control circuit (**140**), and wherein the control unit (**140**) provides a signal to close or open the switches (**124**) of the sensing capacitor (**120**) by determining the variation in sensing material thickness of the reference capacitor (**130**).

2. A humidity sensor as claimed in claim **1**, wherein an isolation layer is provided in between substrate (**150**) and the capacitors (**120**, **130**).

3. A humidity sensor as claimed in claim **2**, wherein the isolation layer is made of oxide material.

4. A humidity sensor as claimed in claim **1**, wherein the humidity sensitive material (**121**, **132**) is made of polyimide.

5. A humidity sensor as claimed in claim **1**, wherein the package sealant (**133**) is made out of plastic, glob-top or the like.

6. A method of calibrating a humidity sensor device (**100**) as claimed in claim **1** to **5**, comprising the steps of:
   a) initializing the sensor device (**100**);
   b) measuring capacitance value of a reference capacitor (**130**) by a control unit (**140**);
   c) comparing the measured capacitance value of a reference capacitor (**130**) with a predetermined expected capacitance value;
   d) determining the number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) to be enabled; and
   e) closing and/or opening a plurality of switches (**124**) to connect the determined number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) to be enabled to the contact pads (**110**).

7. A method as claimed in step **d** of claim **6**, wherein if the measured capacitance value of the reference capacitor (**130**) is equivalent to the predetermined expected capacitance value, the control unit (**140**) enables a predetermined number of the sub-capacitors (**120a**, **120b**, **120c**, **120n**).

8. A method as claimed in step **d** of claim **6**, wherein if the measured capacitance value of the reference capacitor (**130**) is larger or lesser than the predetermined expected capacitance value, the control unit (**140**) determines the number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) by predetermining the expected capacitance value of the sensing capacitor (**120**), and calculating the number of sub-capacitors (**120a**, **120b**, **120c**, **120n**) to be enabled by using the variation in the thickness of the sensing material of the reference capacitor (**130**).

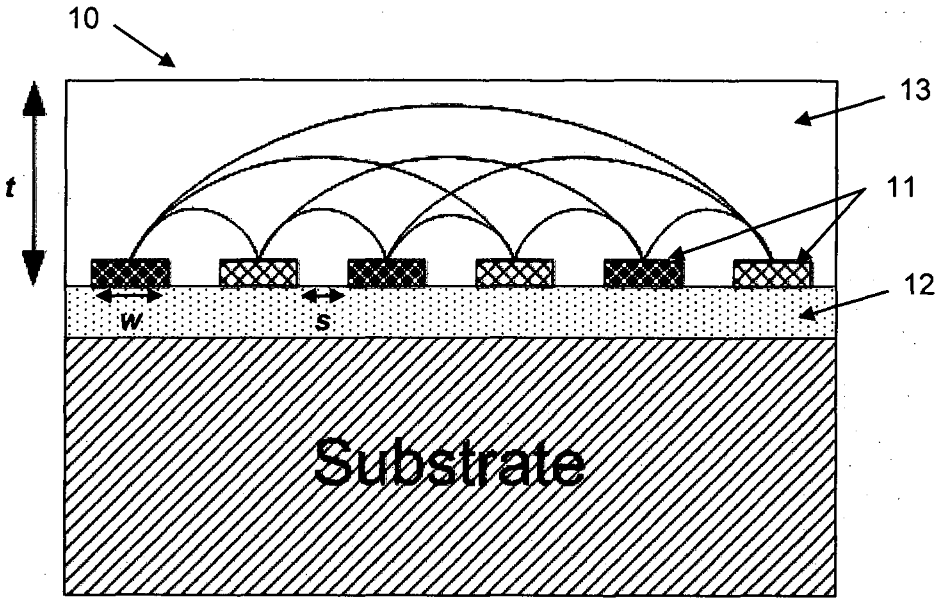

FIG. 1a

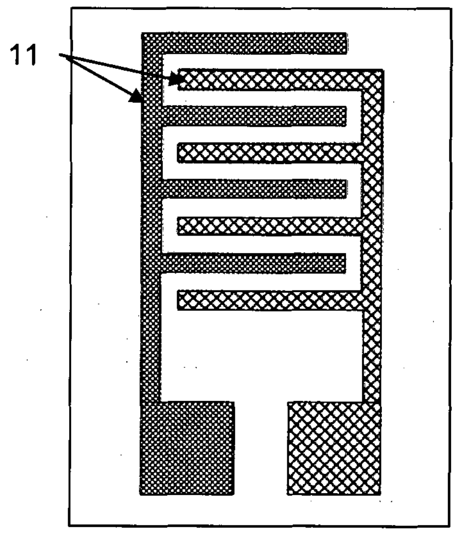

FIG. 1b

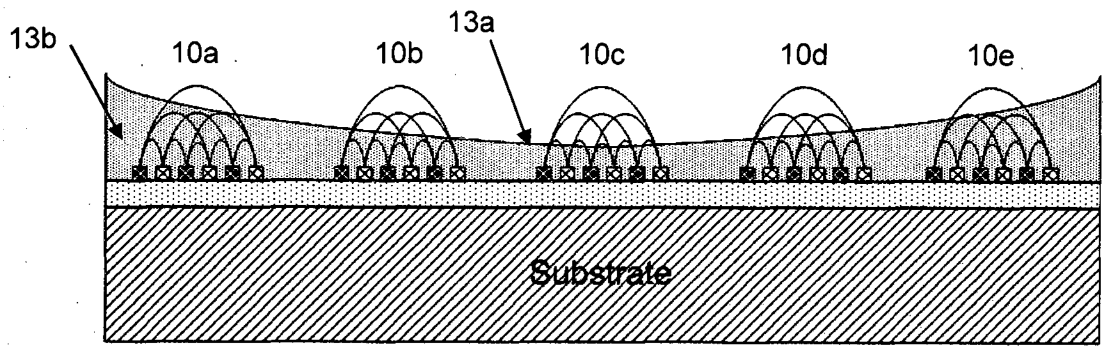

FIG. 2

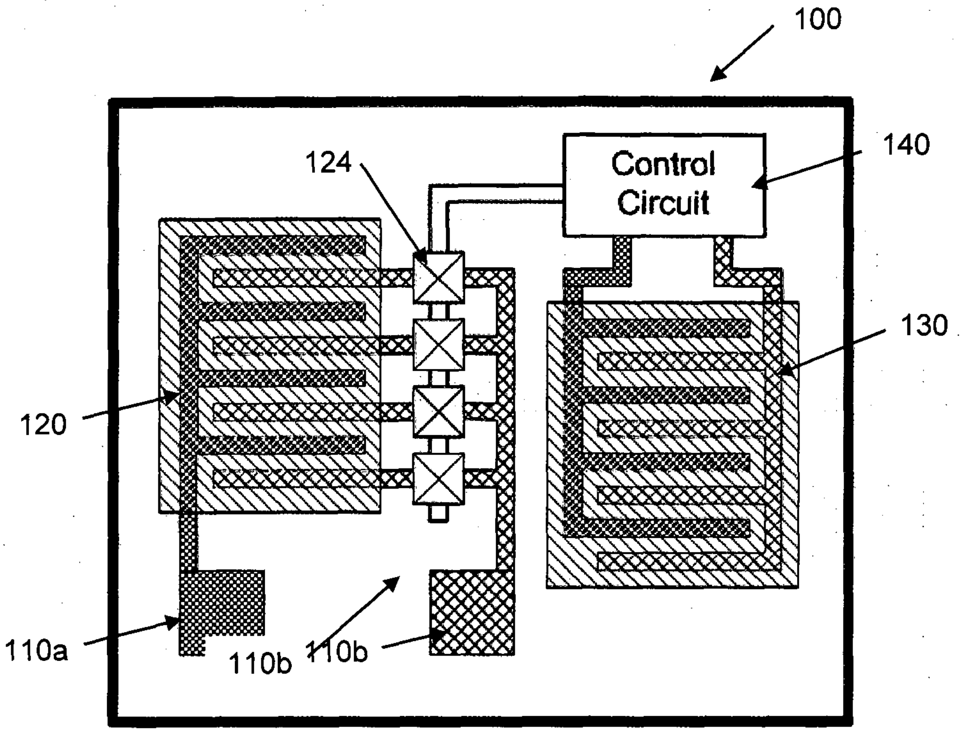
100
Control Circuit
140
124
130
120
110a
110b
110b

FIG. 3

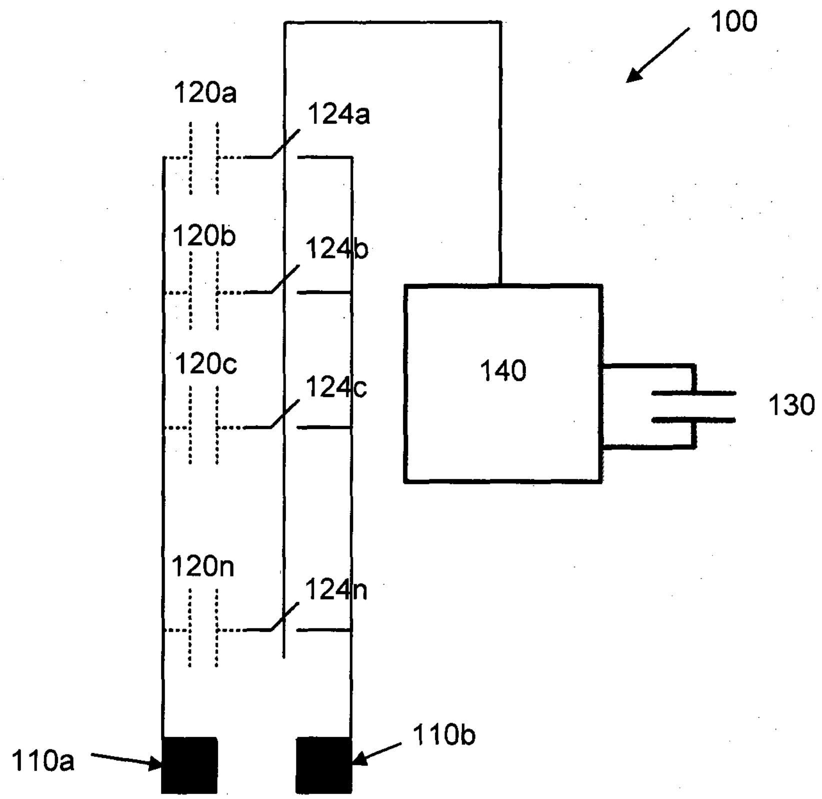
100
120a
124a
120b
124b
120c
124c
140
130
120n
124n
110a
110b

FIG. 4

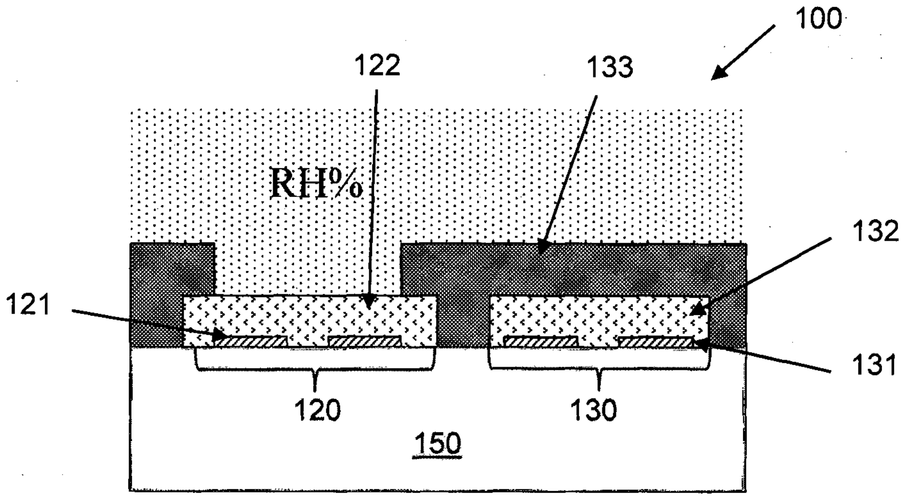
100
122
133
RH%
132
121
131
120
130
150

FIG. 5

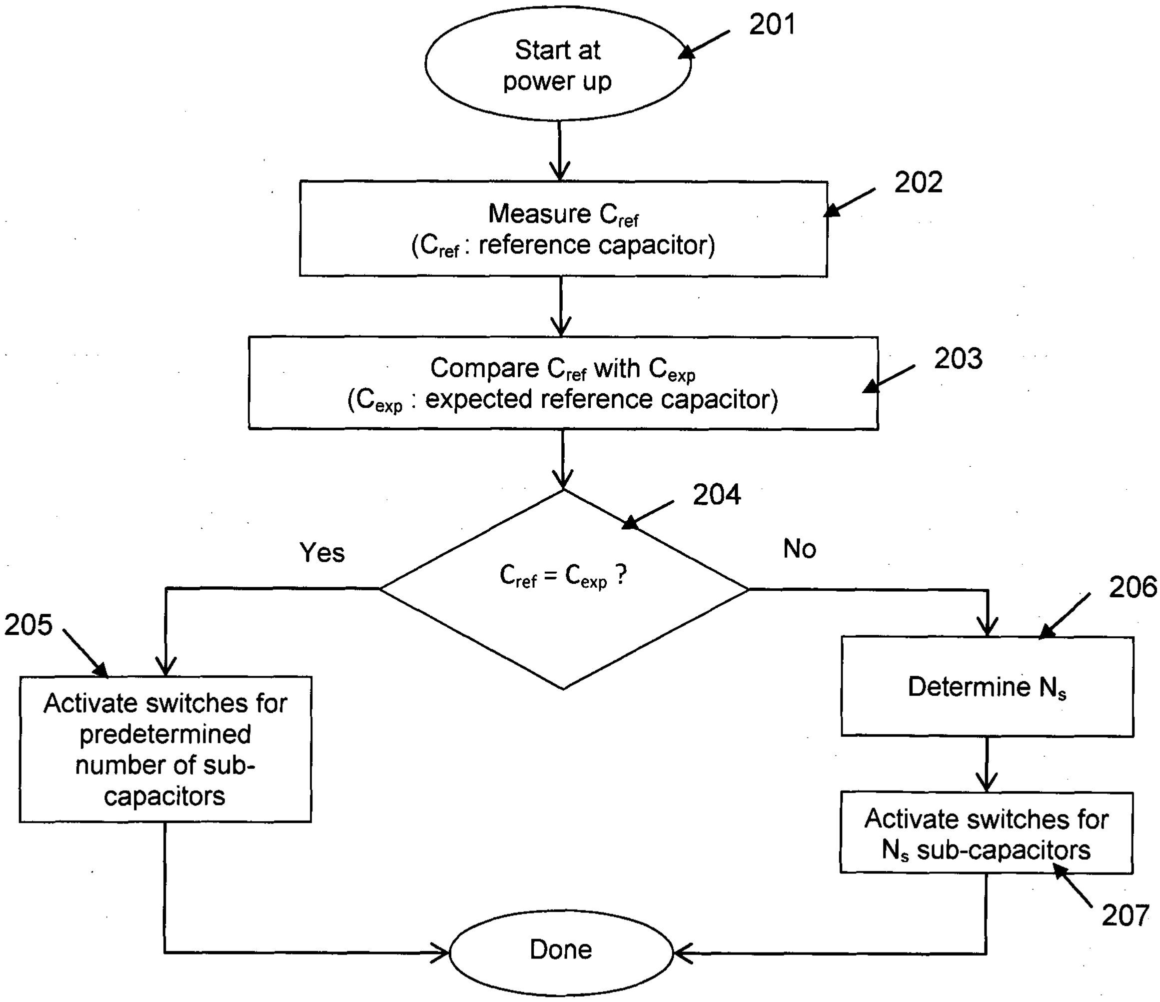
Start at power up
201
Measure C_{ref}
(C_{ref} : reference capacitor)
202
Compare C_{ref} with C_{exp}
(C_{exp} : expected reference capacitor)
203
204
$C_{ref} = C_{exp}$?
Yes
No
205
Activate switches for predetermined number of sub-capacitors
206
Determine N_s
Activate switches for N_s sub-capacitors
207
Done

FIG. 6

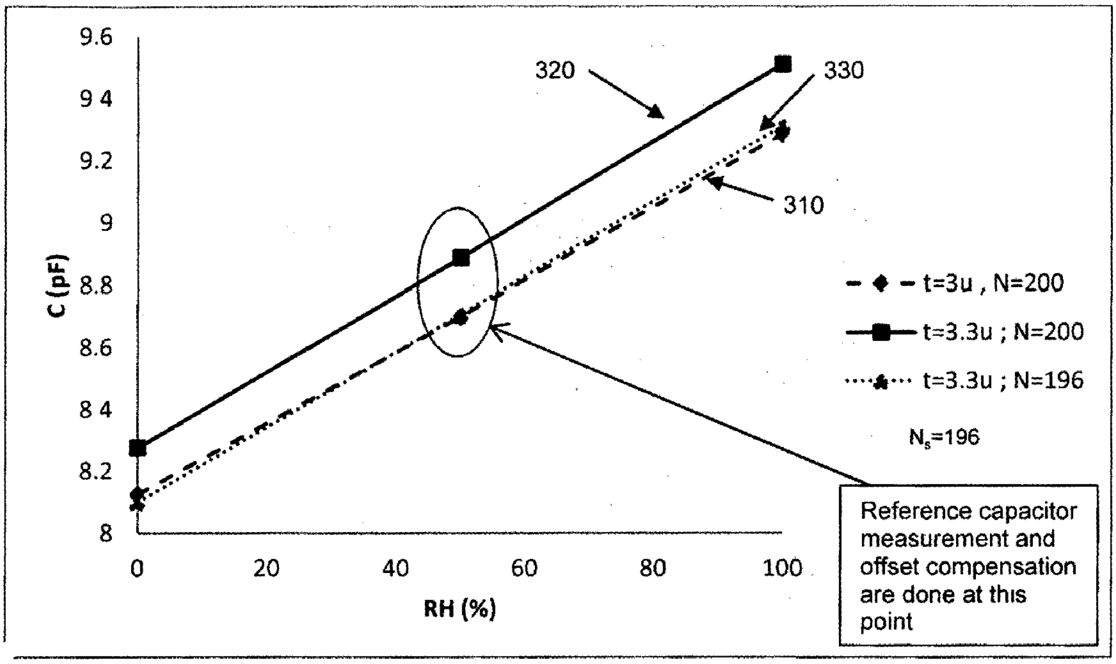
9.6
9 4
9.2
9
8.8
8.6
8 4
8.2
8
C (pF)
0
20
40
60
80
100
RH (%)
320
330
310
t=3u , N=200
t=3.3u ; N=200
t=3.3u ; N=196
N_s=196
Reference capacitor measurement and offset compensation are done at this point

FIG. 7

INTERNATIONAL SEARCH REPORT	International application No. **PCT/MY2012/000083**

A. CLASSIFICATION OF SUBJECT MATTER

G01N 27/22 (OCT 2005)

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)

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 practicable, search terms used)

EPODOC, WPI : IPC (G01N) & Keywords: sensor, detector, humidity, moisture, calibrate, refernce-capacitor, sub-capacitor, compare, difference, relative, predetermine, capacitance, contact, electrode, interdigited, control, switch and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

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Date of the actual completion of the international search	Date of mailing of the international search report
18 June 2012	25 June 2012

Name and mailing address of the ISA/AU	**Authorized officer**
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Publication Number	**Publication Date**	**Publication Number**	**Publication Date**

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