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(71) Applicant: TELEFONAKTIEBOLAGET LM ERICSSON (publ) [SE/SE]; S-126 25 Stockholm (SE).

(72) Inventors: CARLSSON, Erik; Toltorpsgatan 39C, S-431 39 Mölndal (SE). PETROV, Peter; Chalmers Tekniska Högskola, Mikroelektronik, S-412 96 Göteborg (SE). VENDIK, Orest; Korabelostroitelay 42, apt, S.Petersburg, 199155 (RU). WIKBORG, Erland; Lundblads väg 3, S-182 33 Danderyd (SE). IVANOV, Zdravko; Mölndalsvägen 41, S-412 63 Göteborg (SE).

(74) Agents: BERGENTALL, Annika et al.; Cegumark AB, P.O. Box 53047, S-400 14 Göteborg (SE).

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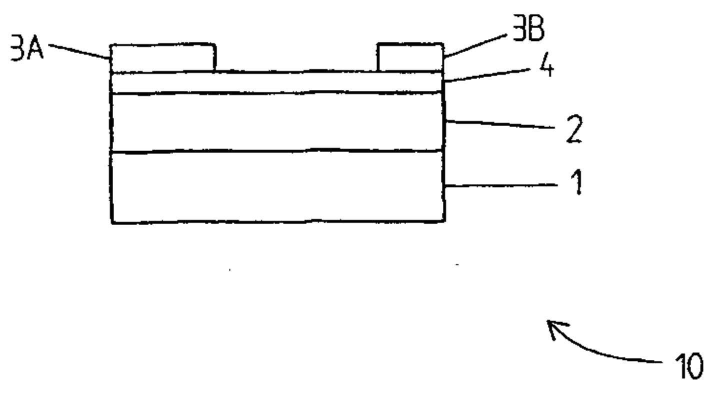
(54) Title: TUNABLE MICROWAVE DEVICES



(57) Abstract: The present invention relates to an electrically tunable device (10), particularly for microwaves. It comprises a carrier substrate (1), conducting means (3A, 3B) and at least one tunable ferroelectric layer (2). Between the conducting means (3A, 3B) and the tunable ferroelectric layer (2) a buffer layer (4) consisting of a thin film structure comprising a non-ferroelectric material is arranged.

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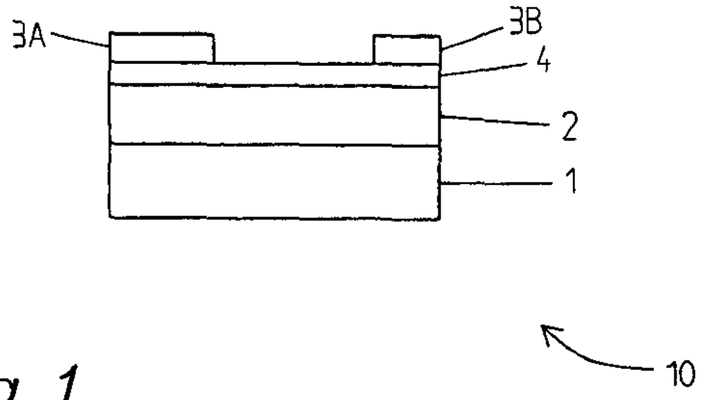

Fig. 1

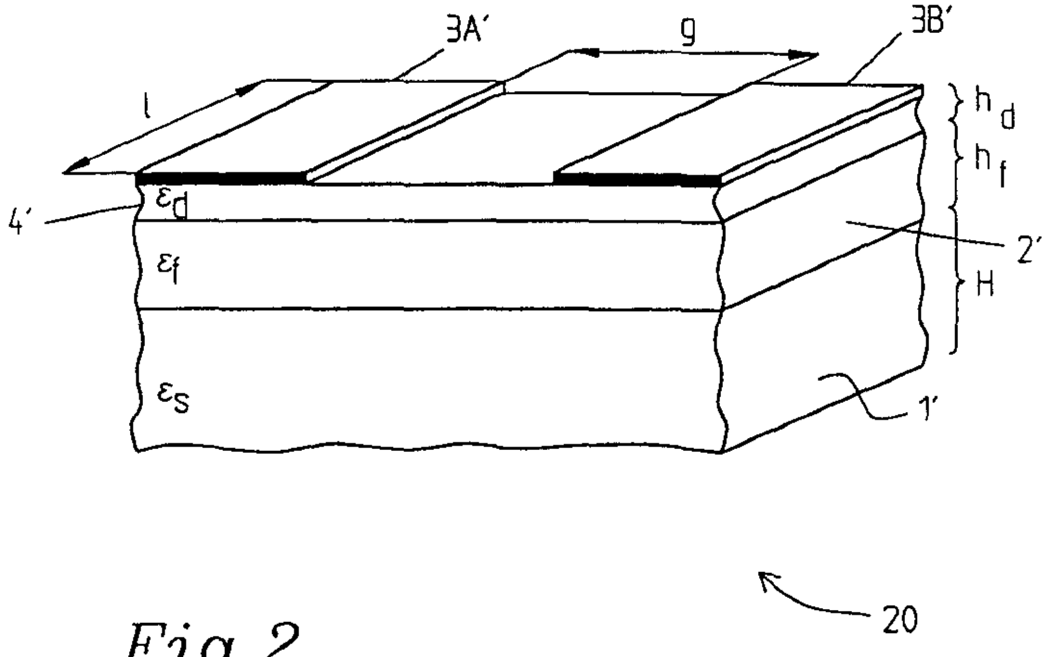

Fig. 2

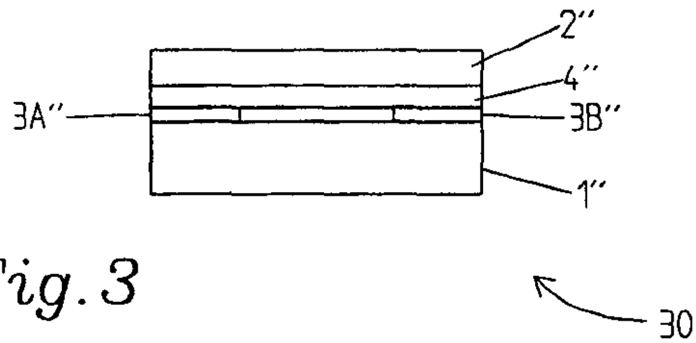

Fig. 3

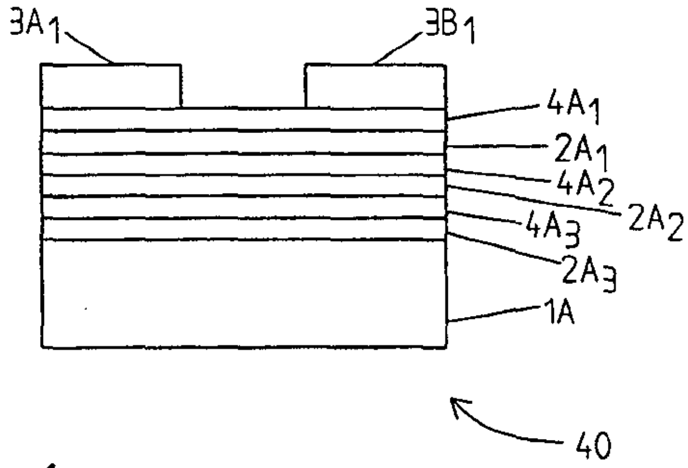

Fig. 4

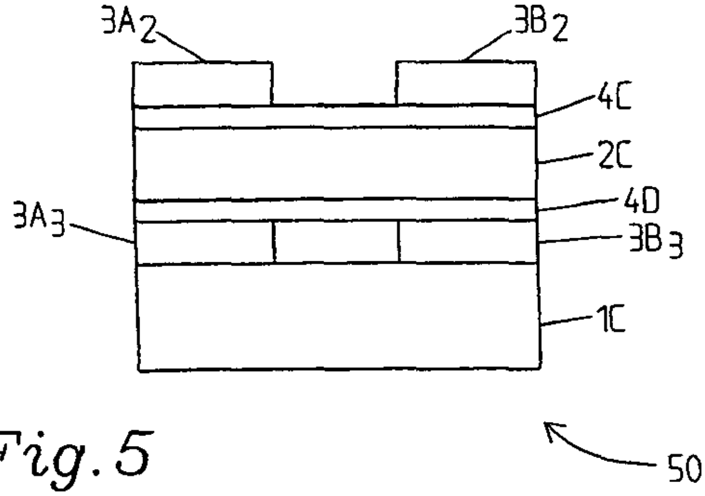

Fig. 5

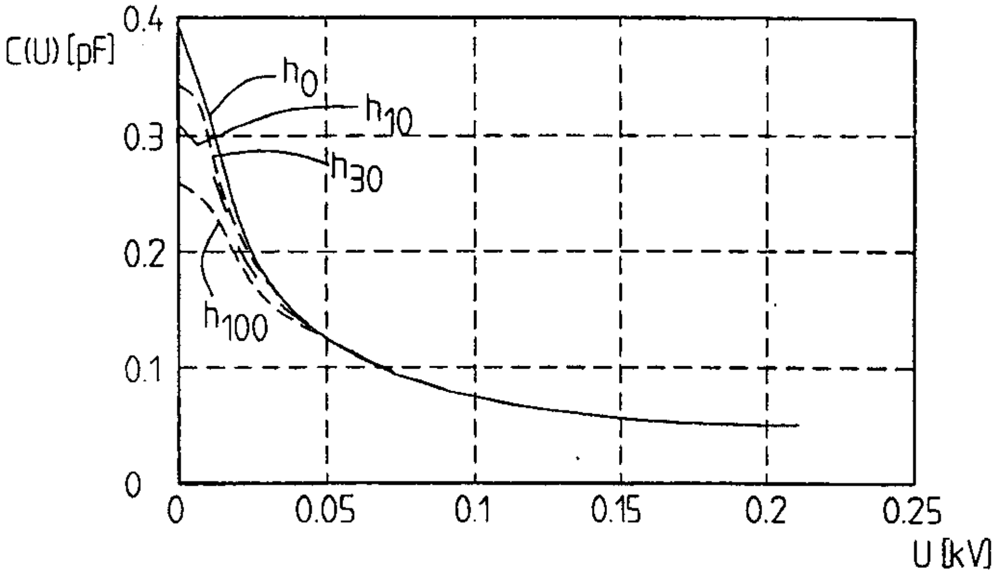
C(U) [pF]
0.4
0.3
0.2
0.1
0
h0
h10
h30
h100
0
0.05
0.1
0.15
0.2
0.25
U [kV]

Fig. 6

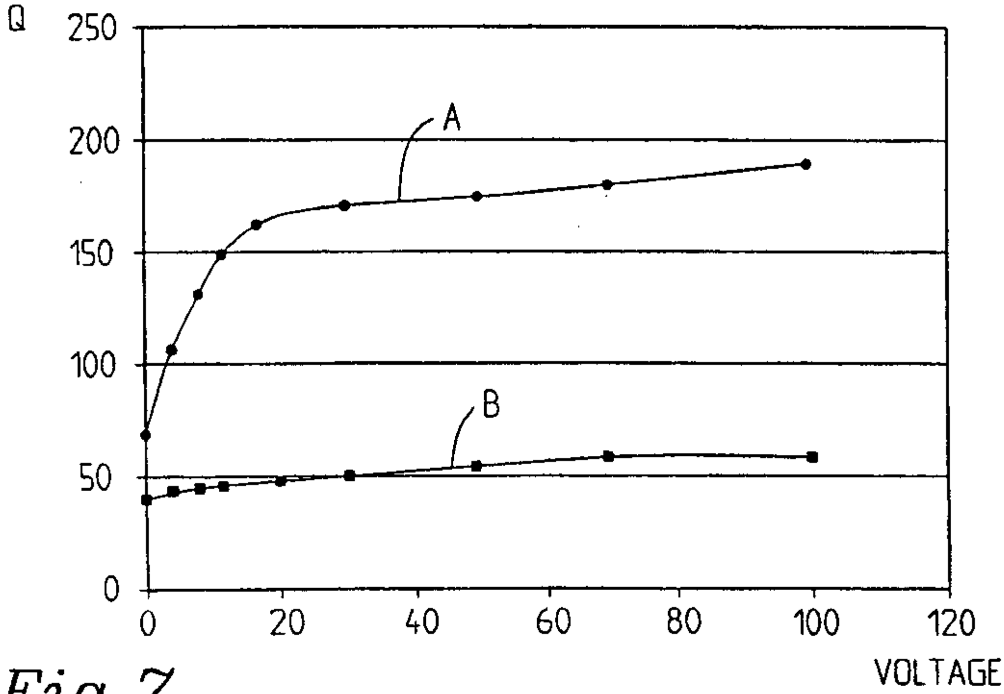
Q
250
200
150
100
50
0
A
B
0
20
40
60
80
100
120
VOLTAGE

Fig. 7

E29 P66PCT AB/ej 00-04-06

Title:

TUNABLE MICROWAVE DEVICES

FIELD OF THE INVENTION

The present invention relates to electrically tunable devices particularly for microwaves, which are based on a ferroelectric structure.

STATE OF THE ART

Known electrically tunable devices, such as capacitors (varactors) and which are based on ferroelectric structures do indeed have a high tuning range but the losses at microwave frequencies are high thus limiting their applicability. Typical ratios between the maximum and the minimum values of the dielectric constant (without and with applied electric fields) ranges from n=1.5 to 3 and the loss tangents ranges from 0.02 to 0.05 at 10 GHz. This is not satisfactory for microwave applications requiring a low loss. Then e.g. a quality factor of about 1000-2000 is needed. WO 94/13028 discloses a tunable planar capacitor with ferroelectric layers. However, the losses are high at microwave frequencies.

US-A-5 640 042 shows another tunable varactor. Also in this case the losses are too high Losses across the interface dielectric material-conductor are produced which are high and furthermore the free surface between the conductors results in the ferroelectric material being exposed during processing (e.g. etching, patterning) which produce losses since the crystal structure can be damaged.

SUMMARY OF THE INVENTION

What is needed is therefore a tunable microwave device having a high tuning range in combination with low losses at microwave frequencies. A device is also needed which has a quality factor at microwave frequencies such as for example up to 1000-2000. A device is also needed in which the ferroelectric layer is stabilized and a device which shows a performance which is stable with the time, i.e. the performance does not vary and become deteriorated with time.

Furthermore a device is needed which is protected against avalanche electric breakdown in the tunable ferroelectric material.

Further yet a device is needed which is easy to fabricate. A device is also needed which is insensitive to external factors as temperature, humidity etc. Therefore an electrically tunable device, particularly for microwaves, is provided which comprises a carrier substrate, conducting means and at least one tunable ferroelectric layer. Between the/each (or at least a number of) conducting means and a tunable ferroelectric layer a buffer layer structure is provided which comprises a thin film structure comprising a non-ferroelectric material.

According to one embodiment the thin film structure comprises a thin non-ferroelectric layer. In an alternative embodiment the thin film structure comprises a multi-layer structure including a number of non-ferroelectric layers. In still further embodiments a multilayer structure including a number of non-ferroelectric layers arranged in an alternating manner with ferroelectric layers (such that a non-ferroelectric layer always is provided adjacent the/a conducting means.

In a particular embodiment the ferroelectric layer is arranged on top of the carrier substrate and the non-ferroelectric thin film structure, including one or more layers, is arranged on top of the ferroelectric layer the conducting means in turn being arranged on top of the non-ferroelectric structure. In an alternative embodiment the ferroelectric layer is arranged above the non-ferroelectric structure including one or more non-ferroelectric layers, which is arranged on top of the conducting means. The conducting means particularly comprise (at least) two longitudinally arranged electrodes between which electrodes or conductors a gap is provided. According to different embodiments the non-ferroelectric structure is deposited in-situ on the ferroelectric layer or deposited ex-situ on the ferroelectric layer.

The deposition of the non-ferroelectric layer may be performed using different techniques such as for examples laser deposition, sputtering, physical or chemical vapour deposition or through the use of sol-gel techniques. Of course also other techniques which are suitable can be used.

Advantageously the ferroelectric and the non-ferroelectric structures have lattice matching crystal structures. The non-ferroelectric structure is particularly arranged so as to cover also the gap between the conductors or the electrodes. In a particular implementation the device comprises an electrically tunable capacitor or a varactor.

In another embodiment the device includes two layers of ferroelectric material provided on each side of the carrier substrate and two conducting means, non-ferroelectric thin film structures being arranged between the respective ferroelectric and non-ferroelectric structures in such a way that the device forms a resonator. According to different implementations the device of the invention may comprise microwave filters or be used in microwave filters. Also devices such as phase shifters etc. can be provided using the inventive concept

Different materials can be used; one example of a ferroelectric material is STO ($SrTiO_3$). The non-ferroelectric material may for example comprise CeO_2 or a similar material or $SrTiO_3$ which is doped in a such a way that it is not ferroelectric. An advantageous use of a device as disclosed is in wireless communication systems.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will in the following be further described in a non-limiting way and with reference to the accompanying drawings in which:

Fig 1 shows a cross-sectional view of a tunable device according to a first embodiment of the invention,

Fig 2 schematically illustrates a planar capacitor similar to the embodiment of Fig 1,

Fig 3 shows a second embodiment of an inventive device,

Fig 4 shows still another embodiment in which a structure comprising alternating layers is used,

Fig 5 illustrates a fourth embodiment of a device according to the invention, Fig 6 schematically illustrates an experimental dependence of the tunability as a function of the capacitance for a number of material thicknesses, and

Fig 7 shows the experimental results relating to the loss factor when using a non-dielectric layer according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

Through the invention devices are disclosed through which it is possible to achieve a high tunability in combination with low losses at microwave frequencies. In general terms this is achieved through a design in which a thin non-ferroelectric, dielectric layer (or layers) is (are) arranged between the conducting layer and a tunable ferroelectric layer. The non-ferroelectric layer will also act as a cover for the ferroelectric layer in the gap between the conducting means or the electrodes. The non-ferroelectric layer can be deposited "in-situ" or "ex-situ" on the ferroelectric layer by laser deposition, sputtering, physical vapour deposition, chemical vapour deposition, sol-gel or any other convenient technique. The non-ferroelectric layer should be oriented and have a good lattice match to the crystal structure of the ferroelectric layer. Further it should have low microwave losses. In all embodiments as referred to below or not explicitly disclosed, the non-ferroelectric layer structure may be a single layered structure or it may comprise a multilayered structure.

The thin non-ferroelectric structure will reduce the total capacitance of the device due to the presence of two capacitances of the thin non-ferroelectric structures in series with the tunable capacitance resulting from the ferroelectric layer. Even if the total capacitance is reduced, which is wanted in most applications, the tunability will only decrease slightly since the change in the dielectric constant of the ferroelectric layer will redistribute the electric field and change the series capacitances due to the thin non-ferroelectric structure.

Fig. 1 shows a first embodiment of a device 10 according to the invention which comprises a substrate 1 or which a ferroelectric material 2, which is tunable, is provided. On said tunable ferroelectric material 2, a non-ferroelectric layer 4 is deposited, for example using any of the techniques as referred to above. Two conducting means comprising a first conductor or electrode 3A and a second conductor or electrode 3B are arranged on the non-ferroelectric layer 4. Between the first and second electrodes 3A, 3B there is a gap. As can be seen from the figure the non-ferroelectric structure 4 covers the tunable ferroelectric structure 2 across the gap between the conductors 3A, 3B. The surface of the ferroelectric structure 4 is thus protected by the non-ferroelectric structure 4 in a finished state but also during processing, i.e. when the device is fabricated. Since the ferroelectric structure 2 is protected in this manner, the ferroelectric structure will be stabilized and its performance will be stable with the time, i.e. it does not deteriorate with the time. Furthermore the losses will decrease since there will be a higher control of the interface of the ferroelectric structure and there will be less defects on the surface layer of the ferroelectric material. Instead of two electrodes, the conducting means may include more than two electrodes e.g. one or more electrodes provided between the electrodes 3A,3B.

Furthermore the non-ferroelectric layer will provide a protection against avalanche electric breakdown in the tunable ferroelectric material.

Although the non-ferroelectric structure 4 is shown as comprising a merely one layer, it should be clear that it also may comprise a multilayer structure.

Fig 2. shows an embodiment relating to a planar capacitor 20. Relating to this embodiment some figures are given relating to dimensions, values etc. which here of course only are given for illustrative purposes. The device includes a substrate 1′ for example of $LaAlO_3$ having a thickness H of for example 0.5 mm, and with a dielectric permittivity ε_s=25. On top of the substrate a ferroelectric layer 2′ for example of STO is arranged which here has a thickness h_f of 0.25μm and with a dielectric permittivity ε_f=1500. Thereon the protective buffer layer 4′, which is a non-ferroelectric e.g. dielectric layer, is arranged having a dielectric permittivity ε_d=10.

In Fig. 3 an alternative device 30 is disclosed in which a non-ferroelectric structure 4″, here comprising a multiple of sublayers, are arranged on top of conducting electrodes, 3A′, 3B′ which are arranged on substrate 1″. The non-ferroelectric multilayer structure is deposited on (below) a tunable ferroelectric material 2″. The functioning is substantially the same as that as described with reference to Fig. 1, only it is an inverted structure as the ferroelectric is arranged above the non-ferroelectric layer, i.e. above the electrodes. Furthermore the non-ferroelectric layer comprises a multilayer structure. Of course in this embodiment the non-ferroelectric structure may alternatively comprise a single layer.

Fig 4 shows a tunable capacitor 40 in which a structure comprising ferroelectric layers $2A_1$, $2A_2$, $2A_3$ and non-ferroelectric layers $4A_1$, $4A_2$, $4A_3$ which are arranged in an alternating manner. The number of layers can of course be any and is not limited to three of each kind as illustrated in Fig. 4, the main thing being that a non-ferroelectric layer (here $4A_1$) is arranged in contact with the conducting means $3A_1$, $3B_1$; also covering a ferroelectric layer (here $2A_1$) in the gap between the electrodes.

Such an alternating arrangement can of course also be used in the "inverted" structure as disclosed in Fig. 3.

Fig. 5 shows yet another device 50 in which first conducting means $3A_2$, $3B_2$ in the form of electrodes are arranged on a non-ferroelectric layer 4C, which in turn is deposited on a ferroelectric, active, layer 2C. Below the ferroelectric layer 2C a further non-ferroelectric layer 4D is provided on the opposite side of which second conducting means $3A_3$, $3B_3$ are arranged, which in turn are arranged on a substrate 1C. Also in this case may an alternating structure as in Fig. 4 be used.

Any of the materials mentioned above can be used also in these implementations. The non-ferroelectric material can be dielectric, but it does not have to be such a material. Still further it may be ferromagnetic.

The active ferroelectric layer structure of any embodiment may for example comprise any of $SrTiO_3$, $BaTiO_3$, $Ba_xSr_{1-x}TiO_3$, PZT (Lead Zirconate Titanate) as well as ferromagnetic materials. The buffer layer or the protective non-ferroelectric structure may e.g. comprise any of the following materials: CeO_2, MgO, YSZ (Ytterium Stabilized Zirconium), $LaAlO_3$ or any other non-conducting material with an appropriate crystal structure, for example PrBCO ($PrBa_2Cu_3O_{7-x}$), non-conductive $YBa_2Cu_3O_{7-x}$ etc. The substrate may comprise $LaAlO_3$, MgO, R-cut or M-cut sapphire,

$SiSrRuO_3$ or any other convenient material. It should be clear that the lot of examples is not exhaustive and that also other possibilities exist.

In Fig. 6 the dynamic capacitance is illustrated as a function of the voltage for three different thicknesses of the non-ferroelectric buffer layer 4′ which here is dielectric. In this case the length of the planar capacitor is supposed to be 0.5 mm whereas the gap between the conductors 3A′, 3B′ is 4μm. A magnetic wall can be said to be formed between the substrate and the ferroelectric layer 2′.

The capacitance is illustrated as a function of the voltage applied between the electrodes for three different values, namely h_{10}=10nm, h_{30}=30mm and h_{100}=100nm of the dielectric non-ferroelectric buffer layer 4′. The capacitance is also illustrated for the case when there is no buffer layer between the conducting means and the ferroelectric layer, curve h_0. This is thus supposed to illustrate how the tunability is reduced through the introduction of a buffer layer 4′ for a number of thicknesses as compared to the case when there is no buffer layer. As can be seen the reduction in tunability is not significant.

Fig. 7 shows the Q value for a capacitance depending on voltage when a buffer layer is provided, corresponding to the upper curve A, and the case when there is no buffer layer, corresponding to the lower curve B. Thus, as can be seen from the experimental behavior, the Q value for a capacitor is considerably increased through the introduction of a buffer layer.

In addition to the advantages as already referred to above, it is an advantage in using a buffer layer across the active (tunable) ferroelectric layer since when a conductive pattern is etched, some etching will also occur in the subsequent, underlying, layer. Thus damages may be produced in the top layer of the ferroelectric material in the gap if it is not protected.

The inventive concept can also be applied to resonators, such as for example the ones disclosed in "Tunable Microwave Devices" which is a Swedish patent application with application No. 9502137-4, by the same applicant, which hereby is incorporated herein by reference. The inventive concept can also be used in microwave filters of different kinds. A number of other applications are of course also possible. As in other aspects the invention is not limited to the particularly illustrated embodiments but can be varied in a number of ways within the scope of the claims.

CLAIMS

1. An electrically tunable device (10;20;30;40;50), e.g. for microwaves, comprising a carrier substrate (1;1';1";1A-1C), conducting means ($3A,3B;3A',3B';3A'',3B'';3A_1,3B_1;3A_2,3B_2;3A_3,3B_3$) and at least one active ferroelectric layer ($2;2';2'';2A_1,2A_2,2A_3$),

c h a r a c t e r i z e d i n t h a t

between at least a number of conducting means ($3A,3B;3A',3B';3A'',3B'';3A_1,3B_1;3A_2,3B_2;3A_3,3B_3$) and a ferro-electric layer ($2;2';2'';2A_1,2A_2,2A_3$) a buffer layer ($4;4';4'';4A_1,4A_2,4A_3;4C,4D$) consisting of a thin film structure comprising a non-ferroelectric material is arranged.

2. A device according to claim 1,

c h a r a c t e r i z e d i n t h a t

the thin film structure ($4;4';4'';4A_1,4A_2,4A_3;4C,4D$) comprises a thin non-ferroelectric layer.

3. A device according to claim 1,

c h a r a c t e r i z e d i n t h a t

the thin film structure comprises a multi-layer structure ($4'';4A_1,4A_2,4A_3$) including a number of non-ferroelectric layers.

4. A device according to claim 2 or 3,

c h a r a c t e r i z e d i n

that a number of ferroelectric layers ($2A_1,2A_2,2A_3$) and non-ferroelectric layers ($4A_1,4A_2,4A_3$) are arranged in an alternative manner adjacent to the conducting means ($3A_1,3B_1$).

5. A device according to any one of claims 1-3,

c h a r a c t e r i z e d i n t h a t

the ferroelectric layer (2;2';$2A_3$) is arranged on top of the carrier substrate (1;1';1A), the non-ferroelectric thin film structure (4;4';$4A_1$) being arranged on top of the ferroelectric layer and in that the conducting means (3A,3B;3A',3B';$3A_1$,$3B_1$) are arranged on top of the non-ferroelectric structure.

6. A device according to any one of claims 1-3,
c h a r a c t e r i z e d i n t h a t
the ferroelectric layer (2") arranged above the non-ferroelectric structure (4") which is arranged on top of the conducting means (3A",3B") being arranged on the substrate.

7. A device according to any one of the preceding claims,
c h a r a c t e r i z e d i n t h a t
the conducting means comprise two longitudinally arranged electrodes (3A,3B;3A',3B';3A",3B";$3A_1$,$3B_1$;$3A_2$,$3B_2$;$3A_3$,$3B_3$) between which a gap is provided.

8. A device according to any one of claims 1-4,
c h a r a c t e r i z e d i n
that second conducting means ($3A_3$,$3B_3$) are provided and in that a non-ferroelectric layer (4D) is arranged between said second conducting means ($3A_3$,$3B_3$) and the ferroelectric layer (2C).

9. A device according to any one of the preceding claims,
c h a r a c t e r i z e d i n t h a t
the non-ferroelectric buffer layer structure is deposited in-situ on the ferroelectric layer.

10. A device according to any one of claims 1-6,
c h a r a c t e r i z e d i n t h a t
the non-ferroelectric buffer layer structure is deposited ex-situ on the ferroelectric layer.

11. A device according to claim 7 or 8, characterized in that the non-ferroelectric buffer layer structure is deposited through the use of laser deposition, sputtering, physical or chemical vapour deposition or sol-gel techniques.

12. A device according to any one of the preceding claims, characterized in that the ferroelectric and the non-ferroelectric structures have lattice matching crystal structures.

13. A device at least according to claim 7, characterized in that the non-ferroelectric buffer layer structure (3A,3B;3A',3B';3A",3B";$3A_1$,$3B_1$;$3A_2$,$3B_2$;$3A_3$,$3B_3$) is arranged to cover the gap between the conductors/electrodes.

14. A device according to any one of the preceding claims, characterized in that it comprises an electrically tunable capacitor (varactor).

15. A device according to any one of the preceding claims, characterized in that it comprises two layers of a ferroelectric material provided on each side of the carrier substrate and two conducting means, non-ferroelectric thin film structures being arranged between the respective ferroelectric and non-ferroelectric structures, the device forming a resonator.

16. A device according to any one of the preceding claims, characterized in

that the non-ferroelectric material of the buffer layer structure is a dielectricum.

17. A device according to any one of claims 1-16, c h a r a c t e r i z e d i n that the non-ferroelectric material is ferromagnetic.

18. A device according to any one of the preceding claims, c h a r a c t e r i z e d i n t h a t it is used in microwave filters.

19. A device according to any one of the preceding claims, c h a r a c t e r i z e d i n t h a t the ferroelectric material comprises STO ($SrTiO_3$).

20. A device according to any one of the preceding claims, c h a r a c t e r i z e d i n t h a t the non-ferroelectric material comprises CeO_2 or a similar material or $SrTiO_3$ doped in a such a way that it is not ferroelectric.

21. Use of a device as in any one of the preceding claims in wireless communication system.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 00/00685

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H01P 1/203, H01P 7/08, H01G 7/06
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)

IPC7: H01G, H01P, H01Q

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

SE,DK,FI,NO classes as above

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5524092 A (JEA K PARK), 4 June 1996 (04.06.96) --	1,2,6
A	EP 0518117 A1 (RAMTRON INTERNATIONAL CORPORATION), 16 December 1992 (16.12.92) --	1,6,8,9,14
A	WO 9413028 A1 (SUPERCONDUCTING CORE TECHNOLOGIES, INC), 9 June 1994 (09.06.94), cited in the application --	1-21
A	US 5640042 A (THOMAS E. KOSCICA ET AL), 17 June 1997 (17.06.97), cited in the application -- -------	1-21

☐ 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" erlier document but published on or after the international filing date
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"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
24 August 2000	29 -08- 2000
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Bo Gustavsson/AE Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

08/05/00

International application No.
PCT/SE 00/00685

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US 5640042 A	17/06/97	NONE	

[19]中华人民共和国国家知识产权局

[51]Int. Cl^7.

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H01P 7/08 H01G 7/06

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[22]申请日 2000.4.11 [21]申请号 00806247.1

[30]优先权

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[71]申请人 艾利森电话股份有限公司

地址 瑞典斯德哥尔摩

[72]发明人 E·卡尔松 P·佩特罗夫 O·文迪克

E·维克堡 Z·伊瓦诺夫

[74]专利代理机构 中国专利代理(香港)有限公司

代理人 罗朋 陈霁

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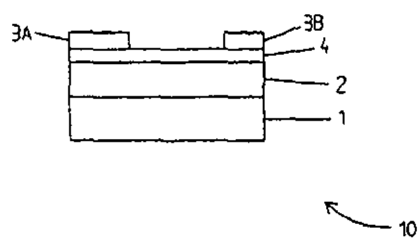
[54]发明名称 可调谐微波设备

[57]摘要

本发明涉及一个电可调谐设备(10),具体地是用于微波的。它至少包括一个载体基底(1),传导装置(3A,3B)和至少一个可调谐铁电体层(2)。在传导装置(3A,3B)和可调谐铁电体层(2)之间放置有一个由薄膜结构构成的缓冲层(4)。



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权　利　要　求　书

1. 一种电可调谐设备（10；20；30；40；50），例如对于微波的，包括一个载体基底（1；1'；1"；1A-1C），传导装置（3A，3B；3A',3B'；3A",3B"；3 A_1,3 B_1；3 A_2,3 B_2；3 A_3,3 B_3）和至少一个有源铁电体层（2；2'；2"；2 A_1,2 A_2,2 A_3），

其特征在于

在至少一些传导装置（3A,3B；3A',3B'；3A",3B",3 A_1,3 B_1；3 A_2,3 B_2；3 A_3,3 B_3）和一个铁电体层（2；2'；2"；2 A_1,2 A_2,2 A_3）之间放置有由包括一个非铁电体材料的薄膜结构所构成的一个缓冲层（4；4'；4"；4 A_1,4 A_2,4 A_3；4C,4D）。

2. 根据权利要求1的一种设备，

其特征在于

该薄膜设备（4；4'；4"；4 A_1,4 A_2,4 A_3；4C,4D）包括一个薄的非铁电体层。

3. 根据权利要求1的一种设备，

其特征在于

该薄膜结构包括一个多层结构（4"；4 A_1,4 A_2,4 A_3），该多层结构包括一些非铁电体层。

4. 根据权利要求2或3的一种设备，

其特征在于

一些非铁电体层（2 A_1，2 A_2，2 A_3）和非铁电体层（4 A_1，4 A_2，4 A_3）被以一种交替方式，紧邻该传导装置（3 A_1,3 B_1）排列。

5. 根据权利要求1－3中任一项的一种设备，

其特征在于

该铁电体层（2；2'；2 A_3）被放置在载体基底（1；1'；1A）的顶部，该非铁电体薄膜结构（4；4'；4 A_1）被排列在铁电体层的顶部并在于该传导装置（3A,3B；3A',3B'；3 A_1,3 B_1）被放置在非铁电体结构的顶部。

6. 根据权利要求1－3中任一项的一种设备，

其特征在于

该铁电体层（2"）放置在该非铁电体结构（4"）上，该非铁电体结构被放置在放置于基底上的传导装置（3A",3B"）的顶部。

7. 根据上述权利要求中任一项的一种设备，

其特征在于

该传导装置包括两个纵向排列的电极（3A,3B;3A’,3B’;3A’’,3B’’;3 A_1,3 B_1;3 A_2,3 B_2;3 A_3,3 B_3），在它们之间有一个间隙。

8. 根据权利要求1－4中任一项的一种设备，

其特征在于

提供有第二传导装置（3 A_3,3 B_3）并在于一个非铁电体层(4D)被放置在所述第二传导装置（3 A_3,3 B_3）和铁电体层（2C）之间。

9. 根据上述权利要求中任一项的一种设备，

其特征在于

该非铁电体缓冲层结构被沉积在铁电体层之内。

10. 根据权利要求1－6中任一项的一种设备，

其特征在于

该非铁电体缓冲层结构被沉积在该铁电体层之外。

11. 根据权利要求7或8的一种设备，

其特征在于

该非铁电体层结构通过使用激光沉积，溅射，物理或化学的汽相沉积或熔胶－凝胶技术而沉积。

12. 根据上述权利要求中任一项的一种设备，

其特征在于

该铁电体和非铁电体结构具有点阵匹配的晶体结构。

13. 根据权利要求7的一种设备，

其特征在于

该非铁电体缓冲层结构(3A,3B;3A’,3B’;3A’’,3B’’;3 A_1,3 B_1;3 A_2,3 B_2;3 A_3,3 B_3)被放置以覆盖在导体/电极之间的间隙。

14. 根据上述权利要求中任一项的一种设备，

其特征在于

它包括一个电可调谐电容器（变容二极管）。

15. 根据上述权利要求中任一项的一种设备，

其特征在于

它包括配置在载体基底的每一侧上的两个铁电体材料层和两个传导装置，被配置在相应的铁电体和非铁电体结构之间的非铁电体薄膜结构，该设备形成一个谐振器。

16. 根据上述权利要求中任一项的一种设备，

其特征在于

缓冲层结构的该非铁电体材料是电介质的。

17. 根据权利要求 1－16 中任一项的一种设备，

其特征在于

该非铁电体材料为铁磁体。

18. 根据上述权利要求中任一项的一种设备，

其特征在于

它被用于微波滤波器中。

19. 根据上述权利要求中任一项的一种设备，

其特征在于

该铁电体材料包括 STO（$SrTiO_3$）。

20. 根据上述权利要求中任一项的一种设备，

其特征在于

该非铁电体材料包括 CeO_2 或一个类似的材料或以使得它不是铁电体的这样方式沉积的 $SrTiO_3$。

21. 在无线通信系统中对在上述权利要求中任一项的设备的使用。

说　明　书

可调谐微波设备

发明领域

本发明涉及具体对于微波的电可调谐设备，它是基于铁电体结构的。

现有技术状态

已知的电可调谐设备，诸如电容（变容二极管）和那些基于铁电体结构的电可调谐设备确实具有高的调谐范围，但是在微波频率的损耗太高，所以限制了它们的可应用性。在（没有和有施加电场的）介电常数的最大和最小值的典型比值范围为 n=1.5 到 3 而在 10Hz 频率处的损耗的正切范围为 0.02 到 0. 05. 这对于要求一个低损耗的微波应用并不令人满意。则需要一个大约为 1000－2000 的质量因子。WO 94/13028 公开了一个具有铁电体层的可调谐平面电容。然而，该电容在微波频率处的损耗也高。

US-A-5 640 042 显示了另一个可调谐变容二极管。另外，在损耗太高的这种情形中，在介电材料－导体界面两端产生高损耗并且在导体之间的自由表面导致铁电材料在处理过程（蚀刻，图案化）中被暴露，这样，由于晶体结构被破坏，将产生损耗。

发明概述

因此，所需要的是一个具有高调谐范围以及在微波频率处的低损耗的可调谐微波设备。另外，还需要一个具有在微波频率高至,例如,1000－2000 的质量因子的设备，其中铁电层被稳定化并且是一种具有时间稳定性的设备，即性能不随时间改变或恶化。

另外，还需要一种可防止在可调谐铁电材料中发生雪崩电击穿的设备。

此外，还需要一种易于制作的设备。还需要一种对于外部因素，诸如温度、湿度等不敏感的设备。因此，提供一个具体对于微波的电可调谐设备，包括一个载体基底，传导装置和至少一个可调谐铁电体层。在该/每一个（或至少一些）传导装置和一个可调谐铁电层之间提供了一个缓冲层结构，该缓冲层包括一个包含非铁电体材料的薄膜结构。

根据一个实施例，该薄膜结构包括一个薄的非铁电层。在另一个实施例中，该薄膜结构包括一个多层结构，该多层结构包括多个非铁电层。在再另一个实施例中，一个多层结构包括一些以一个可选方式来与铁电特层相排列的非铁电层，诸如非铁电体层的多层结构总是紧邻该/一个传导装置来配置。

在一个具体实施例中，该铁电层放置在载体基底顶部而包括一个或多个层的非铁电体薄膜结构被放置在铁电体层的顶部，传导装置依次被放置在非铁电体层的顶部。在另一个实施例中，铁电体层被放置在包括一个或多个非铁电体层的非铁电体层结构的上部，该非铁电体层被放置在传导装置上部。该传导装置具体包括（至少）两个纵向排列的电极，在这两个电极或导体之间有一个间隙。根据不同的实施例，非铁电体结构沉积在铁电体层之内或沉积在铁电体层之外。

非铁电体层的沉积可使用以使用诸如激光沉积、溅射、物理或化学汽相沉积等不同技术或通过使用熔胶－凝胶技术来实现。当然也可以使用其他合适的技术。

有利的，铁电体和非铁电体结构具有点阵匹配晶体结构。非铁电体结构还被特别地放置以覆盖在导体或电极之间的间隙。在具体实例中，该设备包括一个电可调谐电容或一个变容二极管。

在另一个实施例中，该设备包括配置在载体基底每一侧的两个铁电体材料层和两个传导装置，以一种方式放置在相应的铁电体和非铁电体结构之间的非铁电体薄膜结构，使得该设备形成一个谐振器。根据不同的实例，本发明的设备可以包括微波滤波器或被用于微波滤波器中。还有，诸如移相器的设备可以采用本发明的思想来提供。

可以使用不同的材料；铁电体材料的一个例子是STO（$SrTiO_3$）。非铁电体材料例如可以包括CeO_2或一个相似材料或$SrTiO_3$，它以这样一种方式来沉积以使得它是非铁电体材料。使用所公开的这种设备的一个优点是在于无线通信系统中。

附图简述

下面参照附图以一种非限制性方式来描述本发明：

图1示出了根据本发明的第一实施例的可调谐设备的剖面图，

图2示意性的示出了与图1的实施例相似的平面电容器，

图3示出了本发明设备的第二实施例，

图4示出了另一个实施例，其中使用一个包括交替层的结构，

图5示出了根据本发明的第四实施例，

图6示意性的示出了作为对于一系列材料厚度的电容值函数的可调谐性的实验依据，和

图7示出当使用根据本发明的非铁电体材料时与损耗因子相关的实验结果。

发明详述

本发明公开了一种可以实现高可调谐性以及在微波频率的低损耗的设备。用一般术语，这是通过其中一个（或多个）薄膜非铁电体、介电层被放置在导电层和可调谐铁电体层之间的一种设计来实现的。该非铁电体层还用作在传导装置或电极之间的一个间隙中的铁电体层的覆盖。该非铁电体层可以通过激光沉积、溅射、物理汽相沉积、化学汽相沉积、溶胶或任何其他适宜的技术来沉积在铁电体层之内或外。该非铁电体层应该是定向的和具有与 铁电体层的晶体结构相点阵匹配。此外，它应具有低微波损耗。在下面所述的或没有明确公开的所有实施例中，非铁电体层结构可以是单层结构或可以包括多层结构。

薄的非铁电体结构可以减少由于与铁电体层所产生的可调谐电容相串联的薄费铁电体结构的两个电容值的存在带来的总电容值。甚至即使总电容值减少，这是在大多数应用中所希望的，由于铁电体层的介电常数的变化将重新分布电场和和改变由于薄的非铁电体结构所引起的串联电容，因此可调谐性将只有较小的减少。

图1示出了根据本发明的一个设备10的第一实施例，该设备包括一个基底1或提供有一个可调谐的铁电体材料。在所述可调谐铁电体材料2上，例如使用如上所述的技术沉积有一个非铁电体层4。包括第一导体或电极3A和第二导体或电极3B的两个传导装置被放置在非铁电体层4上。在第一和第二电极3A，3B之间有一个间隙。如图所示，非铁电体结构4覆盖了横过在导体3A，3B之间的间隙的铁电体结构2。从而，铁电体结构4的表面被处于一种完成状态但还在处理中，即当制作设备时的非铁电体结构4所保护。因为铁电体结构2被以这种方式保护，则铁电体结构将是稳定的并且其性能将是时间稳定的，即不随时间而恶化。此外，由于在铁电体结构界面有更高的控

制而在铁电体材料的表面层的缺陷更少，所以损耗将降低。替代两个电极，传导装置可以包括多于两个的电极，例如在电极 3A，3B 之间配置有一个或多个电极。

此外，非铁电体层将防止在可调谐铁电体材料中的雪崩式电击穿。

虽然，如图所示，非铁电体结构 4 只包括一层，应该理解，它也可以包括多层。

图 2 示出了一个与平面电容器 20 相关的实施例。与这一实施例有关，只给出了一些与仅仅用于示意性目的的尺度，数值等有关的附图。该设备包括一个基底 1'，例如为具有例如 0.5mm 厚度 H，和具有一个介电常数$\varepsilon_s = 25$ 的 $LaAlO_3$。在该基底顶部放置有一个例如为 STO 的铁电体层 2'，该铁电体层具有一个 h_f 为 0.25μm 的厚度和一个介电常数$\varepsilon_f = 1500$。其上放置了一个具有一个介电常数$\varepsilon_d = 10$ 的保护缓冲层 4'，它是一个非铁电体层。

在图 3 中公开了一个可选设备 30，其中包括多个子层的非铁电体结构 4''被放置在传导电极 3A'，3B'上部，而这两个传导电极被放置在基底 1''上。非铁电体的多层结构被沉积在一个可调谐铁电体材料 2''之上或之下。其工作过程基本与参照图 1 所描述的相同，除了由于铁电体层被放置在非铁电体层之上，即在电极之上，使得其结构与图 1 所示的相反。此外，非铁电体层包括多层结构。当然，在该实施例中，非铁电体层还可以包括单层。

图 4 示出料一个可调谐电容器 40，其中一个结构包括以交替方式放置的铁电体层 $2A_1$，$2A_2$，$2A_3$和非铁电体层 4 A_1，4 A_2，4 A_3。层数当然可以是任意的并不限于如图 4 所示的每种三层，主要是非铁电体层（在此为 4 A_1）是与传导装置 3 A_1，$3B_1$相接触地放置，并且还覆盖在电极之间的间隙中的铁电体层（在此为 2 A_1）。

这样一个交替放置结构当然还可以用于如图 3 所公开的“相反”结构中。

图 5 示出了另一个设备 50，其中以电极形式的第一传导装置 3 A_2，$3B_2$被放置在非铁电体层 4C 上，该铁电体层 4C 依次沉积在一个铁电体，有源层 2C 上。在铁电体层 2C 之下，另一个非铁电体层 4D 被提供在第二传导装置 3 A_3，$3B_3$所放置的另一端，这两个传导装置

被依次放置在一个基底1C之上。在此情形中，如图4所示，还使用了一个交替结构。

任何上述的材料还可以用于这些实例中。非铁电体材料可以是介电体，但是它不必是这种材料。它还可以是铁磁体。

任何实施例的有源铁电体层结构可以，例如，包括任何$SrTiO_3$,$BaTiO_3$,$Ba_xSr_{1-x}TiO_3$,PZT(锆钛酸铅)以及铁磁体材料。该缓冲层或保护性非铁电体结构可以，例如包括任何下列材料：CeO_2,MgO,YSZ(钇稳化锆)，$LaAlO_3$或其他具有适合的晶体结构的非导电材料，例如PrBCO($PrBa_2Cu_3O_{7-x}$)，非导电性$YBa_2Cu_3O_{7-x}$等。该基底可以包括$LaAlO_3$,MgO,R-切割或M－切割的蓝宝石，$SiSrRuO_3$或其他任何适宜的材料。应明确的是，上述许多例子并不是排外的，还有其他可能性存在。

在图6中，动态电容被示出为对于在此为电介质的非铁电体缓冲层4'的三个不同厚度的电压的函数。在此例中，平面电容器的长度假设为0.5mm，而导体3A',3B'之间的间隙为4μm。可以说一个磁壁被形成在基底和铁电体层2'之间。

电容值被示出为施加在对于电介质非铁电体缓冲层4'的三个不同值h_{10}=10nm,h_{30}=30mm,h_{100}=100nm的电极之间的电压的函数。该电容对于当在传导装置和铁电体层之间没有缓冲层的例子，还被示出为曲线h_0。从而，假设示出了与没有缓冲层的例子相比，可调谐性是如何随着一个对于一些厚度的缓冲层4'的加入而减小的。如所示，在可调谐性中的减小是显著的。

图7示出了当提供有一个缓冲层时（对应于上面的曲线A）和在没有提供缓冲层的情形下（对应于下面的曲线B），对于一个电容值的依赖于电压的Q值。从而，由实验性特性可知，对于一个电容器的Q值随着一个缓冲层的加入而相当大地增加。

除了如上所述的优点，在使用一个跨越有源（可调谐）铁电体层的缓冲层中是有利的，这是因为当一个导电性图案被刻蚀时，还可能在后续，在其下的层中产生刻蚀。从而，如果不保护在间隙中的铁电体材料的顶层，将会对它产生损害。

本发明的概念还可以被施加在谐振器上，诸如在同一专利人的专利号为No.9502137-4的瑞典专利申请“可调谐微波设备”中公开的谐

振器。本发明的概念还可以用于不同类型的微波滤波器中。一些其他申请当然也是可能的。在其他方面，本发明不限于具体示出的实施例，而是可以在权力要求的范围内有许多方式的变化。

说 明 书 附 图

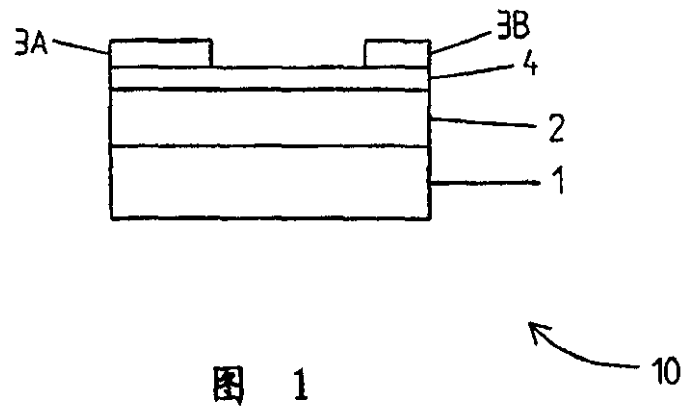
3A
3B
4
2
1
10

图 1

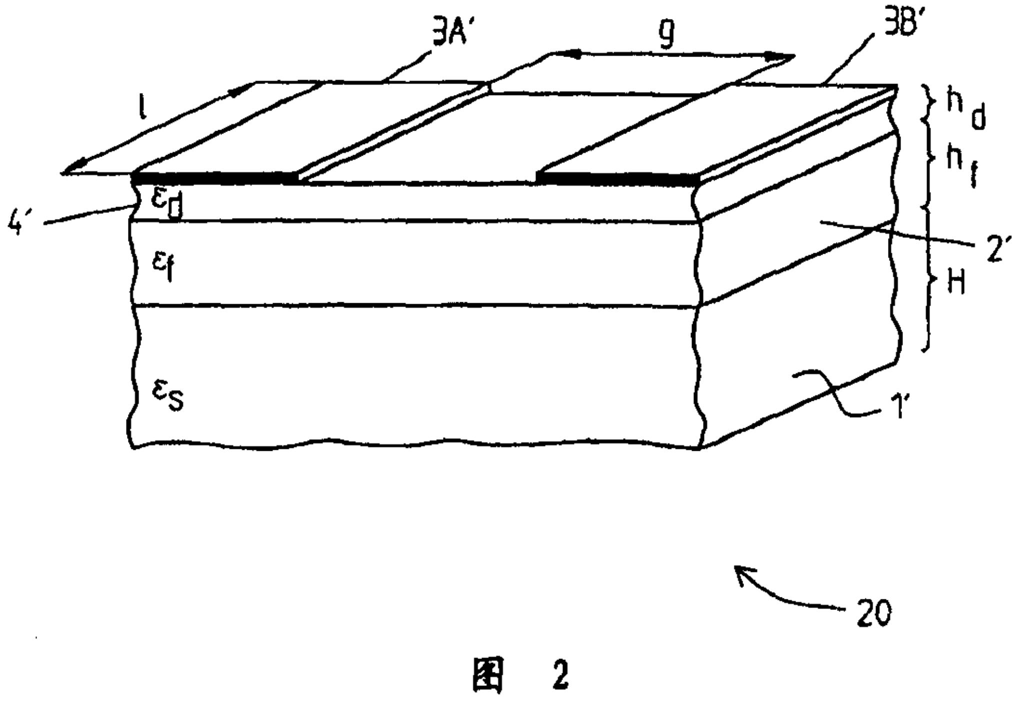
3A'
g
3B'
l
h_d
h_f
ε_d
4'
2'
ε_f
H
ε_s
1'
20

图 2

01·10·15

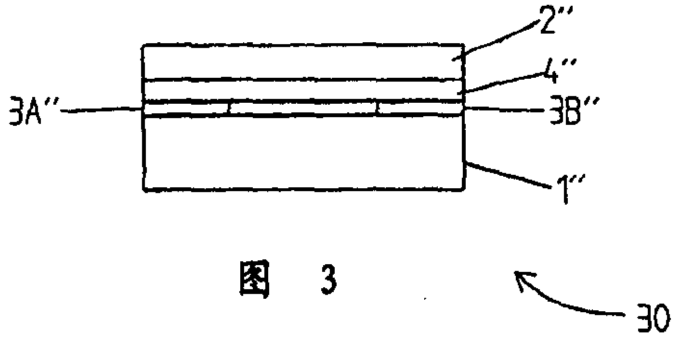

图 3

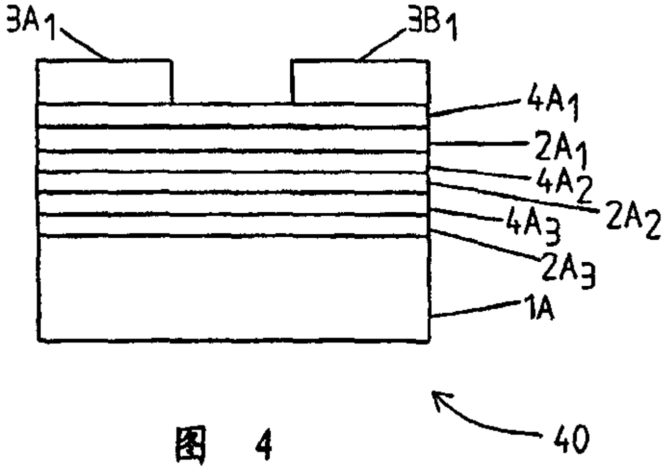

图 4

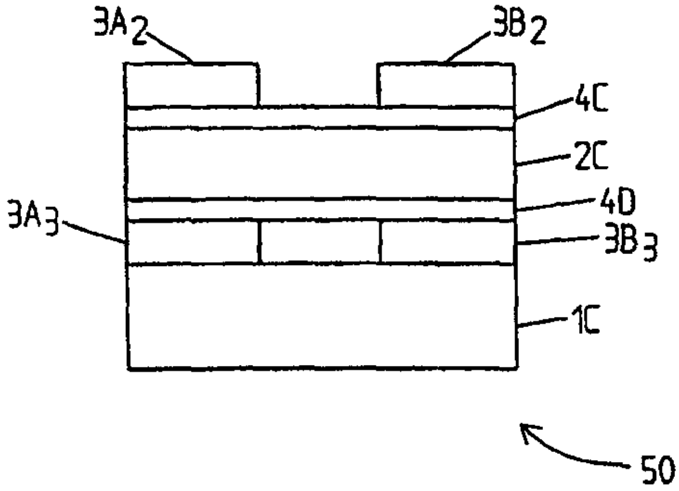

图 5

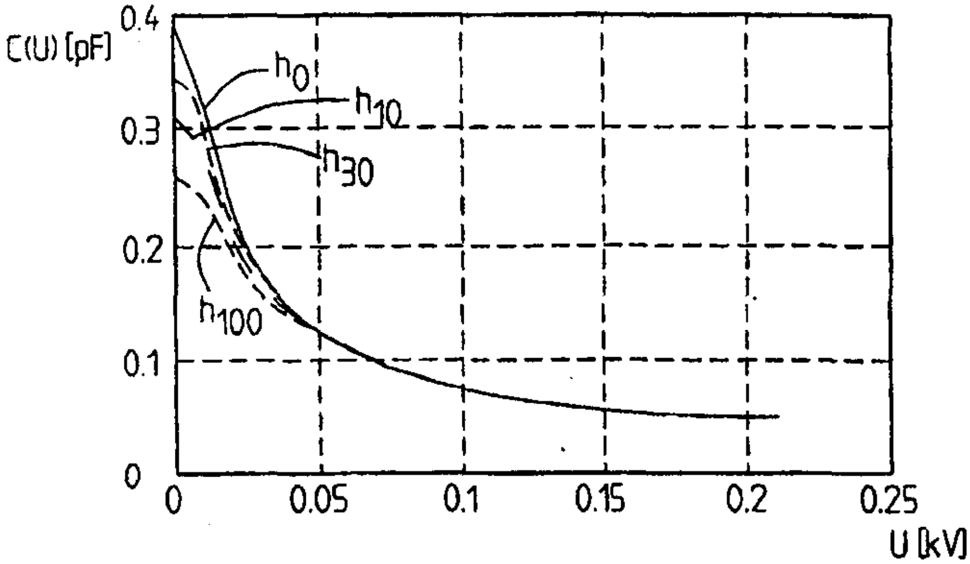
C(U) [pF]
0.4
0.3
0.2
0.1
0
h0
h10
h30
h100
0
0.05
0.1
0.15
0.2
0.25
U [kV]

图 6

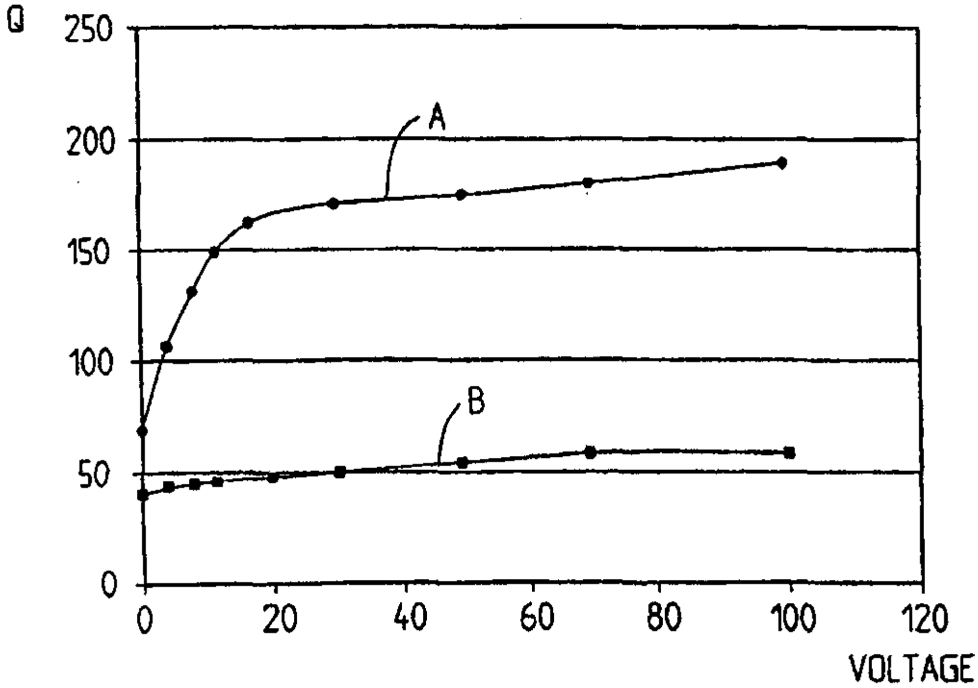
Q
250
200
150
100
50
0
A
B
0
20
40
60
80
100
120
VOLTAGE

图 7