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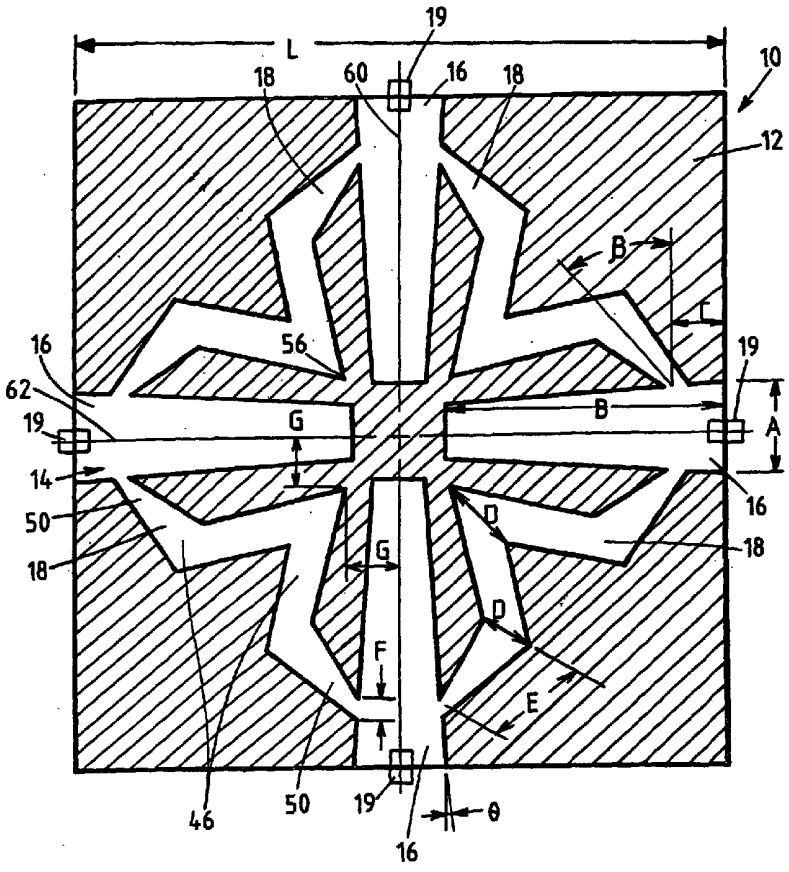
(54) Title: FORMING A COMPOSITE PRESSURE DIAPHRAGM WITH IMPLANTATIONS, EPITAXY, AND A SILICON NITRIDE LAYER



(57) Abstract: A method of forming a composite diaphragm for a pressure transducer is disclosed. The method comprises providing a substrate layer (p-type single crystal silicon) having a first conductivity type and a first surface. Positive implants are deposited in the first surface of the substrate layer, and an epitaxial layer (14) is grown on the first surface of the substrate layer so that the positive implants form positive diffusions in the epitaxial layer. An oxide pattern is formed on the epitaxial layer (14), and a top layer (12) (silicon nitride) is deposited over the epitaxial layer and oxide pattern. The substrate layer and positive diffusions of the epitaxial layer are then etched to form the composite diaphragm. The positive diffusions can be patterned so that the resulting etched structure has improved diaphragm performance characteristics. For example, the remaining pattern can include a plurality of bosses (16) and interconnecting battens (18) so that the diaphragm has a relatively high burst pressure and a high output signal with improved linearity at low pressures.

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FORMING A COMPOSITE PRESSURE DIAPHRAGM WITH IMPLANTATIONS, EPITAXY, AND A SILICON NITRIDE LAYER

FIELD OF THE INVENTION

The present invention generally relates to pressure transducers and, more particularly, to the diaphragm portions of such transducers.

BACKGROUND OF THE INVENTION

Pressure transducers that use piezoresistors are well known in the art. Generally, such transducers are formed with a silicon substrate and an epitaxial layer, which is grown on the substrate. A portion of the substrate is removed, leaving a thin, flexible diaphragm portion. The piezoresistors are located in the diaphragm portion to form a pressure transducer.

In operation, at least one surface of the diaphragm is exposed to a process pressure. The diaphragm deflects according to the magnitude of the pressure, and this deflection bends the attached piezoresistors. Bending of the diaphragm creates changes in the resistance value of the piezoresistors, which is reflected as a change in the output voltage signal of a resistive bridge formed at least partially by the piezoresistors.

The substrate and epitaxial layers are commonly formed of single crystal silicon. Diaphragm portions formed of single crystal silicon produce adequate results for pressures ranging from five inches H_2O to 6,000 PSI. Such material does not, however, produce a high output signal with sufficient linearity at pressures below 5 inches H_2O.

SUMMARY OF THE INVENTION

The following summary of the invention is provided to facilitate an understanding of some of the innovative features unique to the present invention and is not intended to be a full description. A full appreciation of the various aspects of the invention can be gained by taking the entire specification, claims, drawings, and abstract as a whole.

In accordance with certain aspects of the present invention, a method of forming a composite diaphragm for a pressure transducer or similar device is provided. The method comprises providing a substrate layer having a first conductivity type, the substrate layer having a first surface. Positive implants are deposited in the first surface of the substrate layer, and an epitaxial layer is grown on the first surface of the substrate layer so that the positive implants form positive diffusions in the epitaxial layer. An oxide pattern is formed on the epitaxial layer, and a top layer is deposited over the epitaxial layer and oxide pattern. The substrate layer and positive diffusions of the epitaxial layer are etched to form the composite diaphragm.

In accordance with additional aspects of the present invention, a composite diaphragm is provided for use in a pressure sensor or like device. The diaphragm comprises a first layer of silicon nitride and a second layer attached to the silicon nitride layer and comprising a pressure sensor pattern of silicon material.

The novel features of the present invention will become apparent to those of skill in the art upon examination of the following detailed description of the invention or can be learned by practice of the present invention. It should be understood, however, that the detailed description of the invention and the specific examples presented, while indicating certain embodiments of the present invention, are provided for illustration purposes only because various changes and modifications within the scope of the invention will become apparent to those of skill in the art from the detailed description of the invention and claims that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying figures, in which like reference numerals refer to identical or functionally-similar elements throughout the separate views and which are incorporated in and form part of the specification, further illustrate the present invention and, together with the detailed description of the invention, serve to explain the principles of the present invention.

FIG. 1 is a bottom view of a diaphragm portion of the pressure transducer illustrating a preferred boss and batten structure.

FIGs. 2A-2G illustrate various steps during the fabrication of the pressure transducer.

It should be understood that the drawings are not necessarily to scale and that the embodiments are illustrated using graphic symbols, phantom lines, diagrammatic representations and fragmentary views. In certain instances, details which are not necessary for an understanding of the present invention or which render other details difficult to perceive may have been omitted. It should be understood, of course, that the invention is not necessarily limited to the particular embodiments illustrated herein.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to FIG. 1, a bottom view of a diaphragm 10 for a pressure transducer is shown. The diaphragm 10 includes a layer 12 of first diaphragm material formed in a solid square having a length "L" on each side. A second, patterned layer 14 of diaphragm material is attached to the first layer 12. As illustrated in FIG. 1, the second layer 14 comprises four bosses 16 interconnected by four battens 18. While the boss and batten structure shown in FIG. 1 is preferred, it will be appreciated that a variety of different patterns can be formed in accordance with the present invention. Piezoresistors 19 are attached to the second layer 14 at the base of each boss 16.

To form the pressure transducer diaphragm 10 shown in FIG. 1, the steps depicted in FIGS. 2A-2G are followed. FIG. 2A shows the formation of a substrate 20 having a top surface 22 and a bottom surface 24. The substrate 20 can be formed in a variety of known manners and can comprise any one of a variety of known substrate materials. In the preferred embodiment, the substrate comprises single crystal silicon doped with a p-type material.

In FIG. 2B, the top surface 22 of the substrate 20 is coated with a photo resist pattern 26. A p-type material is then directed toward the top surface 22, such as with an ion implanter, so that the exposed areas of the top surface 22 receive the p-type material. The photo resist layer 26 is removed and an n-type epitaxial layer 28 is grown on the top surface 22, as best shown in FIG. 2C. The areas of the top surface 22 that were exposed during the p-type implant create p-type diffusions 30 in the n-type epitaxial layer 28.

As shown in FIG. 2D, an oxide layer 32 is deposited over the epitaxial layer 28, and a second photo resist layer 34 is patterned on the oxide layer 32. The photo resist layer 34 and exposed areas of the oxide layer 32 are bombarded with a p-type material to create p-type diffusions 36 in the epitaxial layer 28, as best shown in FIG. 2E. A top layer of diaphragm material 38 is deposited on top of the oxide layer 32, and a bottom layer of diaphragm material 40 is deposited over the bottom layer 24 of the substrate 20 (FIG. 2F). In the preferred embodiment, the top layer 38 and bottom layer 40 comprise silicon nitride. The top and bottom layers 38, 40 can be deposited

in a known manner, such as by chemical vapor deposition, plasma deposition, or RF sputtering.

The composite structure is then etched so that the p-type diffusions 30, 36 and much of the substrate 20 are removed. During the etching step, the composite structure is preferably placed in a tank of etchant and a stop-etch process is used to remove the p-type material. A stop-etch process is described in commonly assigned U.S. Patent No. 5,360,521, which is incorporated herein by reference.

After the etching step, the structure shown in FIG. 2G remains. As shown therein, the top layer 38 has a substantially uniform thickness across the entire diaphragm, with remaining portions of the n-type epitaxial layer 28 attached to the top layer 38. In the illustrated embodiment, the top layer 38 corresponds to the first layer of diaphragm material 12 shown in FIG. 1. Similarly, the epitaxial layer 28 corresponds to the patterned layer 14, where the remaining portions of the layer 28 form the bosses 16 and battens 18. It will be appreciated, however, that any desirable pattern can be formed in addition to the preferred boss and batten pattern illustrated at FIG. 1. The remaining substrate and bottom layers 20, 40 provide structure for mounting the diaphragm 10 as necessary.

The resulting transducer structure provides a diaphragm having a composite construction that can be adapted to particular design specifications. The boss and batten pattern illustrated at FIG. 1 produces a high output signal with good linearity at low pressure levels, such as 5 inches H_2O. Each boss 16 is formed with an outside width "A" and a length "B." The battens 18 intersect each associated boss 16 at an edge distance "C." Each batten 18 comprises a pair of angled leg portions 46 having a width "D" and a pair of connecting portions 50 having a length "E." Each connecting portion 50 has a width "F" at the point of intersection with an associated boss 16. The leg portions 46 intersect at a point 56 that is an equal distance "G" from center lines 60, 62 of the bosses 16. Each connecting portion 50 intersects in an associated 16 at an angle "β". Furthermore, each boss 16 is preferably tapered at an angle "θ".

In a representative boss and batten embodiment, A is 200 μm, B is 560 μm, C is 180 μm, D is 115 μm, E is 225 μm, F is 15 μm, G is 180 μm, L is 1400 μm, β is 60 degrees, and θ is 6 degrees. The top layer 38 is preferably approximately 2.0 μm and the intermediate layer 30 is approximately 10.5 μm, for an overall diaphragm thickness of approximately 12.5 μm. Each of these dimensions can be adjusted to vary the performance characteristics of the diaphragm 10. For example, the span, defined herein as the algebraic difference between limits of the pressure range, can be increased by decreasing the boss outside width "A," the leg portion width "D," the connecting portion with "F," the intersection point distance "G," and the intersect angles "β," or by increasing the edge distance "C," the connecting portion length "E," and the boss taper angle "θ." Furthermore, a terminal base linearity of the diaphragm 10 can be decreased by decreasing the boss outside width "A," the boss length "B," the connecting portion length "E," and the boss taper angle "θ," or by increasing the edge distance "C," leg portion width "D," connecting portion width "F," intersection point distance "G," and intersect angle "β." Furthermore, it will be appreciated that the span and terminal base linearity will increase as the length "L" of the diaphragm increases.

The embodiments and examples set forth herein are presented to best explain the present invention and its practical application and to thereby enable those skilled in the art to make and utilize the invention. Those skilled in the art, however, will recognize that the foregoing description and examples have been presented for the purpose of illustration and example only. Other variations and modifications of the present invention will be apparent to those of skill in the art, and it is the intent of the appended claims that such variations and modifications be covered. The description as set forth is not intended to be exhaustive nor to limit the scope of the invention. Many modifications and variations are possible in light of the above teaching without departing from the spirit and scope of the following claims. It is contemplated that the use of the present invention can involve components having different characteristics. It is intended that the scope of the present invention be defined by the claims appended hereto, giving full cognizance to equivalents in all respects.

CLAIMS

The embodiments of an invention in which an exclusive property or right is claimed are defined as follows:

1. A method of forming a composite diaphragm (10) for a pressure device, the method comprising the steps of:

providing a substrate layer (20) having a first conductivity type, the substrate layer (20) having a first surface (22);

depositing implants in the first surface (22) of the substrate layer (20);

growing an epitaxial layer (28) on the first surface (22) of the substrate layer (20), the implants forming diffusions (30, 36) in the epitaxial layer (28);

forming an oxide pattern (32) on the epitaxial layer (28);

depositing a top layer (38) over the epitaxial layer (28) and oxide pattern (32); and

etching the substrate layer (20) and diffusions (30, 36) of the epitaxial layer (28) to form the composite diaphragm (10).

2. The method of claim 1, wherein the implants are positive implants and the diffusions (30, 36) are positive diffusions.

3. The method of claim 1, in which the substrate layer (20) comprises a p-type single crystal silicon material.

4. The method of claim 1, in which the positive implants are deposited using an ion implanter.

5. The method of claim 1, in which the top layer (38) comprises silicon nitride.

6. The method of claim 5, in which the substrate layer (20) comprises a p-type single crystal silicon material.

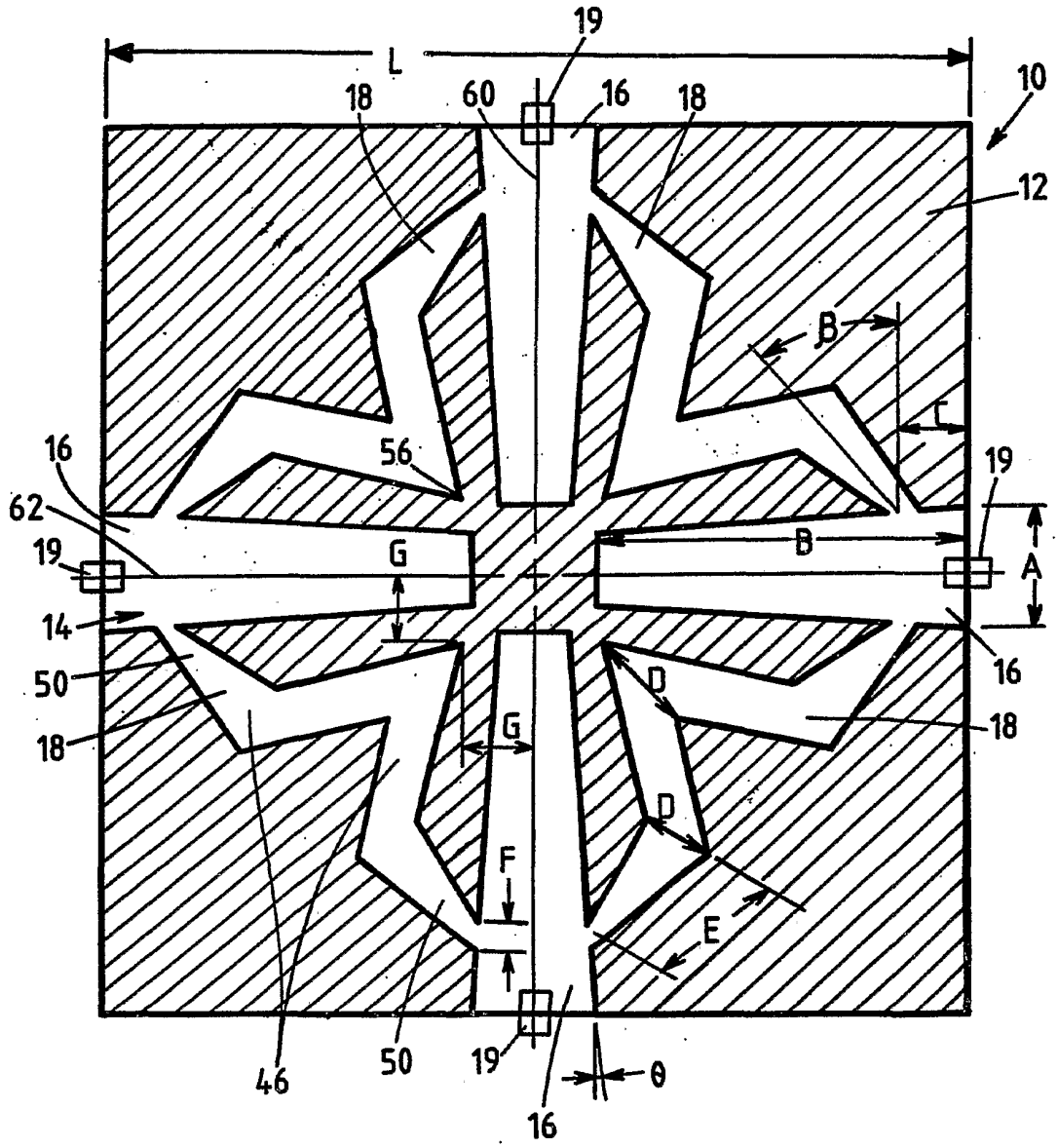
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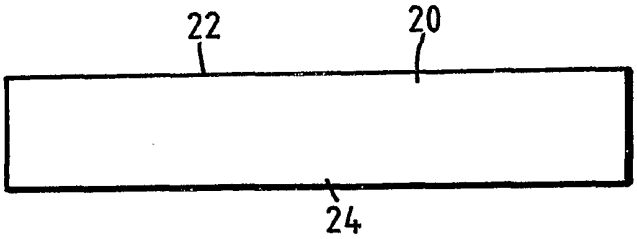
FIG. 1

FIG. 2A



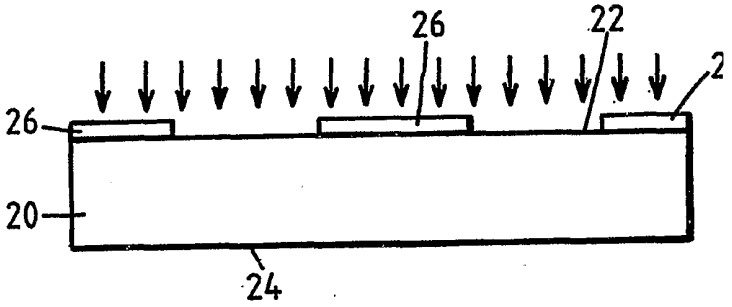


FIG. 2B

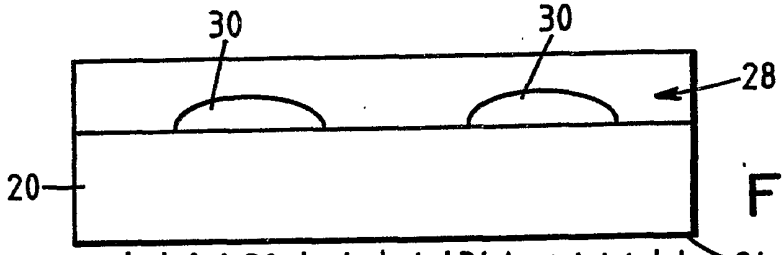


FIG. 2C

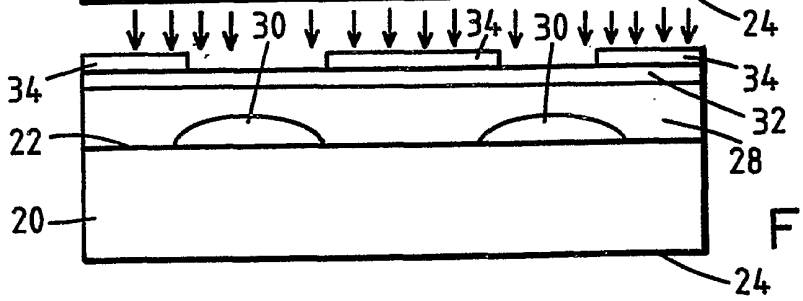


FIG. 2D

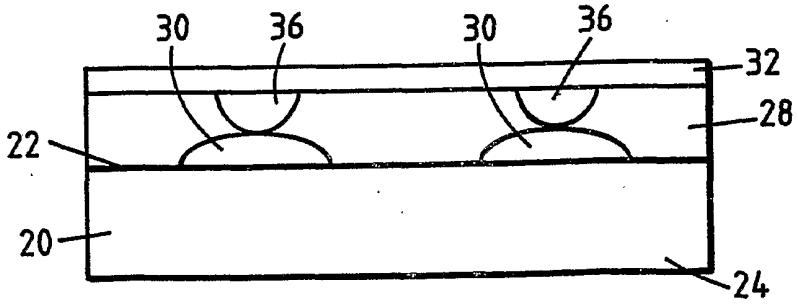


FIG. 2E

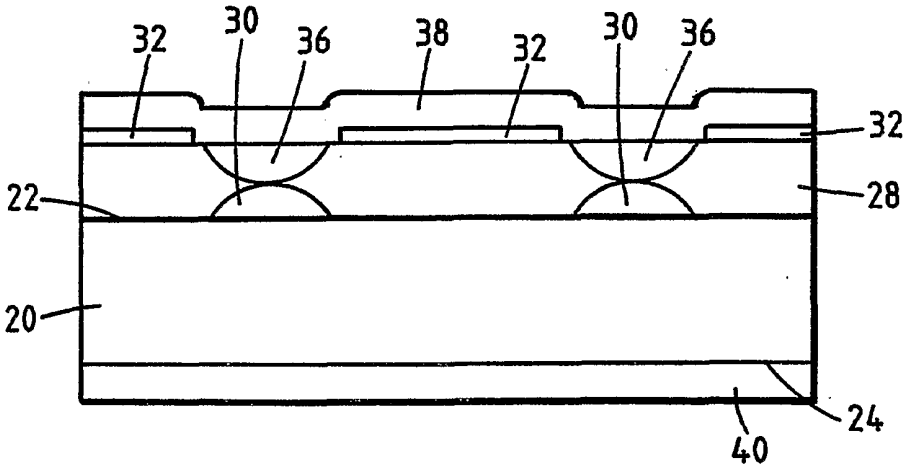


FIG. 2F

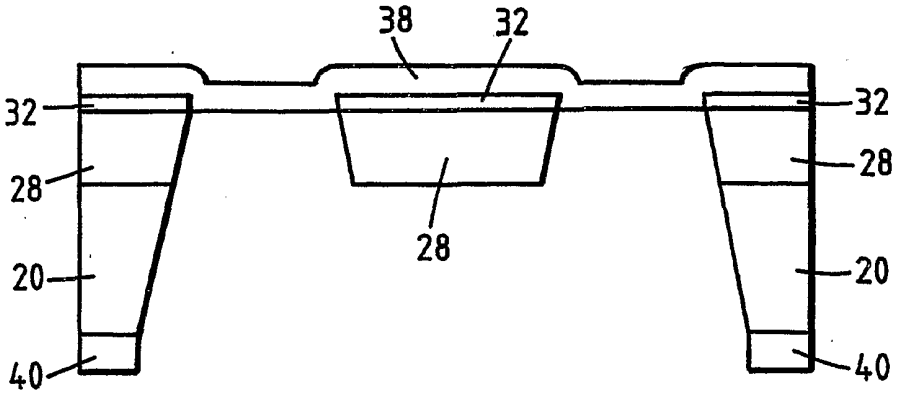


FIG. 2G

INTERNATIONAL SEARCH REPORT

national Application No
PCT/US 01/51357

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01L7/08 H01L29/84

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)
IPC 7 G01L H01L

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 5 583 296 A (FRAUNHOFER GESELLSCHAFT) 10 December 1996 (1996-12-10) column 4, line 16 - line 18; figure 3A ---	
A	US 6 093 579 A (EXAR) 25 July 2000 (2000-07-25) column 2, line 55 - line 67; figures 2A,B ---	
A	US 6 140 143 A (LUCAS NOVASENSOR) 31 October 2000 (2000-10-31) column 3, line 34 - line 50; figures 3A-C ---	
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 May 2002	05/06/2002

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

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national Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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national Application No
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