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(54) **ULTRASOUND TRANSDUCER ASSEMBLY AND METHOD FOR MANUFACTURING AN ULTRASOUND TRANSDUCER ASSEMBLY**

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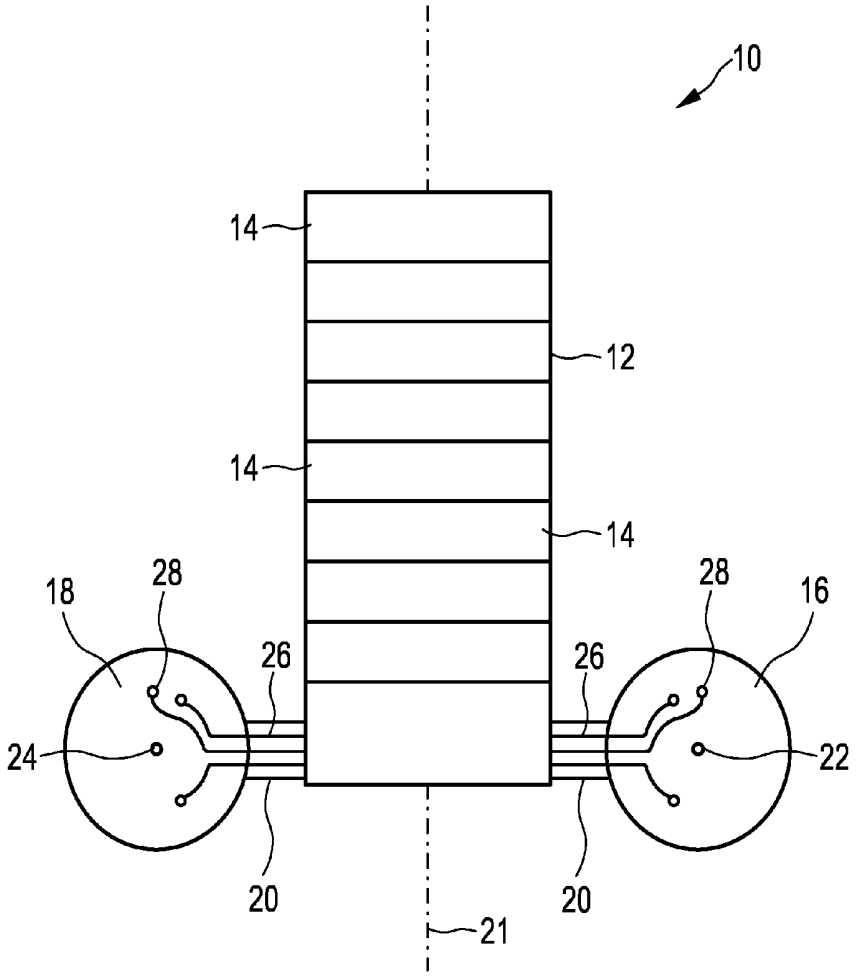
(57) **ABSTRACT**

The present invention relates to an ultrasound transducer assembly (**10**), in particular for intra vascular ultrasound systems. The assembly (**10**) comprises a transducer array (**12**) including a plurality of transducer elements (**14**) for transmitting and receiving ultrasound waves. Two support elements (**16**, **18**) are provided for supporting the transducer array (**12**) in a curved or polygonal shape. The support elements (**16**, **18**) are connected via a flexible connection layer (**20**) to the transducer array (**12**) for flexibly connecting the support elements (**16**, **18**) to the transducer array (**12**).



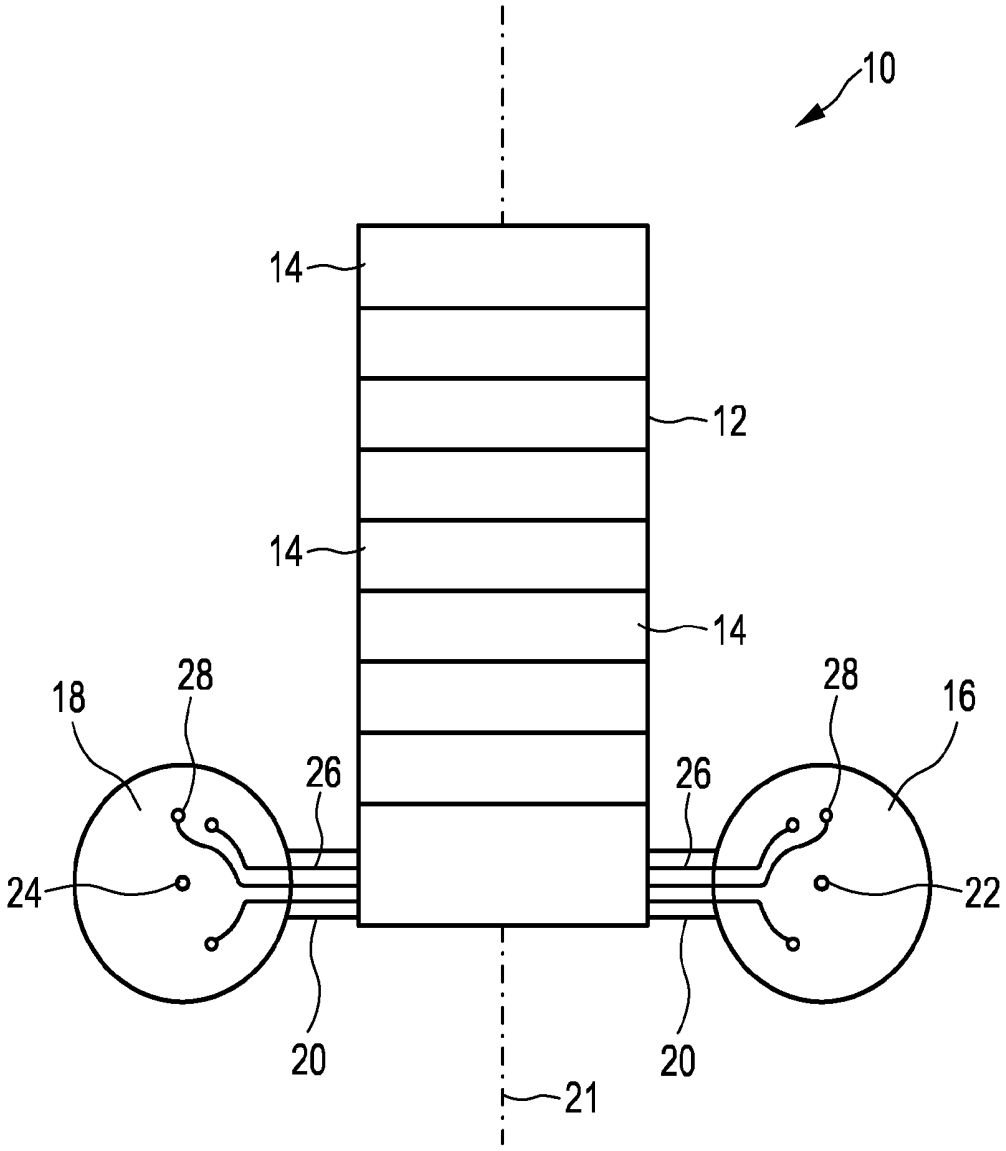


FIG. 1

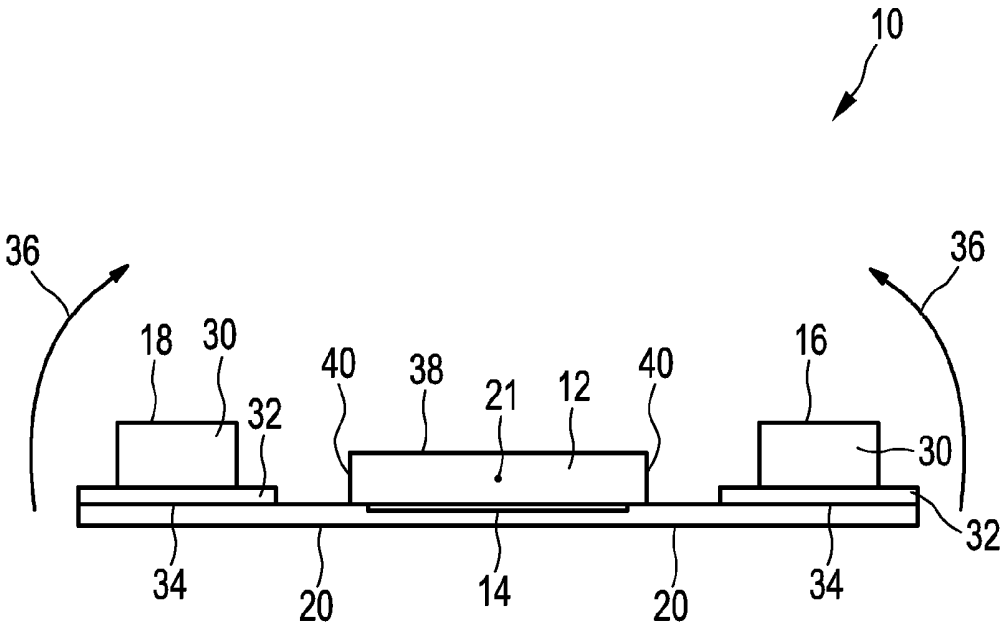


FIG. 2

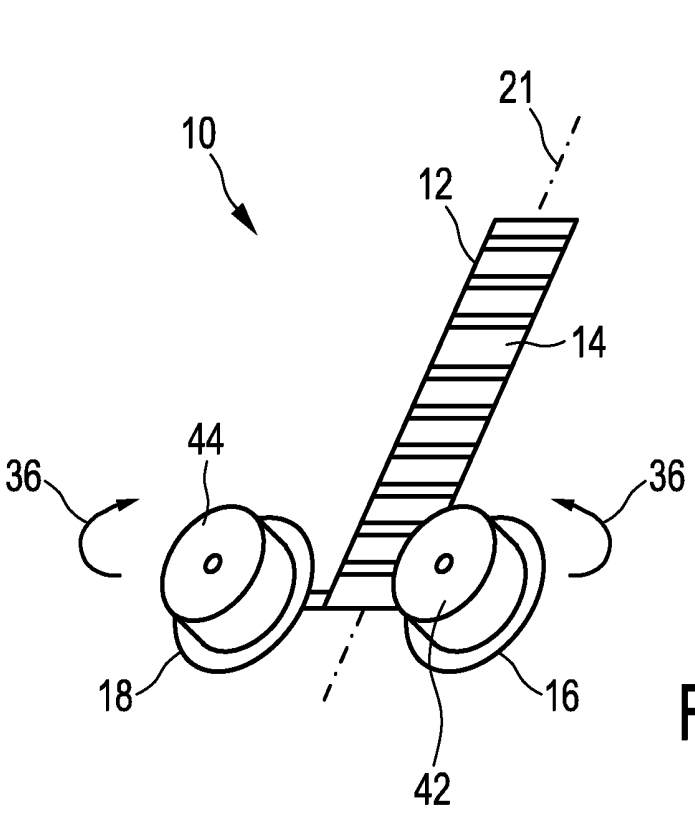


FIG. 3a

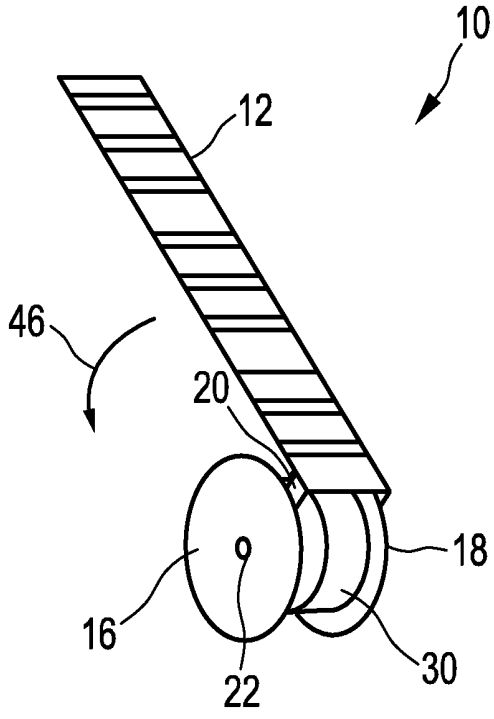


FIG. 3b

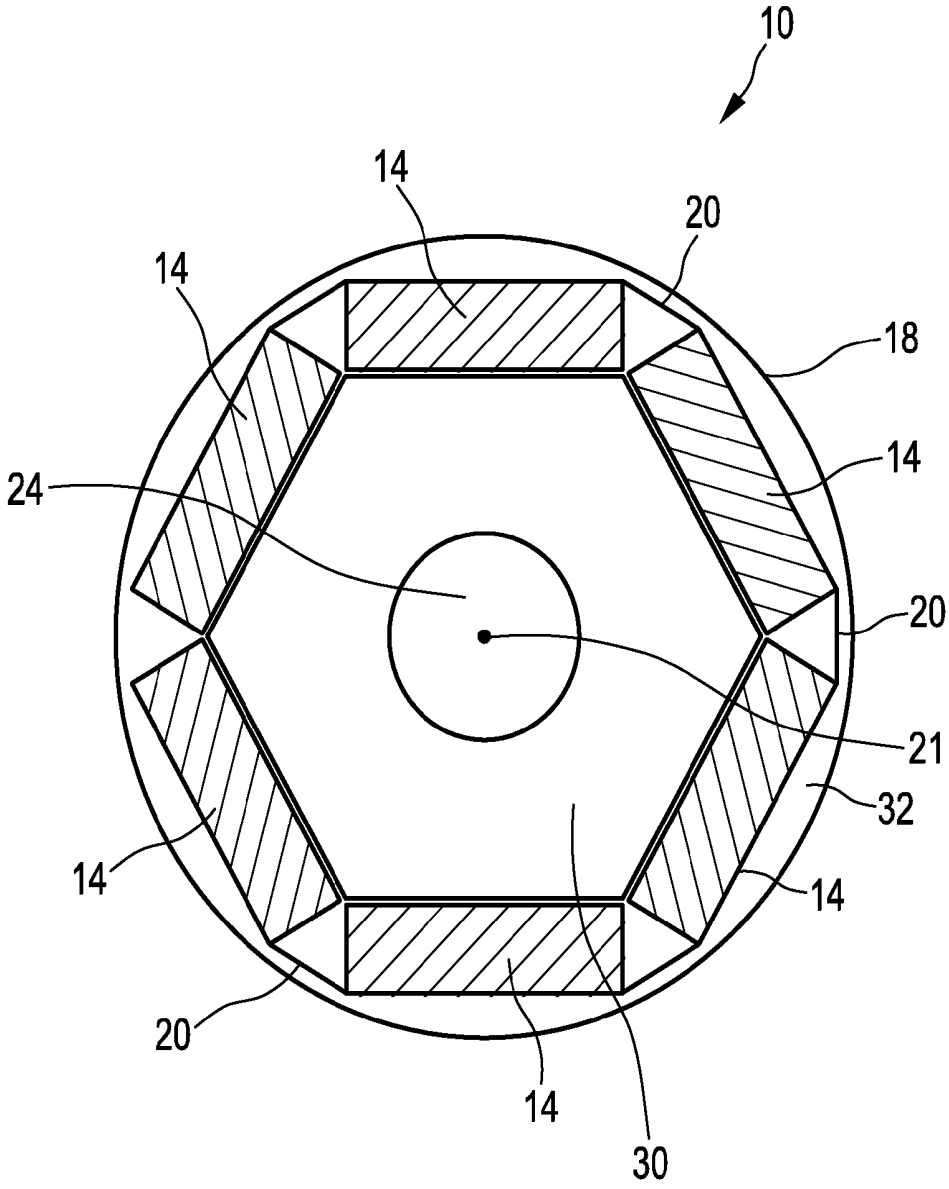


FIG. 4

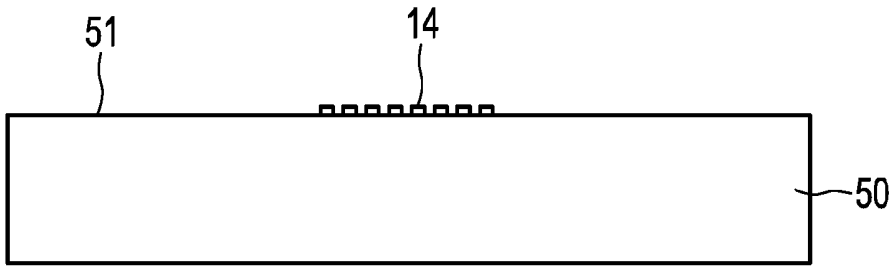


FIG. 5a

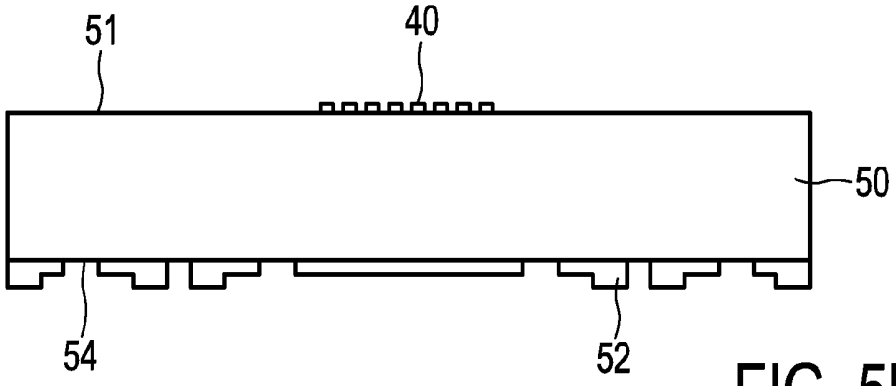


FIG. 5b

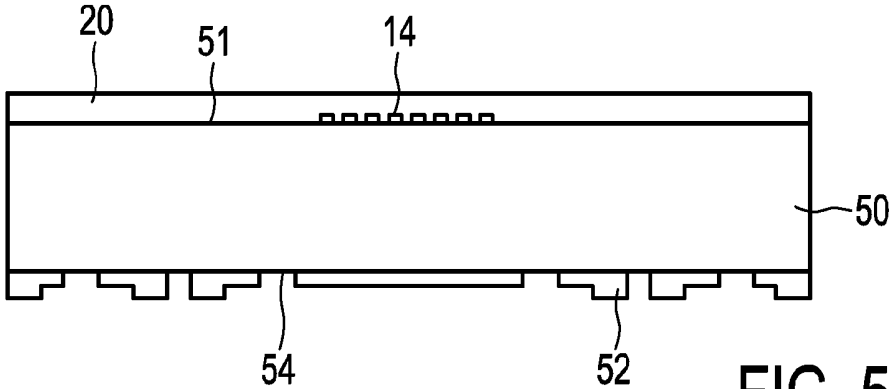


FIG. 5c

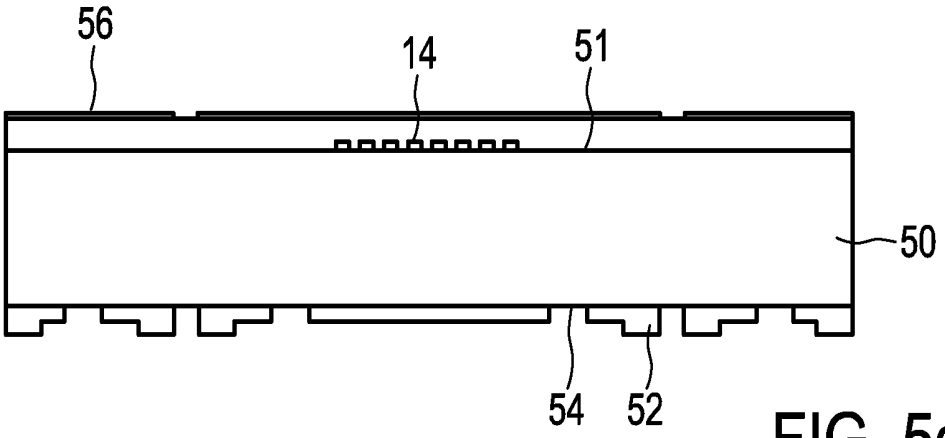


FIG. 5d

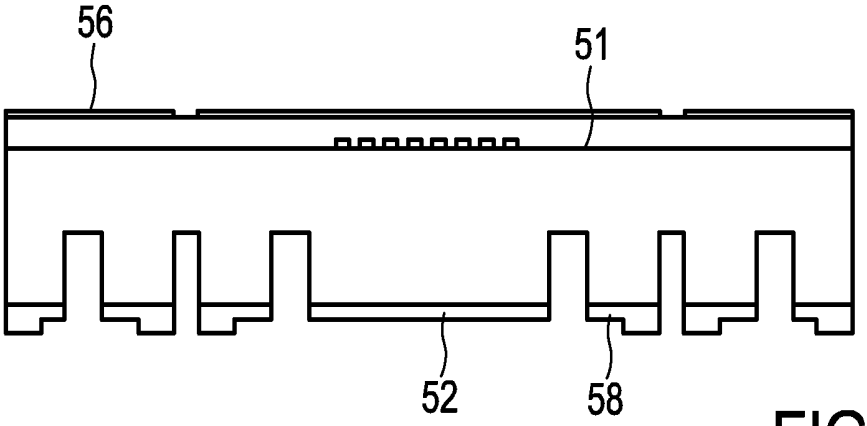


FIG. 5e

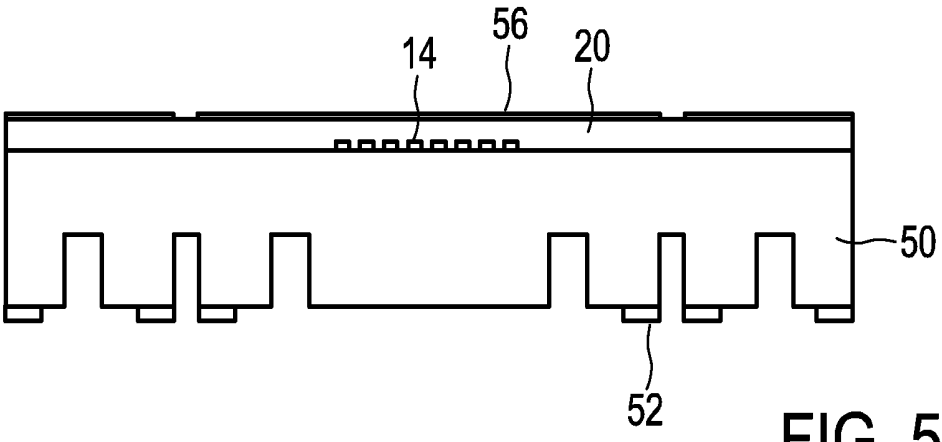


FIG. 5f

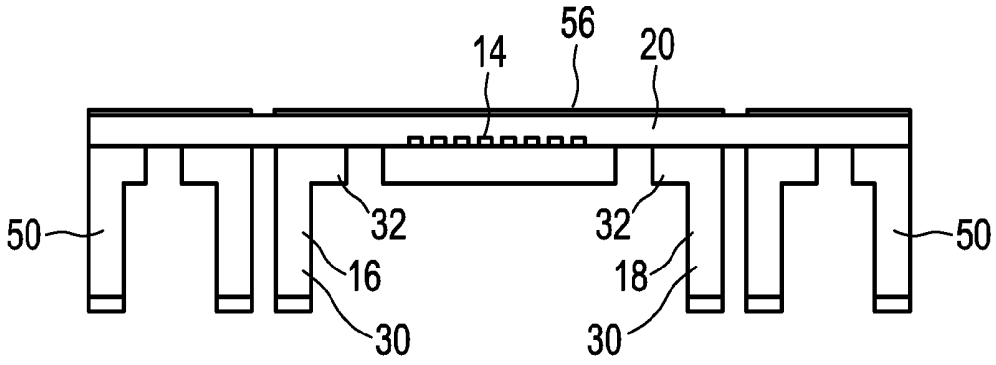


FIG. 5g

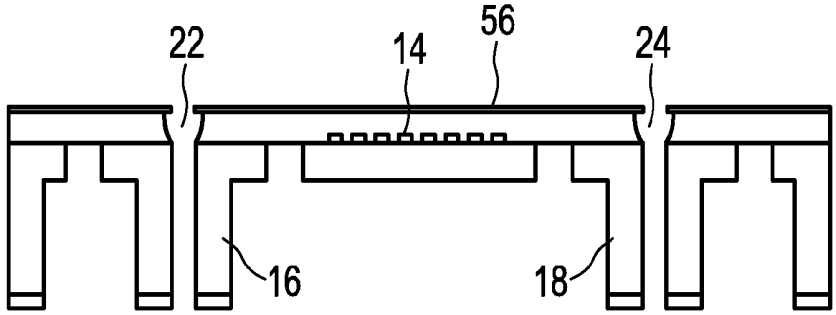


FIG. 5h

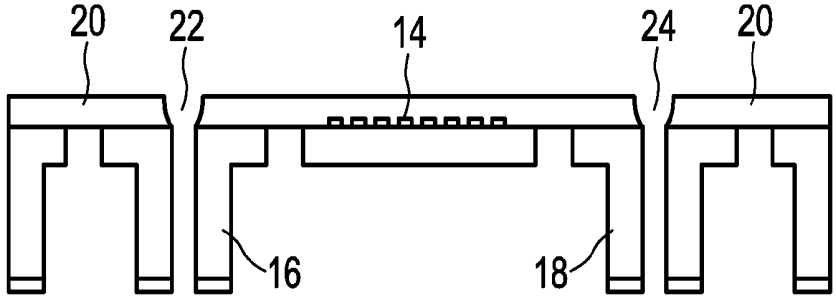


FIG. 5i

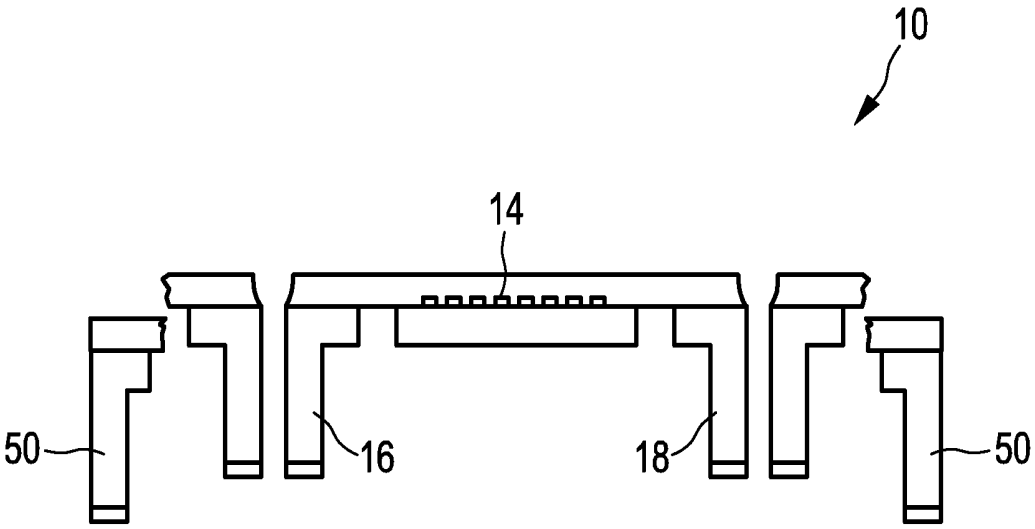


FIG. 5k

ULTRASOUND TRANSDUCER ASSEMBLY AND METHOD FOR MANUFACTURING AN ULTRASOUND TRANSDUCER ASSEMBLY

FIELD OF THE INVENTION

[0001] The present invention relates to an ultrasound transducer assembly, in particular a capacitive micro-machined ultrasound transducer (CMUT) cell for intra vascular ultrasound transducer and a method of manufacturing the same. The present invention relates further to an ultrasound transducer.

BACKGROUND OF THE INVENTION

[0002] In the field of intra vascular ultrasound devices, it is generally known to mount an ultrasound transducer on the tip of a catheter to form a radial ultrasound image e.g. of a blood vessel or the surrounding tissue. The ultrasound transducer elements may be rotated in order to emit and receive ultrasound waves in a radial direction of the catheter tip.

[0003] It is further known to replace the mechanically scanning ultrasound transducer elements in the intra vascular ultrasound devices by electronically scanning devices having an annular array of ultrasound transducer elements. The ultrasound transducer elements used for the electronically scanning intra vascular ultrasound systems are usually based on ceramic piezo-electric material, wherein the fabrication of these devices is expensive and complex and the transducer elements cannot be scaled down to reduce the size of the intra vascular transducer.

[0004] Capacitive micro-machined ultrasound transducers (CMUT) are manufactured on the basis of a silicon wafer by means of IC process technologies and can be manufactured with low costs and can be scaled down to the dimensions of an intra vascular ultrasound transducer. For manufacturing an annular ultrasound transducer array, a semi-flexible ultrasound transducer array is formed on the basis of a silicon wafer substrate wrapped or bend around and attached to a cylindrically shaped submount structure in order to form the annular array and to transmit and receive ultrasound waves in the radial direction of a catheter.

[0005] A bendable micro machine ultrasound transducer array which can be attached to a cylindrical submount structure to form the cylindrically shaped ultrasound transducer array is known from US 2005/0146247 A2.

[0006] The submount structure for supporting the flexible ultrasound transducer array has to be fabricated with high precision and the mounting of the ultrasound transducer array on the submount structure is difficult and requires high precision alignment and complex handling equipment in order to produce the annular shaped ultrasound transducer array for intra vascular ultrasound systems.

[0007] WO 2012/066430 A1 discloses an ultrasound imaging apparatus suitable for minimally invasive ultrasound diagnostic devices in cardiac ablation monitoring and in tumor ablation monitoring, wherein the transducer assembly and the transducer system is manufactured on a patterned flexible foil by embedding transducer patches in apertures of the foil surface.

SUMMARY OF THE INVENTION

[0008] It is an object of the present invention to provide an improved ultrasound transducer assembly, in particular for intra vascular ultrasound systems having a reduced size and which can be produced precisely with low technical effort.

[0009] In a first aspect of the present invention, an ultrasound transducer assembly, in particular for intra vascular ultrasound systems is provided comprising:

[0010] a transducer array including a plurality of transducer elements for transmitting and receiving ultrasound waves,

[0011] two support elements flexibly connected to opposite sides of the transducer array for supporting the transducer array in a curved or polygonal shape, and

[0012] a flexible connection layer connected to the transducer array and to the support elements for flexible connecting the support elements to the transducer array.

[0013] In a further aspect of the present invention, a method for manufacturing an ultrasound transducer assembly, in particular for intra vascular ultrasound systems, is provided comprising the steps of:

[0014] providing a transducer array connected to a transducer support portion of a substrate,

[0015] connecting a flexible connection layer to the substrate,

[0016] separating a portion of the substrate from the transducer support portion to form a support element for supporting the transducer portion so that the support element is connected to the transducer portion via a flexible layer, and

[0017] bending the flexible connection layer to connect the support element to the transducer support portion.

[0018] In a still further aspect of the present invention, an ultrasound transducer, in particular for intra vascular ultrasound systems is provided, comprising an elongated probe including a tip and an ultrasound transducer that comprises an ultrasound transducer assembly of this kind.

[0019] Preferred embodiments of the invention are defined in the dependent claims. It should be understood that the claimed method has similar and/or identical preferred embodiments as the claimed device and as defined in the dependent claims.

[0020] The present invention is based on the idea to manufacture the transducer elements and the support elements in the same micro-fabrication process to reduce the manufacturing effort and to connect the transducer array and the support element via a flexible connection layer in the same manufacturing process so that the support elements and the transducer elements can be assembled to each other precisely with low technical effort. The ultrasound transducer assembly can be assembled by bending the support element via the flexible connection layer to the transducer array for supporting the transducer array in the curved or polygonal shape. Hence, the manufacturing effort is reduced since the support element and the transducer array are preassembled by means of the flexible connection layer and the precision of the assembling is increased, since the flexible connection layer connects the support element and the transducer array in a predefined position. Further, the size of the ultrasound transducer assembly can be reduced, since the transducer array and the support element can be manufactured in a micro-fabrication process.

[0021] In a preferred embodiment, the connection layer comprises electrical interconnects for electrically connecting the transducer elements to the support elements. This is a possibility to further reduce the manufacturing effort, since the electrical connection of the transducer elements is integrated in the transducer assembly.

[0022] In a further preferred embodiment, the support element comprises at least two electrical contact portions for electrically connecting the transducer assembly to a driver device. This is a possibility to connect the ultrasound transducer assembly with low technical effort to a driver device e.g. by means of a connector or a plug.

[0023] In a preferred embodiment, the support element comprises a support portion having a circular or polygonal shape. This is a possibility to define the outer form of the ultrasound transducer assembly and to support the transducer array in a predefined shape.

[0024] It is further preferred that the support element comprises a connection portion having a larger diameter than the support portion, wherein the connection portion is connected to the connection layer. Hence, the transducer array can be supported in a radial direction by means of the support portion and in an axial direction by means of the connection portion which has a larger diameter than the support portion so that the assembled ultrasound transducer assembly has a solid main body.

[0025] In a further preferred embodiment, the connection layer is connected to an end face of the support element. This is a possibility to further reduce the manufacturing effort, since the support element and the transducer array can be connected to a plane surface to the flexible connection layer.

[0026] In a further preferred embodiment, the support element comprises a central recess for supporting the ultrasound transducer assembly. This is a possibility to mount the transducer assembly coaxial to a catheter tip or the like by means of a single connection bolt connectable to the recess.

[0027] The ultrasound transducer assembly comprises two support elements flexible connected to opposite sides of the transducer array. This is a possibility to further improve the stability of the ultrasound transducer assembly since the transducer array can be supported at opposite sides.

[0028] In a preferred embodiment, the flexible layer is a polyimide layer or a parylene layer. This is a simple possibility to provide the flexible connection between the support element and the transducer array with low technical effort.

[0029] In a preferred embodiment, the assembly has a cylindrical or a multifaceted shape, wherein the transducer elements are disposed at a circumferential surface of the ultrasound transducer assembly in order to transmit and receive the ultrasound waves in a radial direction. This is a possibility to transmit and receive ultrasound waves in a radial direction and to combine the ultrasound transducer assembly with a catheter or the like to form an intra vascular ultrasound system.

[0030] In a preferred embodiment of the method for manufacturing an ultrasound transducer assembly, the substrate is covered by an etch mask at a surface opposite to the flexible layer. This is a possibility to separate the support element from the transducer array with low technical effort while the support element and the transducer array are still connected via the flexible layer.

[0031] In a preferred embodiment, the support element is separated by dry etching of the substrate. This is a simple solution to provide a support element having a precise and predefined shape with low technical effort.

[0032] It is further preferred that the ultrasound transducer assembly comprising the transducer array and the support element is separated from the substrate by dry etching of the substrate and by mechanically separating the flexible layer. This is a simple possibility to define the transducer assembly within the substrate and to extract the transducer assembly from the substrate with low technical effort by breaking the elements defined by the dry etching process out of the substrate.

[0033] As mentioned above, due to the flexible layer connecting the support element and the transducer array, the ultrasound transducer assembly can be assembled by bending the support element to the transducer array so that the transducer elements can be connected to the support element in a curved or polygonal shape. Since the transducer array and the support element are formed from a silicon substrate by means of a micro-fabrication process, the ultrasound transducer assembly can be scaled down and provided with small dimensions so that the ultrasound transducer assembly can be used for intra vascular ultrasound systems and can be manufactured with high precision and low technical effort.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter. In the following drawings

[0035] FIG. **1** shows a schematic drawing of an ultrasound transducer assembly in a plane view before assembling;

[0036] FIG. **2** shows a schematic drawing of the transducer assembly of FIG. **1** in a side view;

[0037] FIG. **3***a, b* show perspective views of the ultrasound transducer assembly for illustrating the assembling thereof;

[0038] FIG. **4** shows a schematic cross section of the assembled ultrasound transducer assembly in an axial view; and

[0039] FIG. **5***a-k* show a sequence of manufacturing steps for manufacturing the ultrasound transducer assembly.

DETAILED DESCRIPTION OF THE INVENTION

[0040] FIG. **1** shows a schematic top view of an ultrasound transducer assembly generally denoted by **10**. The transducer assembly comprises a transducer array **12** including a plurality of transducer elements **14** for emitting and receiving ultrasound waves. The transducer assembly **10** comprises two support elements **16**, **18** which serve as submount elements for the transducer array **12**. The support elements **16**, **18** have a circular shape and are connected to the transducer array **12** by means of a flexible connection layer **20**. The transducer array **12** has an elongated shape in the direction of longitudinal axis **21**.

[0041] The transducer elements **14** are formed as capacitive micro-machined ultrasound transducers (CMUT). The transducer elements **14** are flexibly connected to each other so that the transducer array **12** can be bent in order to form an annular, circular or polygonal transducer array **12** as described in the following. The transducer elements **14** can be flexibly connected to each other by means of a flexible layer, which may be connected in one piece to the connection layer **20**.

[0042] The support elements **16**, **18** each comprise a central recess **22**, **24** or a central opening **22**, **24** or a central hole **22**, **24** in order to support the transducer assembly **10**. The flexible connection layer **20** flexibly connecting the support elements **16**, **18** to the transducer array **12** comprises integrated electrical interconnects **26** for electrically connecting the transducer elements **14** to the support elements **16**, **18**. Preferably, the electrical interconnects **26** are connected to electrical connection elements **28** or bond bads **28** formed at a surface of the support elements **16**, **18** in order to electrically

connect the transducer elements **14** to a driver device for driving the transducer array **12**. Each of the transducer elements **14** may be connected to one connection element **28** of the first support element **16** and to one of the connector elements of the second support element **18** in order to drive each of the transducer elements **14** separately. The electrical interconnects **26** may be integrated in the connection layer **20** or may be printed on the connection layer **20**.

[0043] The transducer assembly **10** is made from a silicon wafer by means of a micro-fabrication process using integrated circuit processing technology to form the transducer array **12** and the support elements **16**, **18**. The silicon wafer may be a blank wafer or may include preprocessed active devices or circuits like CMOS transistors.

[0044] The transducer elements **14**, **18** may consist of silicon islands containing CMUT transducers connected to each other by means of the flexible connection layer **20**.

[0045] The support elements **16**, **18** are connected to the transducer array **12** by means of the flexible connection layer **20** so that the support elements **16**, **18** can be bended by 90° so that the flexible transducer array **12** can be wrapped around the support element **16**, **18** in order to form the transducer assembly **10** in a cylindrical form as further described in the following.

[0046] The embodiment shown in FIG. **1** comprises a linear array of transducer elements **14**, however, any shape and any formation of transducer elements **14** is possible and can be used by the present invention, e.g. circular or polygonal transducer elements which are disposed in a one dimensional array or a two dimensional array including columns and rows of transducer elements **14** which may be alternatingly displaced.

[0047] FIG. **2** shows a schematic diagram of the transducer assembly **10** in a side view along the longitudinal axis **21** of the transducer array **12**. The transducer array **12** comprises the transducer elements **14** and is attached to the flexible connection layer **20**, which is preferably formed as one piece. The support elements **16**, **18** have a cylindrical shape including a support portion **30** and a connection portion **32**, wherein the connection portion **32** has a larger diameter than the support portion **30**. In other words, the support elements **16**, **18** have a "champagne cork" shape. A base surface **34** or an end face **34** of each the connection portions **32** of the support elements **16**, **18** are connected to the flexible connection layer **20**. The support elements **16**, **18** and the transducer array **16** are separated by a distance from each other and connected to each other only by means of the flexible connection layer **20**.

[0048] In order to assemble the transducer assembly **10**, the support elements **16**, **18** are bended around the longitudinal axis **21** of the transducer array **12** as indicated by arrows **36**.

[0049] In the fully assembled state, the circumferential surfaces of the support portions **30** are attached to a backside surface **38** of the transducer array **12** in order to support the transducer array **12** and to stabilize the form of the assembled transducer assembly **10**. The connection portion **32** of the support elements **16**, **18** abut at a side surface **40** of the transducer array **12** in order to support the transducer array **12** in the axial direction of the assembled transducer assembly **10**.

[0050] FIG. **3***a, b* show schematic perspective views of the transducer assembly **10** to explain the assembling of the transducer assembly **10**. Identical elements are denoted by identical reference numerals, wherein here merely the differences are explained in detail.

[0051] In a first step, the support elements are bended around the longitudinal axis **21** of the transducer array **12** so that inner end faces **42**, **44** of the support elements **16**, **18** may be attached to each other, e.g. by an adhesive or by soldering.

[0052] In FIG. **3***b*, the support elements **16**, **18** are attached to each other at their inner end faces **42**, **44** to form a cylindrical element to support the transducer array **12**. The flexible transducer array **12** is bended as indicated by an arrow **46** and wrapped around the support portions **30** of the support elements **16**, **18**. Hence, in the assembled form, the transducer array **12** is attached radially to the support portions **30** and supported in an axial direction by means of the connection portions **32**.

[0053] The inner end faces **42**, **44** are connected to each other by means of an adhesive or soldering or the transducer array **12** is connected to the support portions by means of an adhesive, silicon rubber like PDMS or a heat shrinking tube.

[0054] The circumferential surface of the support portions **30** can have a circular or annular shape or may have a multi-faceted shape so that the assembled transducer assembly **10** and in particular the assembled transducer array **12** has a corresponding outer shape.

[0055] FIG. **4** shows a schematic cross sectional view of the assembled transducer assembly **10** in an axial viewing direction.

[0056] The transducer elements **14** are wrapped around the multi-faceted support portion **30** of the support element **18** and respectively attached to the different faces of the support portion **30**. The transducer elements **14** are flexibly connected to each other by means of the connection layer **20** which may be provided at the outside of the transducer array **12**. By means of the so assembled transducer assembly **10**, ultrasound waves can be transmitted and detected in a radial direction of the transducer assembly **10**.

[0057] FIG. **5***a-k* show single method steps for manufacturing the transducer assembly **10**. It is in general manufactured on a silicon wafer base by means of a micro-fabrication process.

[0058] First, pre-processed transducer elements **14** are attached to a silicon wafer substrate **50**. The substrate may be a fully processed wafer including active devices like CMOS transistors. The transducer elements **14** are attached to or formed at a front side **51** at the portion of the substrate **50** where the transducer array **12** will be formed as shown in FIG. **5***a*.

[0059] Further, a hardmask **52** is formed at a backside **54** of the substrate **50** by deposition and patterning of an oxide layer, e.g. a PECVD (plasma-enhanced chemical vapor deposition) oxide as shown in FIG. **5***b*.

[0060] In the following step, the flexible connection layer **20** is formed at the front side **51** of the substrate **50** on the transducer elements **14** as shown in FIG. **5***c*. The flexible connection layer **20** is a polyimide flexible foil consisting of an aluminum re-routing layer sandwiched between two layers of polyimide of equal thickness. The flexible connection layer **20** may be a parylene layer.

[0061] On the front side **51** of the substrate **50**, a thin aluminum layer is deposited and patterned in order to form a hardmask **56** to structure the flexible connection layer **20** at the end of the process as shown in FIG. **5***d*.

[0062] As shown in FIG. **5***e*, the backside **54** of the substrate **50** is etched by means of a dry-etching process to a depth of approximately 100 μm by using the hardmask **52**. Further, a timed oxide etch process is used on the backside **54**

of the substrate **50** in order to remove thinner portions **58** of the hardmask **52** as shown in FIG. **5***f*.

[0063] In a second dry etch process performed on the backside **54** of the substrate **50**, the substrate **50** is partially etched down to the flexible connection layer **20** in order to separate the support elements **16**, **18** from the transducer portion attached to the transducer elements **14**. Due to the anisotropic dry etch process, the thickness of the transducer portion is reduced and a step is formed at the support elements **16**, **18** forming the difference between the connection portion **32** and the support portion **30**. As shown in FIG. **5***g*, after this etch process, the support elements **16**, **18** are separated from the surrounding silicon substrate **50** and are merely connected to the surrounding substrate **50** by means of the flexible connection layer **20**.

[0064] Using the aluminum layer **56** on the front side **51** of the substrate **50** as a hardmask, the flexible connection layer **20** is patterned by means of an oxygen plasma in order to form the recesses **22**, **24**, openings **22**, **24** or the central holes **22**, **24** in the support elements **16**, **18** as shown in FIG. **5***h*. After the recesses or openings or holes **22**, **24** are etched in the support element **16**, **18**, the hardmask **56** is removed by means of a timed wet etch as shown in FIG. **5***i*. At this stage of the process, the transducer assembly **10** is entirely structured and only supported within the substrate **50** by means of small tabs formed from flexible connection layer **20**.

[0065] Finally, the transducer assembly **10** is removed from the substrate **50** by breaking the small flexible tabs **20** which is the only connection of the transducer assembly **10** to the substrate **50** as shown in FIG. **5***k*.

[0066] The overall height of the assembled transducer assembly **10** is limited to two times of the thickness of the substrate **50**, however, by stacking a plurality of transducer assemblies **10** in a column, an ultrasound transducer system having an elongated shape can be formed having an arbitrary length.

[0067] The recesses **22**, **24** or the openings **22**, **24** or the holes **22**, **24** may have a circular shape, a square shape, a triangular shape or a polygonal shape in order to prevent the rotation of the transducer assembly **10** connected to an ultrasound transducer system.

[0068] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustrations and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

[0069] In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single element or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

[0070] Any reference signs in the claims should not be construed as limiting the scope.

1. An ultrasound transducer assembly comprising:

a transducer array including a plurality of transducer elements for transmitting and receiving ultrasound waves,

two support elements flexibly connected to opposite sides of the transducer array configured to support the transducer array in a curved or polygonal shape, and

a flexible connection layer connected to the transducer array and to the support elements for flexibly connecting the support elements to the transducer array, wherein each support element comprises a support portion having a circular or polygonal shape and the transducer array is foldable around the support portions.

2. The ultrasound transducer assembly as claimed in claim **1**, wherein the connection layer comprises electrical interconnects for electrically connecting the transducer elements to the support elements.

3. The ultrasound transducer assembly as claimed in claim **1**, wherein the support element comprises at least two electrical contact portions for electrically connecting the transducer assembly to a driver device.

4. (canceled)

5. The ultrasound transducer assembly as claimed in claim **1**, wherein each support element comprises a connection portion having a larger diameter than the support portion, wherein the connection portion is connected to the connection layer.

6. The ultrasound transducer assembly as claimed in claim **1**, wherein the connection layer is connected to an end face of the support elements.

7. The ultrasound transducer assembly as claimed in claim **1**, wherein each support element comprises a central recess for supporting the ultrasound transducer assembly.

8. The ultrasound transducer assembly as claimed in claim **1**, wherein the flexible layer is a polyimide layer or a parylene layer.

9. The ultrasound transducer assembly as claimed in claim **1**, wherein the transducer assembly has a cylindrical or multifaceted shape, wherein the transducer elements are disposed at a circumferential surface of the ultrasound transducer assembly in order to transmit and receive the ultrasound waves in a radial direction.

10. A method for manufacturing an ultrasound transducer assembly in particular for intra vascular ultrasound systems, comprising the steps of:

providing a transducer array connected to a transducer portion of a substrate,

connecting a flexible connection layer to the substrate,

separating a portion of the substrate from the transducer portion to form two support elements for supporting the transducer portion so that the support element is connected to opposite sides of the transducer array via the flexible layer, wherein each support element comprises a support portion having a circular or polygonal shape, and

bending the flexible connection layer to connect the support element to the transducer portion such that the transducer array is arranged to wrap around the support portions.

11. The method as claimed in claim **10**, wherein the substrate is covered by an etch mask at a surface opposite to the flexible connection layer.

12. The method as claimed in claim **10**, wherein the support element is separated by dry etching of the substrate.

13. The method as claimed in claim **10**, wherein the ultrasound transducer assembly including the transducer array and

the support element is separated from the substrate by dry etching of the substrate and by mechanically separating the flexible layer.

14. An ultrasound transducer apparatus comprising an elongated probe including a tip and the ultrasound transducer assembly as claimed in claim **1** for emitting and detecting ultrasound waves in a radial direction of the probe.

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摘要(译)

超声换能器组件技术领域本发明涉及一种超声换能器组件（ 10 ），特别是用于血管内超声系统。组件（ 10 ）包括换能器阵列（ 12 ），其包括用于发送和接收超声波的多个换能器元件（ 14 ）。提供两个支撑元件（ 16,18 ）用于支撑弯曲或多边形形状的换能器阵列（ 12 ）。支撑元件（ 16,18 ）通过柔性连接层（ 20 ）连接到换能器阵列（ 12 ），以便灵活地连接支持元件（ 16,18 ）到换能器阵列（ 12 ）。