



**AN ULTRASONIC TRANSDUCER ARRAY AND A METHOD OF
FABRICATING AN ARRAY OF ULTRASONIC TRANSDUCERS**

FIELD OF THE INVENTION

5 The present invention relates generally to ultrasonic transducer arrays, particularly though not solely to a method of fabricating an array of piezoelectric ultrasonic transducers.

BACKGROUND

10 It is well known in the art to use piezoelectric devices as transducers. For example ceramic-based piezoelectric lead zirconate titanate (PZT) is used in commercially available ultrasonic transducers. Figure 1 illustrates a typical prior art transducer, including a two-layer transducer element 10 with a poled PZT sheet 11 bonded with a metal sheet 12.

15 The transducer element 10 is fixed by silicone adhesive 14 on a ceramic support 13 within a case 18. A pair of pins 15 are electrically connected to the PZT layer 11 and are fixed in place through the ceramic support 13 by an adhesive 16. The transducer element 10 is deflected when an external voltage is supplied through the pins 15. This provides larger displacements around the centre of the element.

20 In order to intensify the transducer-to-air coupling efficiency, a lightweight cone 17 is attached to the centre of the transducer element 10. A number of sound emission holes 19 are provided in the case 18, in front of the cone 17. This device is good for many applications, but its parametric ability and maximum sound pressure level are limited due to its size.



When applied to a parametric speaker system, such elements may be used in an array form using many elements for effective parametric conversion. Figure 2 is an example of an ultrasonic transducer array employing such type of commercial transducer elements for a parametric speaker. Four elements are displayed, all attached to one support frame 21 through pins 15. The array may be of a matrix, honeycomb or other shape. Building the ultrasonic transducer array in such a way is straightforward, but unfortunately there exist a few important technical problems.

Firstly, it is difficult to align all the transducer elements. Ideally the central axis line c-c' in each element would be perfectly perpendicular to the support frame and all the elements would be at the same level. However since there are non-uniform adhesion points 16 sandwiched between the transducer's ceramic plate 13 and the support frame 21 this is highly difficult to achieve in practice. As a result, each transducer element has a slightly different phase which limits the overall performance.

Secondly, the case 18 or even the ceramic plate 13 of each transducer occupies substantial space, making it more difficult to provide a thin and compact array aperture for mobile device applications. Furthermore, the case 18 tends to unnecessarily increase the centre-to-centre distance between adjacent transducer elements, which is not conducive to suppressing the side-lobes of the transmitted ultrasonic wave.

Thirdly, placing commercial transducers onto a support frame one by one to form an array limits manufacturability and decreases both reliability and repeatability.

SUMMARY OF THE INVENTION

It is therefore the objective of at least one embodiment to provide an improved ultrasonic transducer array and an improved method of fabricating the same, overcoming at least one of the above-mentioned problems.

5 In accordance with a first aspect of the present invention there is provided a method of fabricating an array of ultrasonic transducers comprising the steps of:

forming a transducer layer including a plurality of transducer elements,

forming a support frame including a plurality of supporting elements, and

forming the array including the step of bonding each transducer element
10 substantially co-axially with a corresponding supporting element.

The step of forming the transducer layer may comprise the step of bonding a piezoelectric layer to a metal layer.

The step of forming the transducer layer may further comprise the step of forming the plurality of transducer elements from the piezoelectric layer.

15 The step of forming the array may further comprise the step of separating each transducer element from the transducer layer.

The step of forming the support frame may further comprise the step of forming a plurality of back cavities, each back cavity being inside a corresponding support element.

20 The step of forming the array may further comprise the steps of forming an array of resonators and bonding each resonator to a corresponding transducer element.

The step of forming the array may further comprise the step of forming an electrical connection array and connecting the electrical connection array to each transducer element.

5 The support elements may be elastic and the step of forming the support frame may further comprise the steps of bonding the plurality of elastic support elements to one surface of the support frame and bonding a damping layer to the opposing surface of the support frame.

In accordance with a second aspect of the present invention there is provided an ultrasonic transducer array fabricated according to the method as described in any of the
10 preceding paragraphs.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a prior art example of commercial PZT ultrasonic transducer element.

15 Figure 2 shows a prior art array structure employing commercial PZT ultrasonic transducer elements.

Figure 3 is an illustration of ultrasonic transducer arrays.

Figure 4 shows cross sections of the stages of fabricating the transducer array.

Figure 5 is a flow chart of a method of fabricating the transducer array.

20 Figure 6 is a plan view of a transducer layer.

Figure 7 is a plan view of a support frame.

Figure 8 is a plan view of the transducer array.

DETAILED DESCRIPTION

According to one embodiment of the present invention an ultrasonic transducer array is fabricated consisting of a plurality of ceramic-based piezoelectric transducer elements 31 and a support frame 32 as shown in Figure 3(a).

5 Each transducer element 31 comprises is a bonded two-layer plate in which at least one-layer is made of a functional piezoelectric material such as PZT. A metal wafer may be bonded with the PZT wafer to form the second layer. Alternatively, the two-layer plate may be formed by two PZT units having different polarization directions.

The transducer elements are arranged in an array form.

10 The support frame 32 has a plurality of supporting elements 33 for supporting the array of transducer elements 31. Each support element 33 is bonded onto a corresponding transducer element 31 to support that transducer element 31 and at the same time to form a back cavity 36. The back cavity 36 is inside each support element 33, and therefore behind the transducer element 31. The back cavity 36 may be less than 1mm
15 long. The central axis of each support element is aligned along the same axis as that of the corresponding two-layer transducer element. Each transducer element bonded with the support frame as described above is divided from adjacent transducer elements.

Each transducer element 31 has lightweight structure such as a hollow cone 17 attached in front at its centre to function as a resonator.

20 An adverse piezoelectric effect is used to convert electrical energy into mechanical energy (i.e., mechanical strain, displacement, and vibration of each element) and thus generating an ultrasonic wave. AC voltage is applied across the PZT layer to

produce bending motion to emit the ultrasonic wave, whose transmission efficiency is further enhanced by the resonator.

The individual transducers are not independently cased and all the individual transducers rest on a single substrate (the support frame), resulting in a compact and thin
 5 transducer array structure.

According to one embodiment of the present invention the ultrasonic transducer array is fabricated by:

1. forming a transducer layer including a plurality of transducer elements,
2. forming a support frame including a plurality of supporting elements, and
- 10 3. forming the array including bonding each transducer element substantially co-axially with a corresponding supporting element.

Each of these steps is illustrated in more detail in the method 50 of Figures 4 and 5. The transducer layer is formed according to comprises steps 100 and 102 shown in Figure 5. In step 100 a monolithic metal sheet and a PZT sheet are bonded together using
 15 either a non-conductive or conductive epoxy. Figure 4(a) shows the bonding process of monolithic metal sheet 41 and PZT sheet 42 to form transducer layer 44. In step 102 the PZT sheet is formed into independent elements. The partially fabricated transducer layer 44 is shown in Figures 4(b) and 6, with one of the formed PZT elements indicated as 43. Various fabrication methods such as dicing, milling or grinding may be employed to
 20 separate each element or remove unwanted PZT portions.

The support frame is formed according to step 200 in Figure 5. In step 200 the array of support elements is fabricated from the support frame by a CNC machine tool. Figures 4c and 7 show an example hollow cylinder structure for each support element 33.

The support frame 45 may be formed from either an elastic bulk or composite material, for example plastics, ceramics or metal.

The array is formed according to steps 300, 302 and 304 in Figure 5. In step 300 the transducer layer 44 and the frame 45 are aligned and bonded together by an adhesive. Figure 4(d) shows each transducer element 31 being fixed onto each support element 33 by an adhesive 14. An adhesive having elasticity may be used (e.g., silicone sealant), so as to reduce any possible vibration transferred to the support frame.

In step 302 the transducer layer is cut into separate transducer elements 46. Various fabrication methods such as Electro Discharge Machining (EDM), wire cutting or laser machining may be adopted to move those unwanted metal areas. The transducer element may have a circular shape. Alternatively, it may be of a square or another shape.

In step 304 to efficiently couple the ultrasonic wave to pass through air, an array of lightweight resonators is fabricated and attached to the transducer array. Figure 4(f) shows the resonators aligned in an array in front of the resonator array. Each resonator 17 is bonded onto the corresponding transducer element 31 at the centre, resulting in a compact ultrasonic transducer array. The array of resonators may be made from materials having low densities, for example, aluminium alloy, composite and plastics. Various fabrication methods such as stamping, moulding and plating may be used to manufacture the resonator array. Each resonator is separated from its neighbours before bonding to the transducer.

In step 306 the array is sealed in a case with the front surface being a protective mesh or having a number of holes. Each transducer element is electrically connected to two thin leading wires (plus and minus). The wires extend out through a small hole in the

support frame under each transducer. The wires are all connected in parallel, to form two external connections to a power amplifier.

One skilled in the art will appreciate the fabrication sequence need not be limited to the above embodiment. For example, the transducer layer from step 100 in method 50
5 may be diced into separate elements first, and then each element in-situ bonded onto the support frame. Alternatively the transducer layer from step 100 in method 50 may be first bonded to the support frame before separation. In a further alternative, the resonator array may be bonded onto the membrane wafer before separation.

Figure 3(b) shows an alternative ultrasonic transducer array, in which each
10 support element is an elastic rubber hollow cylinder 34. A damping layer 35 is bonded onto the rear side of the support frame 32. One end of the rubber support element 34 is connected with the support frame 32, while the other connected with the transducer element 31. The rubber support elements may increase the flexibility of the support frame. The rubber support elements and damping layer may reduce any possible vibration of the
15 support frame, especially when the support frame is of thin construction.

CLAIMS:

1. A method of fabricating an array of ultrasonic transducers comprising the steps of:

forming a transducer layer including a plurality of transducer elements,

5 forming a support frame including a plurality of supporting elements, and

forming the array including the step of bonding each transducer element substantially co-axially with a corresponding supporting element.

2. The method as claimed in claim 1 wherein the step of forming the transducer
10 layer comprises the step of bonding a piezoelectric layer to a metal layer.

3. The method as claimed in claim 2 wherein the step of forming the transducer layer further comprises the step of forming the plurality of transducer elements from the piezoelectric layer.

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4. The method as claimed in any one of the preceding claims wherein the step of forming the array further comprises the step of separating each transducer element from the transducer layer.

20 5. The method as claimed in any one of the preceding claims wherein the step of forming the support frame further comprises the step of forming a plurality of back cavities, each back cavity being inside a corresponding support element.

6. The method as claimed in any one of the preceding claims wherein the step of forming the array further comprises the steps of forming an array of resonators and bonding each resonator to a corresponding transducer element.
- 5 7. The method as claimed in any one of the preceding claims wherein the step of forming the array further comprises the step of forming an electrical connection array and connecting the electrical connection array to each transducer element.
8. The method as claimed in any one of the preceding claims wherein the support
10 elements are elastic and the step of forming the support frame further comprises the steps of bonding the plurality of elastic support elements to one surface of the support frame and bonding a damping layer to the opposing surface of the support frame.
9. An ultrasonic transducer array fabricated according to the method as claimed in
15 any one of the preceding claims.