[0007] In addition, the bonding of such transducers which have been fabricated on flat substrates is challenging to conform to the curved surface of structures to be monitored. Furthermore, adhesive used to install or bond the transducers often has a damping effect such that the coupling between the acoustic transducer and the structure is not effective. Additionally, bonding of a large number of transducers causes many serious concerns in practical implementations, such as quality inconsistency, degraded reliability, and unacceptable high cost. In particular, aeronautic applications are weight-sensitive, and are often exposed to fluid flow. High profile and large weight of bonded and installed devices for structural health monitoring can profoundly affect air flow around them, resulting in diminished efficiency, longevity and economy.

[0008] Therefore, there is a need for a method of fabricating light-weight transducers by directly depositing and patterning acoustic active materials and electrodes on prior defined locations on the surface of structural parts or structural assemblies without the extra step of bonding, and incorporating said transducers in-situ in the manufacturing process of engineering structures for structural health monitoring.

[0009] Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

SUMMARY

[0010] According to a first aspect of the invention, a method of fabricating an acoustic transducer for generation and/or detection of acoustic waves for structural health monitoring is described, the method comprising in-situ direct-writing of a piezoelectric material to create a piezoelectric layer on a structure to be monitored, wherein the structure is conductive and the structure functions as a bottom electrode; and in-situ direct-writing of a conductive electrode on top of the piezoelectric layer to act as a top electrode.

[0011] According to a second aspect of the invention, a system with acoustic transducer for structural health monitoring is described, the system comprising a structure to be monitored having one or more of a flat surface and a curved surface thereon, wherein the structure is conductive and the structure functions as a bottom electrode; a layer of piezoelectric material

on top of a portion of the structure; and a layer of electrode on top of the piezoelectric material layer, wherein the layer of electrode is patterned, and wherein the layer of piezoelectric material and the layer of electrode form an acoustic transducer for generating and detecting acoustic waves in the structure to be monitored for identifying defects in the structure to be monitored.

[0012] According to a third aspect of the invention, a method for structural health monitoring is described, the method comprising the step of forming a plurality of acoustic transducers on a structure to be monitored, wherein the structure is conductive and the structure functions as a bottom electrode, wherein each of the plurality of acoustic transducers comprises a layer of piezoelectric material direct-written on top of the structure, and a layer of electrode direct-written on top of the piezoelectric material layer wherein at least a first one and a second one of the plurality of acoustic transducers are formed across a portion of the structure, and wherein the first one and the second one of the plurality of acoustic transducers are configured to generate and detect an acoustic wave in the portion of the structure to obtain structural health information.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments, by way of example only, and to explain various principles and advantages in accordance with a present embodiment.

[0014] FIG. 1 depicts a flow chart of a method of fabricating transducers with direct-write techniques in accordance with a present embodiment.

[0015] FIG. 2 depicts a cross-sectional planar view of a plate structure bearing direct-write acoustic transducers in accordance with the present embodiment.

[0016] FIG. 3, comprising FIGs. 3A and 3B, depicts top planar views of various shadow masks used for patterning by aerosol spray in accordance with the present embodiment, wherein FIG. 3A depicts the top planar view of the shadow mask for deposition of

piezoelectric material and FIG. 3B depicts the top planar view of the shadow mask for deposition of annular array comb electrodes.

CLAIMS

What is claimed is:

1. A method of fabricating an acoustic transducer for generation and/or detection of acoustic waves for structural health monitoring, the method comprising:

in-situ direct-writing of a piezoelectric material to create a piezoelectric layer on a structure to be monitored, wherein the structure is conductive and the structure functions as a bottom electrode; and

in-situ direct-writing of a conductive electrode on top of the piezoelectric layer to act as a top electrode.

2. The method of claim 1 wherein the piezoelectric material is a polymer and wherein the step of in-situ direct-writing of the piezoelectric material comprises in-situ spraying of a precursor solution of the polymer.

3. The method of claim 1 wherein the step of direct-writing of the piezoelectric material comprises one of depositing the piezoelectric layer on a surface of the structure conforming to a contour of the surface of the structure to be monitored or aerosol spraying of the piezoelectric material through a patterned mask directly onto the structure to be monitored.

4. The method of claim 1 further comprising the step of patterning the top electrode to form an annular array comb electrode such that concentric arcs are formed with one common trace connecting all the arcs.

5. The method of claim 4 wherein the step of patterning the top electrode to form an annular array comb electrode comprises forming the annular array comb electrode with a period, wherein the period is a distance between each arc, and wherein the period corresponds to an excitation frequency of a mode of a Lamb mode ultrasonic wave in the piezoelectric material.

6. The method of claim 4 wherein the step of patterning the top electrode to form an annular array comb electrode comprises forming the annular array comb electrode substantially at a corner of a portion of the structure with a spanning angle facing away from the corner.

7. The method of claim 1 wherein the step of in-situ direct-writing of the piezoelectric material comprises inkjet printing of the piezoelectric material directly onto the structure to be monitored.

8. The method of claim 1 further comprising the step of depositing a protective layer over the top electrode.

9. A system with an acoustic transducer for structural health monitoring, comprising:

a structure to be monitored having one or more of a flat surface and a curved surface thereon, wherein the structure is conductive and the structure functions as a bottom electrode;

a layer of piezoelectric material on top of a portion of the structure; and

a layer of electrode on top of the piezoelectric material layer, wherein the layer of electrode is patterned, and wherein the layer of piezoelectric material and the layer of electrode form an acoustic transducer for generating and detecting acoustic waves in the structure to be monitored for identifying defects in the structure to be monitored.

10. The system of claim 9, wherein the acoustic waves comprise a Lamb mode ultrasonic wave for identifying defects in the structure to be monitored, wherein the layer of electrode is in the form of an annular array comb such that the concentric arcs are formed with one common trace connecting all the arcs, and the annular array comb electrode is patterned with a period, the period being a distance between each arc, and wherein the period corresponds to an excitation frequency of the Lamb mode ultrasonic wave.

11. The system of claim 10 further comprising a plurality of the acoustic transducers wherein each of the plurality of the acoustic transducers has annular array comb electrodes positioned substantially at a corner of a portion of the structure with a spanning angle facing away from the corner.

12. A method for structural health monitoring comprising the step of forming a plurality of acoustic transducers on a structure to be monitored, wherein the structure is conductive and the structure functions as a bottom electrode, wherein each of the plurality of acoustic transducers comprises a layer of piezoelectric material direct-written on top of the structure and a layer of electrode direct-written on top of the piezoelectric material layer, wherein at least a first one and a second one of the plurality of acoustic transducers are formed across a portion of the structure, and wherein the first one and the second one of the plurality of acoustic transducers are configured to generate and detect an acoustic wave in the portion of the structure to obtain structural health information.

13. The method of claim 12 wherein a subset of the plurality of acoustic transducers including the first one and the second one of the plurality of acoustic transducers are arranged around a periphery of the portion of the structure, the method further comprising the steps of:

the first one of the plurality of acoustic transducers generating the acoustic wave in the portion of the structure;

the second one of the plurality of acoustic transducers detecting the acoustic wave in the portion of the structure; and

comparing a first electrical signal of the acoustic wave detected by the second one of the plurality of acoustic transducers on the portion of the structure when the portion of the structure is in a pristine condition with a second electrical signal of the acoustic wave detected by the second one of the plurality of acoustic transducers on the structure at a structural health monitoring time to determine if the obtained structural health information indicates formation of a defect in the portion of the structure

14. The method of claim 13 wherein the step of comparing the first and second electrical signals of the acoustic wave detected by the second one of the plurality of acoustic transducers comprises comparing a shift in time of the first and second electrical signals in a time domain to determine a type of defect in the structure.

15. The method of claim 13 wherein the step of comparing the first and second electrical signals of the acoustic wave detected by the second one of the plurality of acoustic transducers comprises comparing amplitudes of the first and second electrical signals to determine a location, a size or a severity of the defect in the structure.

16. The method of claim 13 further comprising the step of actuating each of the plurality of the plurality of acoustic transducers arranged around the periphery of the portion of the structure individually to generate an acoustic wave in the portion of the structure in such a way that when one of the plurality of acoustic transducers is actuated to generate the acoustic wave in the structure, the remaining ones of the plurality of acoustic transducers detect the acoustic wave in the structure.