internal damage in the pipeline structures. There are also reported works employing discrete sensors, e.g., piezoelectric ceramic patches or discrete ultrasonic probes bonded or fixed on the pipeline structures for damage detection. The bonding or coupling of the ultrasonic sensors on pipeline structures has issues of consistency and reliability due to manual installation, and results in high cost with the implementation of a large number of sensors.

[0005] Therefore, a need exists to provide a SHM method and system that can address at least some of the above problems, in particular, a SHM method and system that may be reliable and preferably low-cost and with a capability of monitoring both surface and internal defects over a long pipeline structure.

SUMMARY

[0006] An aspect of the present disclosure provides a structural health monitoring method including forming *in-situ* a plurality of acoustic transducers on a surface of a structure to be monitored~~;~~. Forming *in situ* the plurality of acoustic transducers includes directly coating and patterning a piezoelectric layer and electrode layers of the acoustic transducers on the surface of the structure such that the piezoelectric layer is crystallized *in situ* and polarizing the piezoelectric layer, wherein the piezoelectric layer is polarized in a polarization direction along the surface of the structure. The method also includes generating, from a first position on the structure, bulk acoustic wave signals for propagation in the structure; detecting, at a second position on the structure, the bulk acoustic wave signals propagating in the structure; and analyzing the detected bulk acoustic wave signals to determine structural health of the structure, wherein at least one of generating and detecting the bulk acoustic wave signals is performed by one or more of the acoustic transducers.

[0006a] Another aspect of the present disclosure provides a structural health monitoring method including forming *in-situ* a plurality of acoustic transducers on a surface of a structure to be monitored. Forming *in situ* the plurality of acoustic transducers includes directly coating and patterning a piezoelectric layer and electrode layers of the acoustic transducers on the surface of the structure such that the piezoelectric layer is crystallized *in situ* and polarizing the piezoelectric layer, wherein the piezoelectric layer is polarized in a polarization direction substantially normal to the surface of the structure. The method also includes

generating, from a first position on the structure, bulk acoustic wave signals for propagation in the structure; detecting, at a second position on the structure, the bulk acoustic wave signals propagating in the structure; and analyzing the detected bulk acoustic wave signals to determine structural health of the structure. At least one of generating and detecting the bulk acoustic wave signals is performed by one or more of the acoustic transducers. Generating the bulk acoustic wave signals comprises applying an alternating electric potential in a direction substantially parallel to the polarization direction of the piezoelectric layer.

[0007] Another aspect of the present disclosure provides a structural health monitoring system including a plurality of acoustic transducers formed *in situ* on a surface of a structure to be monitored, wherein one or more of the acoustic transducers are configured to perform at least one of generating, from a first position on the structure, bulk acoustic wave signals for propagation in the structure, and detecting, at a second position on the structure, the bulk acoustic wave signals propagating in the structure; and a processor configured to analyze the detected bulk acoustic wave signals to determine structural health of the structure. The plurality of acoustic transducers includes a piezoelectric layer and electrode layers directly coated and patterned on the surface of the structure, wherein the piezoelectric layer comprises a crystallized structure. The piezoelectric layer is polarized in a polarization direction along the surface of the structure.

[0007a] Another aspect of the present disclosure provides a structural health monitoring system including a plurality of acoustic transducers formed *in situ* on a surface of a structure to be monitored, wherein one or more of the acoustic transducers are configured to perform at least one of generating, from a first position on the structure, bulk acoustic wave signals for propagation in the structure, and detecting, at a second position on the structure, the bulk acoustic wave signals propagating in the structure; and a processor configured to analyze the detected bulk acoustic wave signals to determine structural health of the structure. The plurality of acoustic transducers include a piezoelectric layer and electrode layers directly coated and patterned on the surface of the structure, wherein the piezoelectric layer comprises a crystallized structure. The piezoelectric layer is polarized in a polarization direction substantially normal the surface of the structure. An alternating electric potential is applied in a direction substantially parallel to the polarization direction of the piezoelectric layer to generate the bulk acoustic wave signals.

CLAIMS

1. A structural health monitoring method comprising:

forming *in-situ* a plurality of acoustic transducers on a surface of a structure to be monitored, wherein forming *in situ* the plurality of acoustic transducers comprises:

directly coating and patterning a piezoelectric layer and electrode layers of the acoustic transducers on the surface of the structure such that the piezoelectric layer is crystallized *in situ*; and

polarizing the piezoelectric layer,

wherein the piezoelectric layer is polarized in a polarization direction along the surface of the structure;

generating, from a first position on the structure, bulk acoustic wave signals for propagation in the structure;

detecting, at a second position on the structure, the bulk acoustic wave signals propagating in the structure; and

analyzing the detected bulk acoustic wave signals to determine structural health of the structure,

wherein at least one of generating and detecting the bulk acoustic wave signals is performed by one or more of the acoustic transducers.

~~2. The method as claimed in claim 1, wherein forming *in situ* the plurality of acoustic transducers comprises:~~

~~directly coating and patterning a piezoelectric layer and electrode layers of the acoustic transducers on the surface of the structure such that the piezoelectric layer is crystallized *in situ*; and~~

~~polarizing the piezoelectric layer.~~

~~3. The method as claimed in claim 2, wherein the piezoelectric layer is polarized in a polarization direction substantially normal to the surface of the structure.~~

~~4. The method as claimed in claim 3, further comprising patterning a top electrode layer of the acoustic transducers into a comb pattern, and selecting a period of the comb pattern to be substantially equal to a wavelength of the bulk acoustic wave signals.~~

~~5. The method as claimed in claim 2, wherein the piezoelectric layer is polarized in a polarization direction along the surface of the structure.~~

~~6~~2. The method as claimed in claim ~~5~~1, wherein the structure comprises an elongated pipe, and wherein the piezoelectric layer is polarized in a longitudinal direction of the pipe.

~~7~~3. The method as claimed in claim ~~5~~1, wherein the structure comprises an elongated pipe, and wherein the piezoelectric layer is polarized in a circumferential direction of the pipe.

~~8~~4. The method as claimed in any one of claims ~~3~~ 1 to ~~7~~3, wherein generating the bulk acoustic wave signals comprises applying an alternating electric potential in a direction substantially ~~parallel or~~ perpendicular to the polarization direction of the piezoelectric layer.

5. A structural health monitoring method comprising:

forming *in-situ* a plurality of acoustic transducers on a surface of a structure to be monitored, wherein forming *in situ* the plurality of acoustic transducers comprises:

directly coating and patterning a piezoelectric layer and electrode layers of the acoustic transducers on the surface of the structure such that the piezoelectric layer is crystallized *in situ*; and

polarizing the piezoelectric layer,

wherein the piezoelectric layer is polarized in a polarization direction substantially normal to the surface of the structure;

generating, from a first position on the structure, bulk acoustic wave signals for propagation in the structure;

detecting, at a second position on the structure, the bulk acoustic wave signals propagating in the structure; and

analyzing the detected bulk acoustic wave signals to determine structural health of the structure,

wherein at least one of generating and detecting the bulk acoustic wave signals is performed by one or more of the acoustic transducers; and

wherein generating the bulk acoustic wave signals comprises applying an alternating electric potential in a direction substantially parallel to the polarization direction of the piezoelectric layer.

6. The method as claimed in claim 5, further comprising patterning a top electrode layer of the acoustic transducers into a comb pattern, and selecting a period of the comb pattern to be substantially equal to a wavelength of the bulk acoustic wave signals.

7. The method as claimed in any one of claims 1 to 6, wherein the piezoelectric layer comprises a polymer.

8. The method as claimed in any one of claims 1 to 6, wherein the piezoelectric layer comprises a ceramic, and wherein the ceramic is substantially lead-free.

9. The method as claimed in any one of claims 1 to 8, wherein forming *in situ* the plurality of acoustic transducers comprises forming two groups of acoustic transducers at the first and second positions respectively, and wherein the bulk acoustic wave signals are generated by one or more acoustic transducers of the first group and detected by one or more acoustic transducers of the second group.

10. The method as claimed in any one of claims 1 to 8, wherein forming *in situ* the plurality of acoustic transducers comprises forming one group of acoustic transducers at the first position, and wherein the bulk acoustic wave signals are generated by the *in-situ* formed acoustic transducers and detected by one or more discrete acoustic transducers.

11. The method as claimed in any one of claims 1 to 8, wherein forming *in situ* the plurality of acoustic transducers comprises forming one group of acoustic transducers at the second position, and wherein the bulk acoustic wave signals are generated by one or more discrete acoustic transducers and detected by the *in-situ* formed acoustic transducers.

12. The method as claimed in any one of claims 1 to 11, wherein at least one of generating and detecting the bulk acoustic wave signals comprises operating the acoustic transducers substantially at a resonant frequency.

13. The method as claimed in any one of the claims 1 to 12, wherein the bulk acoustic wave signals are generated for propagation based on at least one of a longitudinal mode, a torsional mode, a shear mode and a flexural mode.

14. A structural health monitoring system comprising:

a plurality of acoustic transducers formed *in situ* on a surface of a structure to be monitored, wherein one or more of the acoustic transducers are configured to perform at least one of:

generating, from a first position on the structure, bulk acoustic wave signals for propagation in the structure; and

detecting, at a second position on the structure, the bulk acoustic wave signals propagating in the structure; and

a processor configured to analyze the detected bulk acoustic wave signals to determine structural health of the structure,

wherein the plurality of acoustic transducers comprise a piezoelectric layer and electrode layers directly coated and patterned on the surface of the structure, and wherein the piezoelectric layer comprises a crystallized structure; and

wherein the piezoelectric layer is polarized in a polarization direction along the surface of the structure.

~~15. The system as claimed in claim 14, wherein the plurality of acoustic transducers comprise a piezoelectric layer and electrode layers directly coated and patterned on the surface of the structure, and wherein the piezoelectric layer comprises a crystallized structure.~~

~~16. The system as claimed in claim 15, wherein the piezoelectric layer is polarized in a polarization direction substantially normal to the surface of the structure, wherein a top electrode layer of the acoustic transducers is patterned into a comb pattern, and wherein a period of the comb pattern is substantially equal to a wavelength of the bulk acoustic wave signals.~~

~~17. The system as claimed in claim 15, wherein the piezoelectric layer is polarized in a polarization direction along the surface of the structure.~~

15. A structural health monitoring system comprising:

a plurality of acoustic transducers formed *in situ* on a surface of a structure to be monitored, wherein one or more of the acoustic transducers are configured to perform at least one of:

generating, from a first position on the structure, bulk acoustic wave signals for propagation in the structure; and

detecting, at a second position on the structure, the bulk acoustic wave signals propagating in the structure; and

a processor configured to analyze the detected bulk acoustic wave signals to determine structural health of the structure,

wherein the plurality of acoustic transducers comprise a piezoelectric layer and electrode layers directly coated and patterned on the surface of the structure, and wherein the piezoelectric layer comprises a crystallized structure; and

wherein the piezoelectric layer is polarized in a polarization direction substantially normal the surface of the structure, and wherein an alternating electric potential is applied in a direction substantially parallel to the polarization direction of the piezoelectric layer to generate the bulk acoustic wave signals.

16. The system as claimed in claim 15, wherein a top electrode layer of the acoustic transducers is patterned into a comb pattern, and wherein a period of the comb pattern is substantially equal to a wavelength of the bulk acoustic wave signals.

17. The system as claimed in any one of claims 14 to 16, wherein the piezoelectric layer comprises a polymer.

18. The system as claimed in any one of claims 14 to 16, wherein the piezoelectric layer comprises a ceramic, and wherein the ceramic is substantially lead-free.

~~18~~19. The system as claimed in any one of claims 14 to ~~17~~18, wherein the *in-situ* formed acoustic transducers comprise two groups of acoustic transducers disposed at the first and second positions respectively, and wherein one or more acoustic transducers of the first group are configured to generate the bulk acoustic wave signals and one or more acoustic transducers of the second group are configured to detect the bulk acoustic wave signals propagating in the structure.

~~19~~20. The system as claimed in any one of claims 14 to ~~17~~18, further comprising one or more discrete acoustic transducers disposed at the second position, wherein the *in-situ* formed acoustic transducers comprise one group of acoustic transducers disposed at the first position and configured to generate the bulk acoustic wave signals, and wherein the one or more discrete acoustic transducers are configured to detect the bulk acoustic wave signals.

~~20~~21. The system as claimed in any one of claims 14 to ~~17~~18, further comprising one or more discrete acoustic transducers disposed at the first position and configured to generate the bulk acoustic wave signals, wherein the *in-situ* formed acoustic transducers comprise one group of acoustic transducers disposed at the second position and configured to detect the bulk acoustic wave signals.