Claims

1. A device, positioned within a borehole, configured to generate and direct an acoustic beam into a rock formation around the borehole, the device comprising:

a source configured to generate a first signal at a first frequency and a second signal at a second frequency different from the first frequency;

an array of transducers located within the borehole and configured to receive the generated first signal and the second signal, wherein a first group of transducers of the array of transducers is configured to generate an acoustic wave at the first frequency and a second group of transducers of the array of transducers is configured to generate an acoustic wave at the second frequency; and

a non-linear material, coupled to the transducers, configured to generate a collimated beam with a frequency equal to the difference between the first frequency and the second frequency by a non-linear mixing process, wherein the non-linear material includes one or more of a mixture of liquids, a solid, a granular material, embedded microspheres, or an emulsion, and wherein the collimated beam has a frequency of 20 kHz to 120 kHz.

2. A device in accordance with claim 1, further comprising:

an acoustic beam guide configured to guide the collimated beam in a given direction.

3. A device in accordance with claim 2, wherein the acoustic beam guide includes an acoustic reflector, an acoustic lens, or both.

4. A device in accordance with claim 1, further comprising:

a receiver configured to receive the collimated beam after it has reflected or backscattered from an inhomogeneity in the formation.

5. A device in accordance with claim 4, wherein the receiver includes more than one receiver arranged along an axial direction of the device within the borehole.

6. A device in accordance with claim 4, wherein the receiver includes more than one receiver arranged in a different borehole.

7. A device in accordance with claim 1, wherein the array of transducers is arranged in a linear, a circular, a filled circle, or a square configuration.

8. A device in accordance with claim 2, further comprising:

a housing configured to house the array of transducers, the non-linear material and the acoustic beam guide within the borehole.

9. A device in accordance with claim 1, further comprising:

an encoder configured to encode the collimated beam with a time-varying code by introducing a time-varying component including one or more of frequency chirping or frequency sweep to one of the first and the second signals.

10. A device in accordance with claim 9, wherein the time-varying components include a variation in amplitude, frequency, and/or phase.

11. A device in accordance with claim 3, wherein the acoustic reflector is configured to control the direction of propagation of the collimated beam or the acoustic lens is configured to focus the collimated beam.

12. A device in accordance with claim 1, wherein the collimated beam is analyzed by a processor to create an image, which may be a three-dimensional image, of the rock formation around the borehole.

13. A device in accordance with claim 1, wherein the collimated beam has a frequency between 20 kHz and 100 kHz.

14. A device in accordance with claim 1, wherein the frequencies of the first and the second signals are between 300 kHz and 2 MHz.

15. A device in accordance with claim 1, wherein the length of the non-linear material is between 5 cm and 2 m.

16. A method of generating a beam of acoustic energy in a rock formation penetrated by a borehole, the method comprising:

generating a first acoustic wave at a first frequency;

generating a second acoustic wave at a second frequency different than the first frequency, wherein the first acoustic wave and second acoustic wave are generated by an array of transducers located within the borehole, the first acoustic wave being generated by a first group of transducers of the array of

transducers and the second acoustic wave being generated by a second group of transducers of the array of transducers;

transmitting the first and the second acoustic waves into an acoustically non-linear medium to produce a collimated beam by a non-linear mixing of the first and second acoustic waves, wherein the collimated beam propagates through the non-linear medium in a same direction as an initial direction of the first and second acoustic waves and has a frequency equal to a difference of the first and the second acoustic waves, wherein the collimated beam has a frequency of 20 kHz to 120 kHz, and wherein the non-linear medium includes one or more of a mixture of liquids, a solid, a granular material, embedded microspheres, or an emulsion; and

directing the collimated beam, using an acoustic beam guide, in a given direction away from the borehole into the rock formation.

17. A method in accordance with claim 16, further comprising:

receiving the collimated beam at one or more receivers after it has reflected or backscattered from an inhomogeneity in the formation, materials near the borehole, or both.

18. A method in accordance with claim 16, wherein the one or more receivers are located in the borehole.

19. A method in accordance with claim 16, wherein the one or more receivers are located in another borehole.

20. A method in accordance with claim 17, wherein the acoustic beam guide includes an acoustic reflector, an acoustic lens or both.

21. A method in accordance with claim 20, wherein the array of transducers, the acoustically non-linear medium, the acoustic beam guide, and the receivers are arranged within an enclosure.

22. A method in accordance with claim 18, further comprising:

analyzing the collimated beam after it has reflected or backscattered from an inhomogeneity in the formation to generate an image of the rock formation, materials near the borehole, or both.

23. A method in accordance with claim 19, further comprising:

analyzing the collimated beam after it has reflected or backscattered from an inhomogeneity in the formation to generate an image of the rock formation between the boreholes and to generate information to characterize linear and non-linear properties of the rock formation and fluid contents surrounding the borehole, or to generate images of invaded zones, cement bonding, damaged zones, fractured zones, stratigraphic layering, and sources of scatter.

24. A method in accordance with claim 20 or 21, further comprising:

encoding the collimated beam with a time-varying code by introducing a time-varying component including one or more of chirping or frequency sweep to one of the first and the second acoustic signals, wherein the analysis comprises using the encoding to measure a time-of-flight of the third signal.

25. A method in accordance with claim 24, wherein the time-varying components comprise a variation in amplitude, frequency, and/or phase.

26. A method in accordance with claim 16, wherein

the collimated beam is directed by selectively controlling the azimuth of the beam acoustic guide by rotation around a guide axis and the inclination between the plane of the guide and the guide axis;

and wherein the method further comprises

receiving the collimated beam at one or more receivers located in the borehole after it has reflected or backscattered from an inhomogeneity in the formation, materials near the borehole, or both.

WHAT IS CLAIMED IS:

1. A device, positioned within a borehole, configured to generate and direct an acoustic beam into a rock formation around the borehole, the device comprising:

a source configured to generate a first signal at a first frequency and a second signal at a second frequency;

a transducer located within the borehole and configured to receive the generated first and the second signal and produce acoustic waves at the first frequency and the second frequency; and

a non-linear material, coupled to the transducer, configured to generate a collimated beam with a frequency equal to the difference between the first frequency and the second frequency by a non-linear mixing process, wherein the non-linear material includes one or more of a mixture of liquids, a solid, a granular material, embedded microspheres, or an emulsion, and wherein the collimated beam has a frequency of 20 kHz to 120 kHz.

2. A device in accordance with claim 1, further comprising:

an acoustic beam guide configured to guide the collimated beam in a given direction.

3. A device in accordance with claim 2, wherein the acoustic beam guide includes an acoustic reflector, an acoustic lens, or both.

4. A device in accordance with claim 1, further comprising:

a receiver configured to receive the collimated beam after it has reflected or backscattered from an inhomogeneity in the formation.

5. A device in accordance with claim 4, wherein the receiver includes more than one receiver arranged along an axial direction of the device within the borehole.

6. A device in accordance with claim 4, wherein the receiver includes more than one receiver arranged in a different borehole.

7. A device in accordance with claim 1, wherein the transducer includes more than one transducer arranged in an array, and wherein the array is preferably arranged in a linear, a circular, a filled circle, or a square configuration.

8. A device in accordance with claim 2, further comprising:

a housing configured to house the transducer, the non-linear material and the acoustic beam guide within the borehole.

9. A device in accordance with claim 1, further comprising:

an encoder configured to encode the collimated beam with a time-varying code by introducing a time-varying component including one or more of frequency chirping or frequency sweep to one of the first and the second signals.

10. A device in accordance with claim 9, wherein the time-varying components include a variation in amplitude, frequency, and/or phase.

11. A device in accordance with claim 3, wherein the acoustic reflector is configured to control the direction of propagation of the collimated beam or the acoustic lens is configured to focus the collimated beam.

12. A device in accordance with claim 1, wherein the collimated beam is analyzed by a processor to create an image, which may be a three-dimensional image, of the rock formation around the borehole.

13. A device in accordance with claim 1, wherein the collimated beam has a frequency between 1 kHz and 100 kHz.

14. A device in accordance with claim 1, wherein the frequencies of the first and the second signals are between 300 kHz and 2 MHz.

15. A device in accordance with claim 1, wherein the length of the non-linear material is between 5 cm and 2 m.

16. A method of generating a beam of acoustic energy in a rock formation penetrated by a borehole, the method comprising:

generating a first acoustic wave at a first frequency;

generating a second acoustic wave at a second frequency different than the first frequency, wherein the first acoustic wave and second acoustic wave are generated by a transducer located within the borehole;

transmitting the first and the second acoustic waves into an acoustically non-linear medium to produce a collimated beam by a non-linear mixing process, wherein the collimated beam propagates through the non-linear medium in a same direction as an initial direction of the first and second acoustic waves and has a frequency equal to a difference of the first and the second acoustic waves, wherein the non-linear medium includes one or more of a mixture of liquids, a solid, a granular material, embedded microspheres, or an emulsion; and

directing the collimated beam, using an acoustic beam guide, in a given direction away from the borehole into the rock formation, wherein the collimated beam has a frequency of 20 kHz to 120 kHz.

17. A method in accordance with claim 16, further comprising:

receiving the collimated beam at one or more receivers after it has reflected or backscattered from an inhomogeneity in the formation, materials near the borehole, or both.

18. A method in accordance with claim 16, wherein the one or more receivers are located in the borehole.

19. A method in accordance with claim 16, wherein the one or more receivers are located in another borehole.

20. A method in accordance with claim 16, wherein the transducer includes a plurality of transducers arranged in an array.

21. A method in accordance with claim 17, wherein the acoustic beam guide includes an acoustic reflector, an acoustic lens or both.

22. A method in accordance with claim 21, wherein the transducer, the acoustically non-linear medium, the acoustic beam guide, and the receivers are arranged within an enclosure.

23. A method in accordance with claim 18, further comprising:

analyzing the collimated beam after it has reflected or backscattered from an inhomogeneity in the formation to generate an image of the rock formation, materials near the borehole, or both.

24. A method in accordance with claim 19, further comprising:

analyzing the collimated beam after it has reflected or backscattered from an inhomogeneity in the formation to generate an image of the rock formation between the boreholes and to generate information to characterize linear and non-linear properties of the rock formation and fluid contents surrounding the borehole, or to generate images of invaded zones, cement bonding, damaged zones, fractured zones, stratigraphic layering, and sources of scatter.

25. A method in accordance with claim 21 or 22, further comprising:

encoding the collimated beam with a time-varying code by introducing a time-varying component including one or more of chirping or frequency sweep to one of the first and the second acoustic signals, wherein the analysis comprises using the encoding to measure a time-of-flight of the third signal.

26. A method in accordance with claim 25, wherein the time-varying components comprise a variation in amplitude, frequency, and/or phase.

27. A method in accordance with claim 16, wherein the collimated beam is directed by selectively controlling the azimuth of the beam acoustic guide by rotation around a guide axis and the inclination between the plane of the guide and the guide axis; and wherein the method further comprises

receiving the collimated beam at one or more receivers located in the borehole after it has reflected or backscattered from an inhomogeneity in the formation, materials near the borehole, or both.