Claims

1. Wellbore temperature sensing apparatus for use in sensing temperature along a wellbore, comprising:

tubing being metallic tubing, comprising a plurality of temperature sensor modules provided at locations along the inside of the tubing, having electrical properties that vary with temperature; and

an electrical network comprising a plurality of wires and said plurality of temperature sensor modules, wherein the plurality of wires and plurality of temperature sensor modules are configured as a matrix by which the plurality of wires comprises a first group of wires and a second, different group of wires and each wire of the first group is electrically connected to each wire of the second group once, each electrical connection being by a respective temperature sensor module of the plurality of temperature sensor modules, such that each temperature sensor module can be individually electrically connected by a pair of wires comprising a first wire from the first group and a second wire from the second group;

a wireless data communication module coupled, wirelessly, by a separate wireless connection or electrically by a wired connection, to the apparatus, and arranged to, in use, wirelessly transmit along the well, signals indicative of a temperature sensed in the wellbore by the apparatus; wherein the wireless data communication module is configured to transmit said signals acoustically and/or electromagnetically, and

a power source configured to provide operational power to the apparatus; wherein the power source is arranged to be provided as an in-well power source in use.

2. Apparatus as claimed in claim 1, wherein at least one, or each temperature sensor module comprises a single electronic component.
3. Apparatus as claimed in claim 2, wherein the maximum physical extent of the single electronic component in any axis is less than 7mm, preferably less than 5mm, more preferably less than 4mm, even more preferably less than 3mm.
4. Apparatus as claimed in any preceding claim, wherein the temperature sensor modules comprise temperature sensors provided at least in part by at least one semiconductor element having electrical properties that vary with temperature and, optionally, wherein the apparatus is configured to use only the temperature sensitivity of the or each temperature sensitive semiconductor element of each temperature sensor module to infer a temperature of the temperature sensor module.

5. Apparatus as claimed in claim 4, wherein the at least one semiconductor element is a diode.
6. Apparatus as claimed in claim 5, wherein the diode is selected from at least one of: constant current diodes; constant voltage diodes.
7. Apparatus as claimed in any preceding claim, wherein at least one, or each temperature sensor module comprises a single passive electronic component.
8. Apparatus as claimed in any of claims 1 to 4, wherein the temperature sensor modules comprise temperature sensors that are configured as silicon bandgap temperature sensors each having two p-n junctions that, in use, are operated a different current densities to infer a temperature by determining a voltage difference between the two p-n junctions at the different current densities, which is proportional to absolute temperature.
9. Apparatus as claimed in any of claims 1 to 3, wherein the temperature sensor modules each further comprise a resistance thermometer, optionally a platinum resistance thermometer, wherein the apparatus is configured such that the temperature sensitivity of each resistance thermometer is used to infer a thermal characteristic of the environment to which the tubing is exposed at the location of that temperature sensor.
10. Apparatus as claimed in any preceding claim, wherein the temperature sensor modules each comprise a diode arranged to block current from flowing back through the temperature sensor modules in the matrix and, optionally, wherein the blocking diode is a low reverse current leakage diode, optionally having a reverse current leakage of less than 50 nA at the operational voltage of the apparatus and at a temperature of 25 degrees Celsius.
11. Apparatus as claimed in any of claims 4 to 6, wherein the temperature sensor modules each comprise a diode arranged to block current from flowing back through the temperature sensor modules in the matrix, and wherein the blocking diode is a low reverse current leakage diode, optionally having a reverse current leakage of less than 50 nA at the operational voltage of the apparatus and at a temperature of 25 degrees Celsius, and wherein the low reverse current leakage diode provides the temperature sensitivity of each temperature sensor module.
12. Apparatus as claimed in any preceding claim, wherein the tubing comprises a matrix of at least 10 wires, preferably at least 15 wires, more preferably at least 18 wires, and in particular 19 wires.
13. Apparatus as claimed in any preceding claim, wherein the tubing comprises 6 temperature sensor modules along its length, preferably at least 16 modules, more

preferably at least 19 modules, still more preferably at least 30 modules, still more preferably at least 60 modules, and still more preferably at least 80 modules.

14. Apparatus as claimed in any preceding claim, further comprising a control module electrically connected to multiple temperature sensor modules, via the electrical network, and configured to, in use, periodically switch through combinations of pairs of wires to electrically connect and infer a temperature at each of the temperature sensors, and wherein the control module comprises one or more relays arranged to, in use, switch through the combinations of pairs of wires, wherein the relays are optionally electromechanical relays or a semiconductor switches.

15. Apparatus claimed in claim 14, wherein the control module is configured to infer a thermal characteristic of each temperature sensor module based on the known sensitivity of the current in or voltage across the temperature sensor to variations in temperature and by measuring variations in the current in and/or voltage across the temperature sensor over time.

16. Apparatus as claimed in any of claims 14 to 15, further comprising calibration means configured to compensate for the resistance of wires in the electrical network that connect the temperature sensor modules to the control module, and preferably also for the temperature dependence of the resistivity of those wires, wherein optionally the calibration means is provided as part of the control module.

17. Apparatus as claimed in any of claims 14 to 16, wherein the control module further comprises a common reference signal generator used to calibrate the measurement of the voltage or current of each of the temperature sensor modules to changes in temperature.

18. Apparatus as claimed in claim 17, wherein the common reference signal generator is a reference voltage source.

19. Apparatus as claimed in any preceding claim, wherein the tubing is filled with and encapsulates a non-conducting liquid, optionally an oil, and optionally wherein the tubing comprises a pressure balancing means, optionally including a bellows or flexible bladder, configured to act to equalise internal pressure in the tubing with the ambient environment.

20. Apparatus as claimed in any preceding claim, wherein the tubing is one of a stainless steel, a duplex or super-duplex stainless steel, a nickel alloy, titanium or a titanium alloy.

21. Apparatus as claimed in any preceding claim, wherein the tubing outer diameter is in the range of 3 mm to 14 mm, optionally in the range of 6 mm to 10 mm, at the location in the tubing of at least one of the temperature sensor modules, preferably at

least 50%, more preferably at least 90%, and particularly 100% of the temperature sensor modules.

22. Apparatus as claimed in any preceding claim, wherein multiple control modules are provided, wherein individual control modules control sets of temperature sensor modules, and the control modules are linked to one or more master control modules, wherein optionally the apparatus further comprises communication means within the tubing to enable data communication along the tubing to enable communication between control modules, or to enable communication with other devices within the well.
23. Apparatus as claimed in any preceding claim, wherein the tubing containing the temperature sensor modules is arranged as a ring or helix to extend around a tubular element of a well apparatus.
24. Apparatus as claimed in any preceding claim, wherein the power source is replaceable in the well.
25. Apparatus as claimed in any of claims 1 to 23, wherein the apparatus is configured to be powered in use from a position higher in the well, optionally from surface, and optionally via inductive or capacitive coupling.
26. Apparatus as claimed in any preceding claim, wherein the wireless data communication module is arranged to, in use:

    wirelessly receive control signals for controlling the operation of the apparatus, optionally for control of data acquisition, data transmission, and/or to control heating or cooling of the sensors.

27. A well comprising a wellbore temperature sensing apparatus having apparatus for use in sensing temperature in a wellbore as claimed in any of claims 1 to 26 arranged to sense a temperature in a wellbore of the well.
28. A well as claimed in claim 27, wherein the well apparatus comprises a tubular element and an annular sealing device provided at least 100m below a surface of the well, and between the wellbore or a casing of the wellbore and a tubular.
29. A well as claimed in claim 28, wherein the apparatus for use in sensing temperature in a wellbore is provided entirely below the annular sealing device.
30. A well as claimed in claim 28, wherein the tubing of the apparatus for use in sensing temperature in a wellbore does not extend across the annular sealing device.
31. A well as claimed in any of claims 27 to 30, wherein the well apparatus comprises a tubular element and wherein the tubing of the apparatus for use in sensing temperature in a wellbore extends along and/or around the tubular element.

32. A well as claimed in 31, wherein the tubular element in the well is a drill string, and wherein the drill string comprises a drill bit or mill.

33. A well as claimed in any of claims 31 to 32, wherein the tubing is clamped to the tubular element in the well.

34. A well as claimed in any of claims 27 to 30, wherein the apparatus is deployed in the well on wireline, or coiled tubing, and optionally set and/or suspended in the well.

35. A well as claimed in any of claims 27 to 33, wherein the tubing is clamped to and extends across perforating guns.

36. A well as claimed in 35, wherein the apparatus is configured to monitor the firing of the perforating gun.

37. A well as claimed in claim 35 or 36, wherein the apparatus, or a plurality of the apparatus, extend across multiple guns, and multiple perforating guns are independently activatable.

38. A well as claimed in any of claims 27 to 30, wherein the apparatus is configured to monitor the temperature at a barrier in the well.

39. A well as claimed in any of claims 27 to 37, wherein the apparatus is configured to monitor the well during a well test or drill stem test.

40. A well as claimed in any of claims 27 to 39, wherein the well is a production and/or injection well.

41. A well as claimed in any of claims 27 to 40, wherein the apparatus is configured to monitor an exothermic reaction associated with a fluid treatment of the well.

42. A method of calibrating apparatus as claimed in any of claims 1 to 26, comprising:

determining the resistance characteristics of the individual circuits associated with each temperature sensor of the apparatus, and

compensating for that circuit resistance to isolate the responsiveness of the electrical properties of the temperature sensors to temperature variations.