CLAIMS

1. A polymerase chain reaction (PCR) amplification and detection apparatus, comprising:

a) an assembly subsystem comprising:

i) a plurality of vessels;

ii) said plurality of vessels each comprising an aqueous oil matrix, each aqueous oil matrix comprising:

1) an aqueous reaction mix comprising a polynucleotide sample and reagents, the reagents comprising a first reagent capable of excitation by a fluorescence excitation light having a first spectral wavelength when the first reagent hybridizes to the polynucleotide sample; and

2) one or two non-miscible oils selected from the group consisting of an encapsulation oil, a carrier oil, and both an encapsulation oil and a carrier oil;

wherein components of the aqueous reaction mix do not mix with the one or two non-miscible oils;

b) a plurality of heating positions, temperature monitoring positions, and PCR product detection positions defining a plurality of alternating first vessels stations and second vessels stations where the plurality of vessels may be stationed, and wherein:

each of the first vessels stations comprises one of the heating positions and one of the temperature monitoring positions, and each of the second vessels stations comprises one of the PCR product detection positions, or

each of the first vessels stations comprises one of the heating positions, and each of the second vessels stations comprises one of the PCR product detection positions and one of the temperature monitoring positions;

c) a reaction-by-reaction, light-driven photonic heating subsystem comprising a plurality of electromagnetic radiation sources, wherein, when the plurality of vessels are in the heating position, each vessel is in optical communication

with an electromagnetic radiation source, and the electromagnetic radiation source emits electromagnetic radiation to that vessel;

d) a reaction-by-reaction temperature monitoring subsystem comprising a plurality of thermal detection devices, wherein each vessel corresponds to a thermal detection device and the thermal detection device is configured to provide a measuring signal dependent on the temperature of the aqueous oil matrix contained in the vessel;

e) a microcontroller temperature feedback and light source control subsystem communicatively connected to both the photonic heating subsystem and the temperature monitoring subsystem, wherein the microcontroller temperature feedback and light source control subsystem is configured to regulate an energy input required for controlling an output and a duration of an electromagnetic energy emitted by each electromagnetic radiation source through a cycle of reaction temperatures;

f) a fluorescence detection subsystem comprising:

i) one or more fluorescence excitation light sources;

ii) one or more fluorescence emission light sensing devices;

iii) a plurality of first optical members in optical communication with the one or more fluorescence excitation light sources, wherein, when the vessels are in the PCR detection positions each first optical member is configured to provide an optical path for fluorescence excitation light having the first spectral wavelength from the one or more fluorescence excitation light sources to one of said vessels containing the aqueous oil matrix, and wherein each first optical member is further configured to provide an optical path for fluorescence emission light from the aqueous reaction mix to the one or more fluorescence emission light sensing devices; and

iv) an active or passive cooling mechanism at the PCR product detection positions whereby each of the vessels in the PCR product detection positions are cooled; and

g) a positioning device, a mechanical and electronic control system, wherein the mechanical and electronic control system is communicatively connected to the positioning device and to the assembly subsystem, wherein the mechanical and electronic control system causes the assembly subsystem to assemble the

aqueous oil matrices in the plurality of vessels, and wherein the mechanical and electronic control system causes the positioning device to move the plurality of vessels with the aqueous oil matrix from the assembly subsystem to each of the heating positions, temperature monitoring positions, and PCR product detection positions.

2. The apparatus of Claim 1, wherein each electromagnetic radiation source is configured to uniformly heat the volume of the aqueous reaction mix in each corresponding vessel when the vessel is in the heating position through the cycle of reaction temperatures comprising: (i) an annealing temperature in the range from 50 ºC to 65 ºC; (ii) an elongation temperature in the range from 65 ºC to 75 ºC; and (iii) a denaturation temperature in the range from 90 ºC to 99 ºC; and wherein the active or passive cooling mechanism is configured to cool each of the vessels to a temperature range from 55 ºC to 65 ºC when the vessel is in the PCR product detection position.

3. The apparatus of Claim 2, wherein the aqueous reaction mix is heated through the cycle of temperatures (i), (ii), and (iii), in less than or equal to 20 seconds and wherein the volume of the aqueous reaction mix portion of the aqueous reaction mix is less than or equal to 10 μL.

4. The apparatus of Claim 3, wherein the aqueous reaction mix is heated through the cycle of temperatures (i), (ii), and (iii), in less than or equal to 15 seconds and wherein the volume of the aqueous reaction mix portion of the aqueous reaction mix is less than or equal to 10 μL.

5. The apparatus of Claim 4, wherein the aqueous reaction mix is heated through the cycle of temperatures (i), (ii), and (iii), in less than or equal to 10 seconds and wherein the volume of the aqueous reaction mix portion of the aqueous reaction mix is less than or equal to 10 μL.

6. The apparatus of any one of Claims 3 to 5, wherein the cycle of reaction temperatures in (i), (ii), and (iii) is repeated for an additional 1 to 60 cycles.

7. The apparatus of any one Claims 1 to 6, wherein the fluorescence detection subsystem further comprises:

v) a first excitation filter which receives light from the one or more fluorescence excitation light sources and allows passage of the fluorescence excitation light having the first spectral wavelength;

vi) a first emission filter for allowing transmission therethrough of fluorescence emission light to the one or more fluorescence emission light sensing devices from the aqueous reaction mix in response to the fluorescence excitation light having the first spectral wavelength and for substantially blocking transmission of wavelengths other than the wavelengths of the emitted light; or

vii) both v) and vi).

8. The apparatus of Claim 1, wherein each first optical member is further configured to provide an optical path for fluorescence excitation light having a second spectral wavelength from the one or more fluorescence excitation light sources to one of said vessels containing the aqueous oil matrix when the vessel is in the PCR product detection position, wherein the volume of the aqueous reaction mix comprises a second reagent capable of excitation by the fluorescence excitation light having the second spectral wavelength when the second reagent hybridizes to the DNA sample, and wherein each first optical member is further configured to provide an optical path for fluorescence emission light from the aqueous reaction mix to the one or more fluorescence emission light sensing devices.

9. The apparatus of Claim 1, wherein the one or more fluorescence emission light sensing devices is a charged-coupled device (CCD) camera, complimentary metal-oxide semiconductor (CMOS) camera, sensor array, or a combination thereof.

10. The apparatus of Claim 8, wherein the first reagent, the second reagent, or both the first reagent and the second reagent comprises a nucleic acid probe covalently linked to a fluorophore.

11. The apparatus of any one of Claims 1 to 10, wherein each vessel comprises the aqueous reaction mix, the carrier oil, and the encapsulation oil, wherein the carrier oil is non-miscible with both the encapsulation oil and the components of the aqueous reaction mix.

12. The apparatus of Claim 11, wherein the carrier oil has a density ranging from 1,200 kg/m^3 to 2,000 kg/m^3, the encapsulation oil has a density ranging from 700 kg/m^3 to 990 kg/m^3, and the aqueous reaction mix has a density ranging from 990 kg/m^3 to 1,200 kg/m^3.

13. The apparatus of any one of Claims 1 to 12, wherein the electromagnetic radiation sources are laser diodes emitting infrared light having a spectral wavelength in the range from 1,300 nm to 2,200 nm.

14. The apparatus of any one of Claims 1 to 13, wherein the electromagnetic radiation sources are laser diodes emitting infrared light having a spectral wavelength in the range from 1,300 nm to 1,500 nm.

15. The apparatus of any one of Claims 1 to 14, further comprising one or more hot start heating positions prior to the plurality of heating positions.

16. The apparatus of any one of Claims 1 to 15, wherein the photonic heating subsystem further comprises a lens that focuses the electromagnetic radiation of the photonic heating subsystem onto a metallic film disposed between the bottom of the vessel and the oil.