Claims

We claim:

1. A logic gate, comprising a metamaterial surface enhanced Raman scattering (MetaSERS) sensor, comprising
   (a) alphabetical metamaterials in the form of split ring resonators operating in the wavelength range of from 560 nm to 2200 nm, wherein each split ring resonator has a bar width ranging from about 30nm to about 80 nm; and
   (b) a guanine (G) and thymine (T)-rich oligonucleotide that can, upon presence of potassium cations (K^+), fold into a G-quadruplex structure, and in presence of Hg^{2+}, form a T-Hg^{2+}-T hairpin complex that inhibits or disrupts the G-quadruplex structure formed in presence of K^+; wherein the concentration of Hg^{2+} ranges from about $2x10^{-4}$ ppb to about $4x10^{-1}$ ppb to form the T-Hg^{2+}-T hairpin complex; wherein the alphabetical metamaterials are configured to generate a SERS signal based on the configuration of the G- and T-rich oligonucleotide to be detected by the MetaSERS sensor.

2. The logic gate according to claim 1, wherein the alphabetic metamaterials are disposed on a substrate to form the split ring resonators.

3. The logic gate according to claim 1, wherein the split ring resonators are U, V, H, S, Ū or Y-shaped and have a bar width from 30 to 50 nm.

4. The logic gate according to claim 1, wherein the split ring resonators comprise a noble metal film deposited on their surface.

5. The logic gate according to claim 4, wherein the noble metal film comprises gold, silver, or alloys thereof.

6. The logic gate according to claim 1, wherein the G- and T-rich oligonucleotide has the consensus nucleotide sequence $(((g)_x(t)_y)_m(x)_n((t)_y(g)_x)_o)_p$, wherein x is a, g, t, or c, each x is independently an integer from 1 to 4, each y is independently 1 or 2, each m is independently an integer from 1 to 10, each n is independently an integer from 1 to 10, each o is independently an integer from 1 to 10, and p is an integer from 1 to 5, wherein m + o = at least 4.

7. The logic gate of claim 1, wherein the oligonucleotide sequence has a length of up to 50 nucleotides.

8. The logic gate of claim 1, wherein the oligonucleotide comprises or consists of the nucleotide sequence $(GGT)_4TG(TGG)_4$ (SEQ ID NO:1).

9. The logic gate of claim 1, wherein the oligonucleotide is single-stranded DNA (ssDNA).

10. A method of operating the logic gate according to claim 1, the method comprising
    (a) providing the MetaSERS sensor, wherein the oligonucleotide is comprised in an aqueous solution, wherein the split ring resonators are immersed in the aqueous solution;
    (b) (adding one or more ions selected from the group consisting of potassium ions (K^+), mercury ions (Hg^{2+}), iodide ions (I^-), and combinations thereof; wherein the one or more ions are added at the same time or different times and in any order to generate an AND, OR or INHIBIT logic operation; and
    (c) measuring the SERS signal based on a structure formed by the oligonucleotides after adding the one or more ions.

11. The logic gate of claim 1, wherein the logic gate further comprises one or both of potassium ions and Hg^{2+} to allow two or more logic gate operations selected from the group consisting of "AND," "OR," "INHIBIT," and combinations thereof.

12. The logic gate of claim 1, wherein the concentration of Hg^{2+} ranges from about 2×10^{-4} ppb to about 4×10^{-2} ppb to form the T-Hg^{2+}-T hairpin complex.

13. The logic gate of claim 1, wherein the concentration of Hg^{2+} ranges from about 2×10^{-4} ppb to about 4×10^{-3} ppb to form the T-Hg^{2+}-T hairpin complex.

14. A method for the detection of mercury ions (Hg^{2+}) in a sample, the method comprising
    (a) providing a MetaSERS sensor, comprising alphabetical metamaterials in the form of split ring resonators operating in the wavelength range of from 560 nm to 2200 nm, wherein each split ring resonator has a bar width ranging from about 30nm to about 80 nm; and an aqueous solution comprising a guanine (G) and thymine (T)-rich oligonucleotide, wherein in the presence of the potassium cations (K^+) the oligonucleotide adopts a G-quadruplex structure, and in presence of Hg^{2+}, forms a T-Hg^{2+}-T hairpin complex that inhibits or disrupts the G-quadruplex structure, wherein the aqueous solution is in contact with the split ring resonators, wherein the concentration of Hg^{2+} ranges from about $2x10^{-4}$ ppb to about $4x10^{-1}$ ppb to form the T-Hg^{2+}-T hairpin complex;
    (b) contacting the MetaSERS sensor with the sample in the presence of potassium ions (K^+) under conditions that allow any Hg^{2+} that is present in the sample to form a T-Hg^{2+}-T hairpin complex with the oligonucleotide that inhibits formation of or disrupts the G-quadruplex structure; and
    (c) measuring the SERS signal based on a structure formed by the oligonucleotide after adding K^+.

15. The method of claim 14 wherein the sample is an environmental sample, a food sample or a biological sample.