A particularly promising method of DNA detection of hand-held systems involves the use of graphene-based sensors, and numerous reports in the literature have shown that graphene can provide an excellent alternative method to selectively sense DNA. Graphene is a two-dimensional sheet of sp^2-bonded carbon, which can be realized in monolayer form either through mechanical exfoliation, or through growth on copper using chemical vapor deposition (CVD).

Due to its monolayer nature, graphene can provide excellent sensitivity to adsorbed biomolecules, and can also be functionalized to provide selectively to chemically-active targets.

Conventional graphene sensors utilize simple diffusion processes to attract particles to the surface. This can be slow. On the other hand, dielectrophoresis (DEP) can be used to attract particles to a region of high electric field gradient, but does not provide a convenient means of selective sensing. In this invention, a sensor is described that solves the problem of how to achieve selectivity within a DEP-based sensors by the use of graphene which is functionalized with a probe material on the surface. It also provides a way to separate the DEP-attraction bias voltages, which are relatively large, and the sensing bias voltages, which are often smaller.

SUMMARY

In a first aspect, the present disclosure provides a dielectrophoretic (DEP) sensor, comprising: a graphene electrode adjacent a channel for confining a target particle in a liquid; a surface probe attached to a surface of the graphene electrode, the surface probe having a selective reaction with the target particle; and a voltage source electrically connected to the graphene electrode and configured to (i) apply a voltage to the graphene electrode to cause DEP trapping of the target particle at the graphene electrode, and (ii) apply a measurement signal to the graphene electrode, the measurement signal being sufficient to readout a response from the DEP sensor indicative of a presence of the target particle.

In a second aspect, the present disclosure provides a readout method for a dielectrophoretic (DEP) sensor comprising a graphene electrode with a surface probe attached to a surface of the graphene electrode, the surface probe having a selective

reaction with a target particle, the readout method comprising: applying an AC excitation to the graphene electrode sufficient to dielectrophoretically attract the target particle toward the graphene electrode; and applying a measurement signal to the graphene electrode, the measurement signal being sufficient to readout a response from the DEP sensor indicative of a presence of the target particle.

In certain embodiments, the disclosure features a graphene-edge dielectrophoretic (DEP) sensor that utilizes surface functionalization to achieve specificity and selective sensing. In some embodiments, the disclosure features a methodology by which to detect the selective response of the sensor.

In some embodiments, the graphene-based DEP sensor utilizes surface functionalization on the graphene or adjacent surfaces (or substrates) to achieve selectivity. The graphene-based DEP sensor can use a time-varying excitation for DEP attraction that enables the sensor response to be read out independent of the DEP AC excitation.

Among other advantages, embodiments can achieve selectivity to a range of target molecules or biological particles using a DEP-based graphene sensor. Embodiments can

WHAT IS CLAIMED IS:

1. A dielectrophoretic (DEP) sensor, comprising:

a graphene electrode adjacent a channel for confining a target particle in a liquid;

a surface probe attached to a surface of the graphene electrode, the surface probe having a selective reaction with the target particle; and

a voltage source electrically connected to the graphene electrode and configured to (i) apply a voltage to the graphene electrode to cause DEP trapping of the target particle at the graphene electrode, and (ii) apply a measurement signal to the graphene electrode, the measurement signal being sufficient to readout a response from the DEP sensor indicative of a presence of the target particle.

2. The DEP sensor of claim 1, wherein the surface probe and target particle are a complementary pair selected from the group consisting of molecules, proteins, aptamers, antibodies, lipids, vesicles, cell-derived particles, functionalized nanoparticles and whole cells.

3. The DEP sensor of claim 1 or 2, wherein the graphene electrode comprises a plurality of strips.

4. The DEP sensor of claim 3, wherein the strips are parallel to each other.

5. The DEP sensor of any one of the preceding claims, further comprising a second electrode overlapping with the graphene electrode and electrically connected with the voltage source.

6. The DEP sensor of claim 5, further comprising a source meter in electrical communication with the graphene electrode and the second electrode.

7. The DEP sensor of any one of the preceding claims, wherein the DEP sensor is a resistance-based sensor.

8. The DEP sensor of any one of the preceding claims, wherein the DEP sensor is a capacitance based sensor.

9. A readout method for a dielectrophoretic (DEP) sensor comprising a graphene electrode with a surface probe attached to a surface of the graphene electrode, the surface probe having a selective reaction with a target particle, the readout method comprising:

applying an AC excitation to the graphene electrode sufficient to dielectrophoretically attract the target particle toward the graphene electrode; and

applying a measurement signal to the graphene electrode, the measurement signal being sufficient to readout a response from the DEP sensor indicative of a presence of the target particle.

10. The readout method of claim 9, wherein the measurement signal is a DC signal.

11. The readout method of claim 9, wherein the measurement signal is an AC signal.

12. The readout method of any one of claims 9-11, wherein an amplitude of the AC excitation is larger than an amplitude of the measurement signal.

13. The readout method of any one of claims 9-12, wherein the readout is based on a change of capacitance measured by the sensor.

14. The readout method of any one of claims 9-12, wherein the readout is based on a change of current measured by the sensor.

15. The readout method of any one of claims 9-14, wherein the surface probe and target particle are a complementary pair selected from the group consisting of molecules, proteins, aptamers, antibodies, lipids, vesicles, cell-derived particles, functionalized nanoparticles and whole cells.