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 apply a voltage to the graphene electrode to cause DEP trapping of the target particle at the graphene electrode.

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

also enable reading out the sensor response in the presence of a relatively large AC excitation meant to attract particles to the graphene edge.

The details of one or more embodiments of the disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the disclosure will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

FIGS. 1a – 1c are schematic diagrams showing a top view of a resistance-based DEP sensor. Fig. 1a shows the sensor with the attached probe on the graphene surface, in a solution containing the target. Fig. 1b shows the sensor with the targets attracted to the graphene edges using DEP via an applied AC bias. Fig. 1c shows the targets bonding to nearby probes after the DEP excitation is removed, enabling sensor readout.

FIGS. 2a – 2c are schematic diagrams showing a top view of a capacitance-based DEP sensor. Fig. 2a shows the sensor with the attached probe on the graphene surface, in a solution containing the target. Fig. 2b shows the sensor with the targets attracted to the graphene edges using DEP via an applied AC bias. Fig. 2c shows the targets bonding to nearby probes after the DEP excitation is removed, enabling sensor readout.

FIG. 3 shows plots of the applied voltage signal and anticipated response for a resistance-based DEP sensor.

FIG. 4 shows plots of the applied voltage signal and anticipated response for a capacitance-based DEP sensor.

FIGS. 5a and 5b show plots of an anticipated response of a capacitance-based DEP sensor with varied AC bias.

FIGS. 6a – 6e illustrate a graphene-edge DEP tweezer fabrication process. FIG. 6a shows gate oxide recess and gate metal patterning. FIG. 6b shows graphene transfer. FIG. 6c shows graphene patterning into trapping segments. FIG. 6d shows contact metallization and lift off. FIG. 6e shows the surface functionalization with a probe object.

Like reference symbols in the various drawings indicate like elements.