Accordingly, there is a need to provide a sensor that overcomes or at least ameliorates the disadvantages or drawbacks discussed above. There is further a need to provide a method for making such sensors.

Summary ~~of invention~~

In a first aspect of the present disclosure, there is provided a sensor comprising a semi-permeable film layer, ~~said~~ the semi-permeable film layer comprising at least one integrally formed well having at least one sensing element disposed therein; wherein the well is sealed by a second film layer, ~~said~~ the semi-permeable film layer being impermeable to ~~said~~ the sensing element but is permeable to at least one analyte detectable by ~~said~~ the sensing element. The analytes may be water soluble or oil soluble analytes.

Advantageously, the second film layer substantially engages with the semi-permeable film layer to seal the one or more integrally-formed wells of the semi-permeable film, thereby encapsulating the sensing element within the wells of the semi-permeable film. The second film layer may be impermeable to the analytes and the sensing element.

In one embodiment, a plurality of wells (or "microcompartments" or "microwells") is integrally-formed on the semi-permeable film layer. The arrangement and shape of the wells are not particularly limited so long as they provide sufficient volume for encapsulating the sensing elements of choice. The arrangement of wells on the semi-permeable film (e.g. size, distribution density, pitch, etc.) can also be configured as necessary to generate a desired output signal (whether captured manually or automatically by a machine). In one embodiment, the array of wells is a highly ordered array, wherein the wells are arranged in a manner to provide sensing elements adapted for detecting particular analytes in designated zones or locations to enable easy signal capture.

The disclosed sensor is capable of assessing the spoilage characteristics of a food product regardless of the cause of spoilage, whether from extended period of storage or violation of the appropriate storage conditions or due to leaking or tampered packaging. Also advantageously, the disclosed sensor does not require direct contact with an analyte to be detected or measured and can be employed in non-destructive or non-contact measurements of various physical / chemical parameters.

Advantageously, the disclosed semi-permeable film may be provided as a thin, flexible layer that can be readily affixed to a substrate, e.g., an interior surface of a food packaging. In particular embodiments, the disclosed sensor may have a total thickness of 10 micron or less taking into account the depth of the wells. Accordingly, the disclosed sensor can be easily incorporated into food packaging without requiring additional packaging space.

More advantageously, the disclosed sensor is able to separately or concurrently detect (whether directly or indirectly) dissolved gases (e.g. CO_2 or O_2), glucose, and other water/oil-soluble analytes such as metabolite compounds formed by cell autolysis or due to bacterial

layers and at least one or more layers of clay, calcium carbonate, or other suitably charged filler layer.

Particularly, where the PEM film is a composite material, its mechanical properties (both stiffness and tensile strength) can be adjusted to withstand shear forces and pressure experienced in conditions mimicking the real food transportation. Appropriate fine-tuning of the specific composition of the PEM film and its thickness may be useful to prevent rupturing of the wells and leakage of the sensing elements contained therein.

In one embodiment, the disclosed sensor may contain at least one exposed outer layer that is not substantially engaged with the semi-permeable film layer. Advantageously, the exposed outer layer can be an adhesive layer or may be made adhesive for coupling to or for reversibly engaging with a substrate, e.g., an interior surface of typical packaging material (e.g. polyvinyl chloride, polystyrene and polylactic acid). Still advantageously, the disclosed sensor, and in particular the PEM films, may be biocompatible which makes for easy disposal and additionally prevents or ameliorates the risk of toxic food contamination.

In a second aspect of the present disclosure, there is provided a method of assessing food quality in packaged food, the method comprising the steps of: a) contacting a sensor as defined herein with the food; b) detecting at least one measurable output from the sensor.

In a third aspect of the present disclosure, there is provided the use of a sensor as defined herein to detect spoilage in a food product.

In a fourth aspect of the present disclosure, there is provided a method of making a sensor, the method comprising the steps of:

i. depositing a semi-permeable film coating on a patterned template to thereby form a semi-permeable film having at least one integrally formed well;

ii. disposing one or more sensing elements in the well; and

iii. encapsulating the sensing elements in the well;

wherein the semi-permeable film layer is not permeable to the sensing element but is permeable to at least one analyte detectable by the sensing element.

Brief description of drawings

The invention will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

[Fig. 1a] shows emission spectra of SNARF-1 dextran dye (0.05 mg/mL in phosphate buffer) depending on the solution pH, excitation wavelength 530 nm.

[Fig. 1b] shows emission spectra of SNARF-4F dye (5 μg / mL in phosphate buffer) depending on the solution pH, excitation wavelength 550 nm.

[Fig. 1c] is a graph showing the ratios between emission intensities I585/I630 depending on the pH for SNARF-1 and SNARF-4F.

[FIG. 2] shows an emission spectra of Amplex®UltroxRed dye formed in cascade enzymatic reactions in system containing Amplex®UltraRed (50 μM), horseradish peroxidase ("HRP") (3.6 Units/mL), XOD (0.15 Units/mL), NP (2.5 Units/mL), phosphate buffer at pH 5.5, and different concentrations of Hx in the range from 0 to 15 μM. Excitation wavelength was 500 nm.

[FIG. 3] is a graph showing the intensities of emission at 585 nm (after subtraction the intensities of self-oxidized Amplex®UltroxRed) obtained for the solutions of sensing element III containing pure Hx (**represented by square data points**), Ino (**represented by circular data points**), and IMP (**represented by triangular data points**) as well as the mixed solution of Hx + Ino + IMP (represented by **diamond** data points) and for the solution of sensing element IV containing the mixed solution of Hx + Ino + IMP (represented by **star** data points). Symbols represented by cross (+) data points indicate difference between the