Figures:

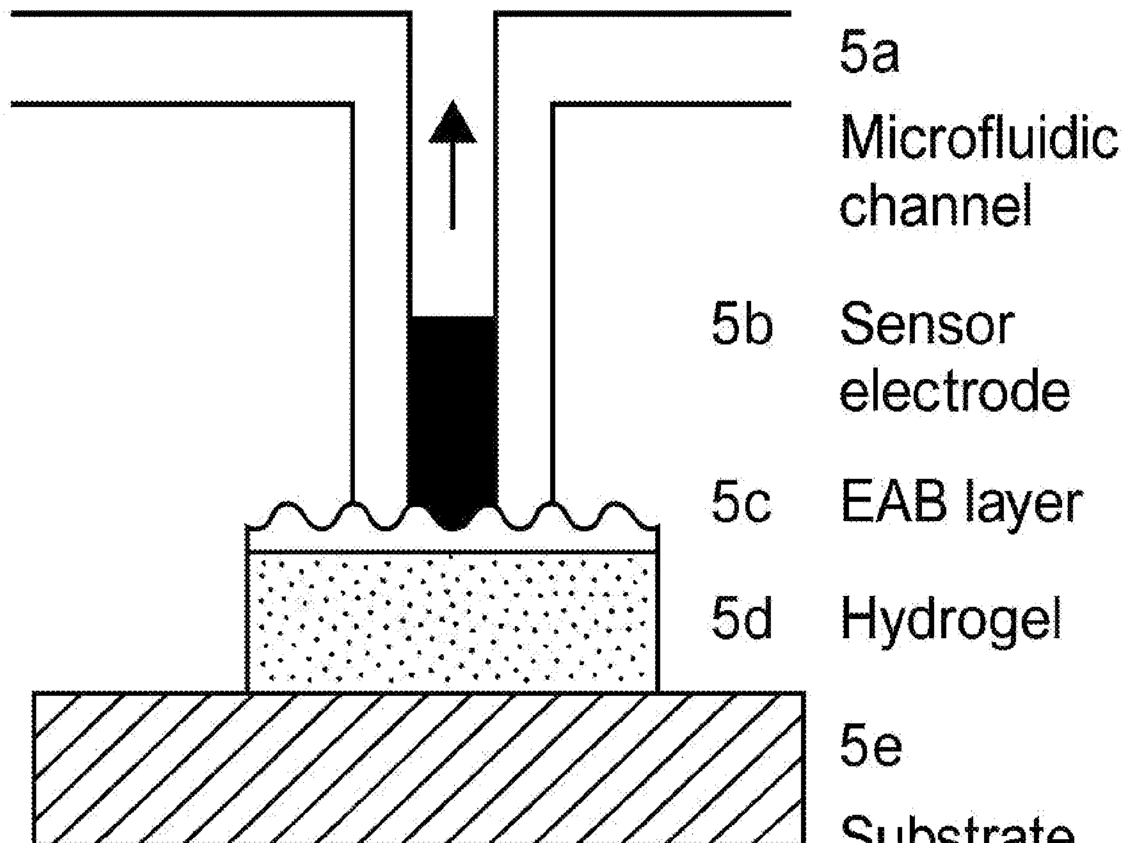
5a
Microfluidic
channel
5b
Sensor
electrode
5c
EAB layer
5d
Hydrogel
5e
Substrate

FIG 12

- FIG. 12A – Colour aid showing identical stack-up with dashed shading for didactic clarity; not required for claim scope.
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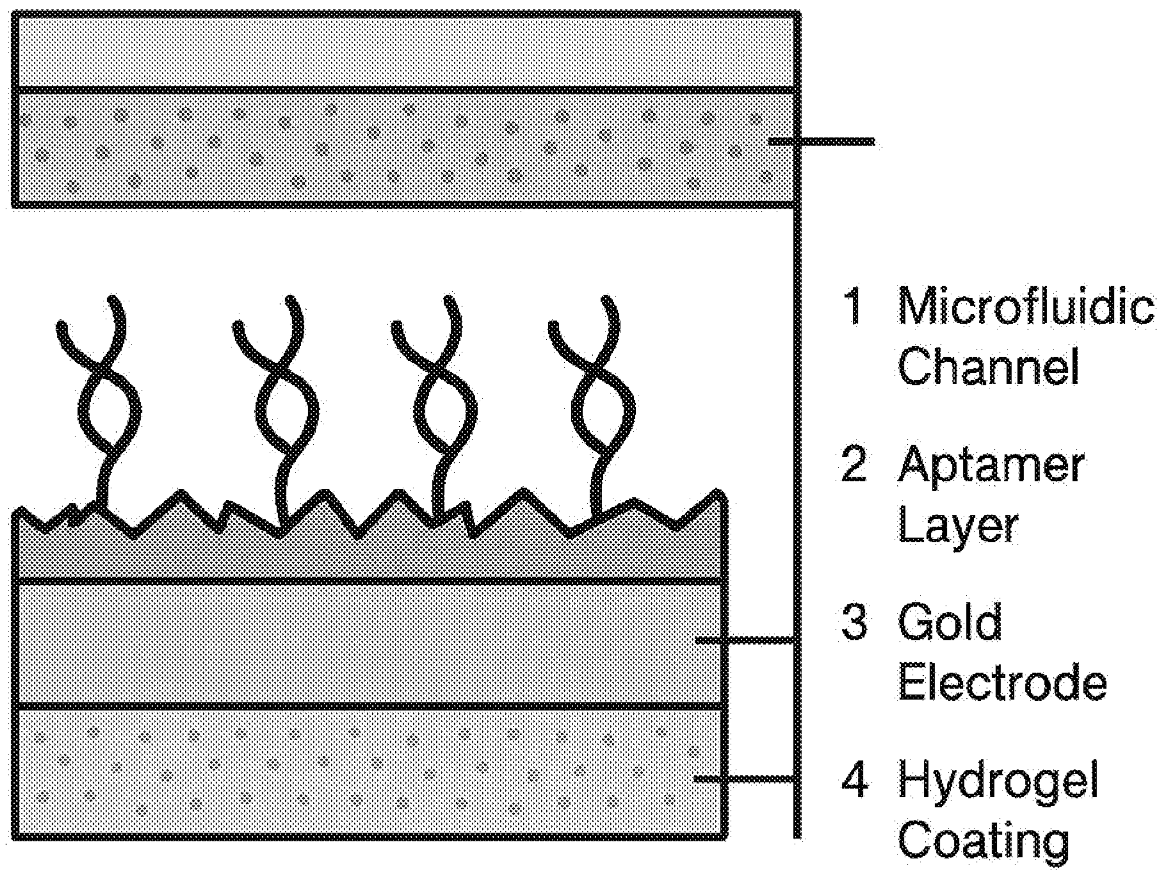

Fig12A
Cross-sectional view of microfluidic/EAB sensor

9.2 Microfluidic / EAB Cartridge

Reference to FIG. 12. Whole-blood or dialysate enters microfluidic channel 5a and flows across planar sensor electrode 5b. The electrode is functionalised with a densely packed aptamer layer 5c that undergoes a conformational change upon binding an analyte (e.g., heparin–Anti-Xa complex or citrate ion). A porous hydrogel layer 5d overlays the aptamers, limiting fouling and providing a three-dimensional ion reservoir that improves signal-to-noise. The entire stack is fabricated on inert substrate 5e (glass, polyimide, or alumina).

9.2.1 Fabrication

1. Substrate preparation – Substrate 5e is cleaned, silanised, and patterned with Ti/Au (20 nm / 150 nm) by lift-off to form electrode 5b.

2. Aptamer immobilisation – A mixed monolayer of thiol-terminated aptamers and PEG spacers is self-assembled on Au at 4 °C for 12 h (improves orientation and reduces nonspecific binding).

3. Hydrogel deposition – Poly(HEMA) pre-polymer containing 0.2 % photo-initiator is spin-coated (2000 rpm, 45 s) and UV-cured for 60 s, yielding ~25 µm hydrogel 5d.

4. Microchannel bonding – A laser-micromachined cyclic-olefin copolymer (COC) lid forms channel 5a and is solvent-bonded at 65 °C under 200 kPa for <5 min to preserve aptamer activity.

9.2.2 Electrical & Data Interface

A three-wire shielded cable routes to a low-noise transimpedance amplifier on the TraceLoop MX backplane. The amplifier samples at 20 kHz and reports a rolling-window current (Isig) integrated over 100 ms. The MCU converts Isig to concentration units using a two-point in-situ calibration curve that is refreshed every heparin-free sensor flush cycle (see §9.4). Data are timestamped (µs resolution) and published on CAN ID 0x5E8 as JSON: { "antiXa_IU_mL": 0.54, "timestamp": 1712 µs, "quality_flag": "OK" }.

9.2.3 Sterility & Single-Use

The cartridge (channel 5a + aptamer + hydrogel) is supplied γ-irradiated and is single-patient, 72-h use. The gold electrode pad remains in situ; only the disposable flow-cell snaps off, minimising daily consumable cost.

9.3 Citrate-Specific Variant

Replacing the Anti-Xa aptamer with a citrate-responsive E-AB probe yields an inline CRRT anticoagulation loop sensor. Channel geometry is scaled for 150 mL min-1 extracorporeal flow. Guard-rail tier enforces a failsafe if post-filter Ca^{2+} <0.9 mmol L-1 and citrate sensor saturates, as described in §8.2.

9.4 Sensor-Flush & Calibration Subsystem (FIG. 13)

FIG. 13 depicts an automated flush manifold with three solenoid valves (13a-13c) delivering (i) heparin-free saline, (ii) low-standard, (iii) high-standard calibrant. A micro-peristaltic pump (13d) circulates 2 mL of calibrant through the sensor every 8 h. Calibration coefficients are written to non-volatile memory and broadcast to the arbitration layer so that sensor confidence weights can be updated dynamically.

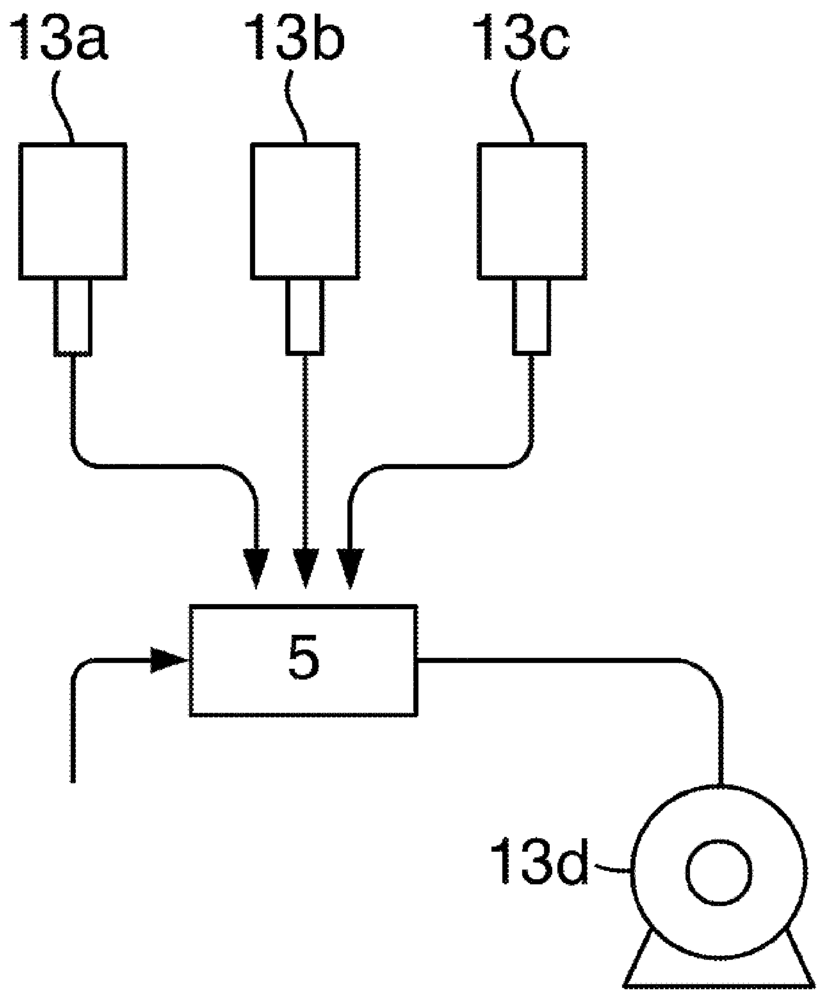

FIG. 13

9.5 Mechanical Dock & Safety Interlocks

Each cartridge mates via a keyed luer-lock tee. An RFID tag embedded in the disposable stores serial number, lot, and remaining shelf-life; TraceLoop's MCU blocks loop activation if tag fails checksum or if remaining life <24 h. A mechanical duckbill valve prevents retrograde blood flow during cartridge changeover.

9.6 Integration with Factor Graph

The EAB sensor activates factor ANTI_XA (thresholds 0.30/0.70 IU mL-1) or factor CITRATE_GAP (thresholds 3/7 mmol L-1). Because sensor latency is <3 s, the reversibility_window column (FIG. 11) for the corresponding loop is set to SHORT, permitting tighter PID gains than lab-only inputs.

9.7 Alternate Embodiments

- Optical interferometric sensor – FIG. 14 illustrates a waveguide-based aptasensor using Mach–Zehnder interferometry on SiN; eliminates electrode passivation issues.

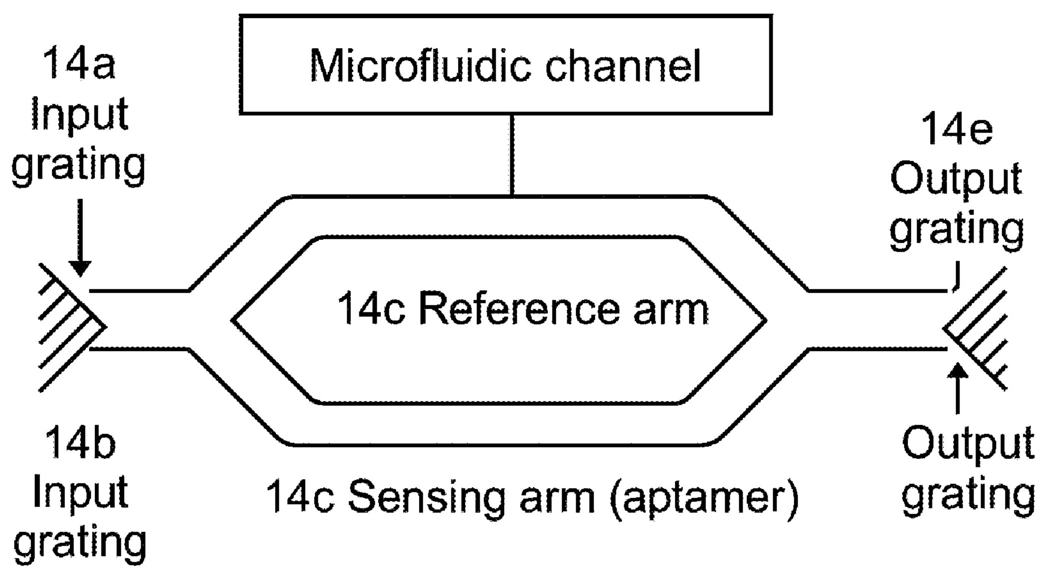

FIG. 14 Optical waveguide interferometric aptamer sensor

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- Disposable fibre optic probe – FIG. 15 shows an evanescent-field fluorescence design for bedside throw-away sensors in resource-limited settings.
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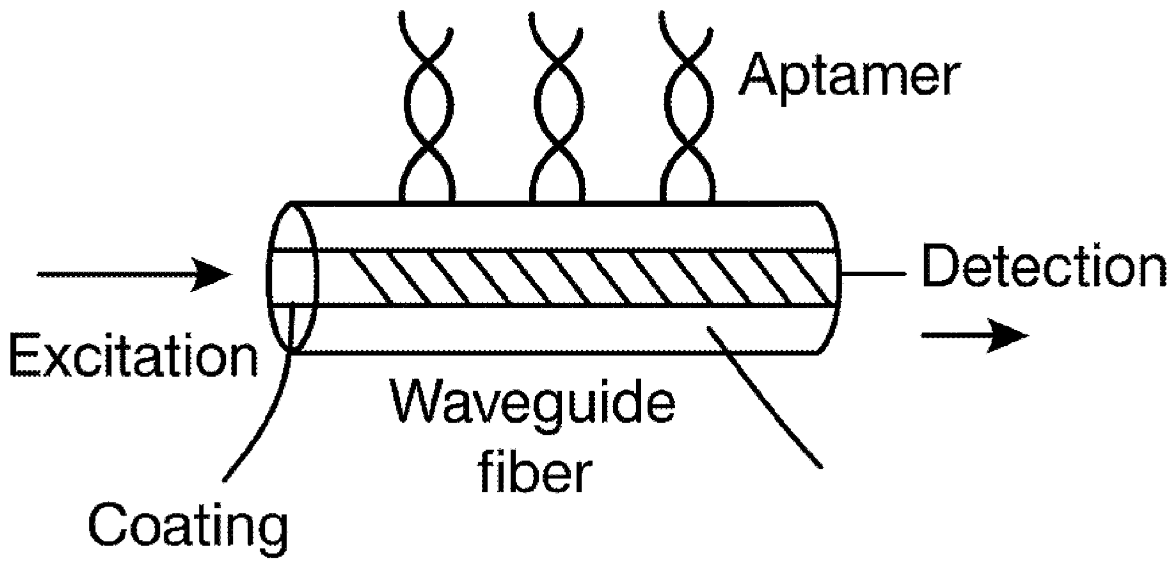

FIG. 15

Disposable fibre optic probe
evanescent-field fluorescence sensor

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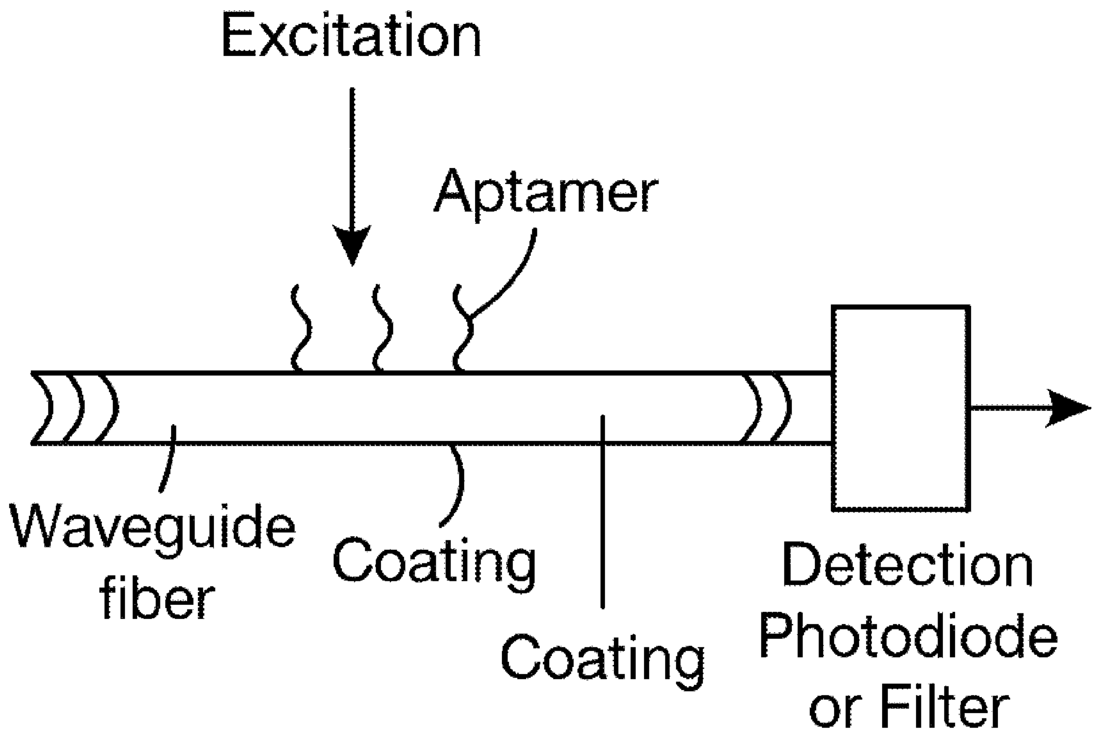

FIG. 15

Disposable fibre optic probe evanescent-field fluorescence sensor

- MEMS ion-selective FET – FIG. 16 outlines a lithographically patterned calcium-selective ISFET for post-filter Ca^{2+} monitoring without reagents.

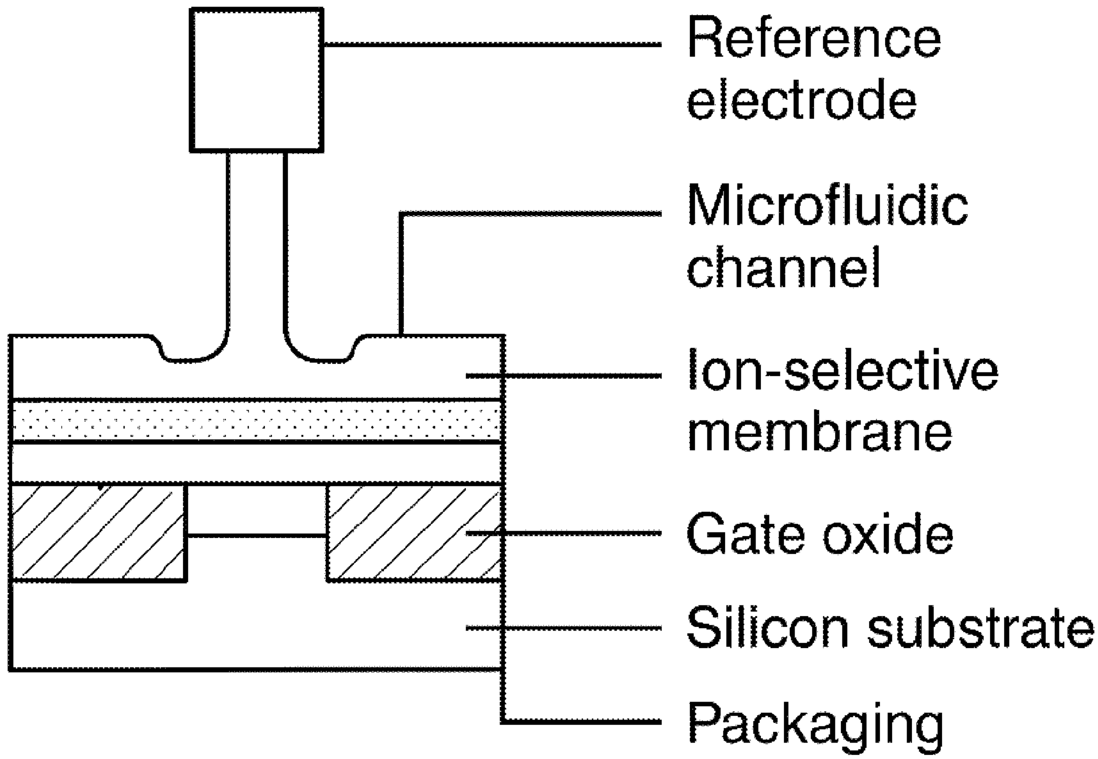

FIG. 16 MEMS ion-Selective Field-Effect Transistor Sensor

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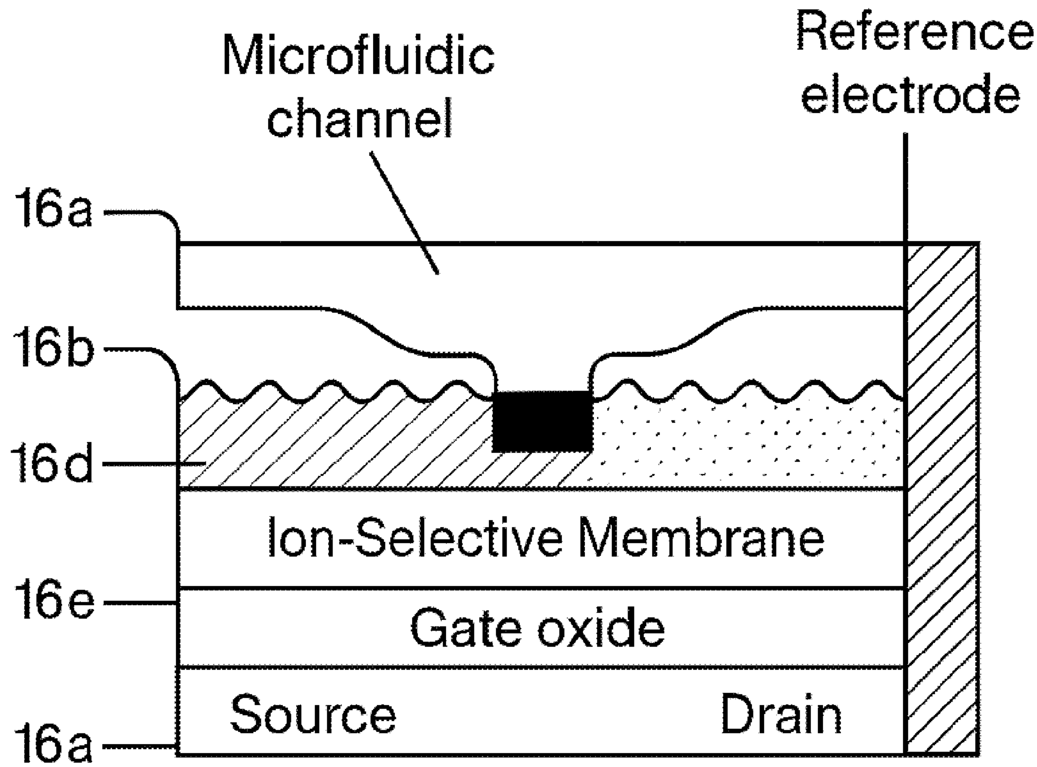


FIG. 16

MEMS ISFET calcium sensor

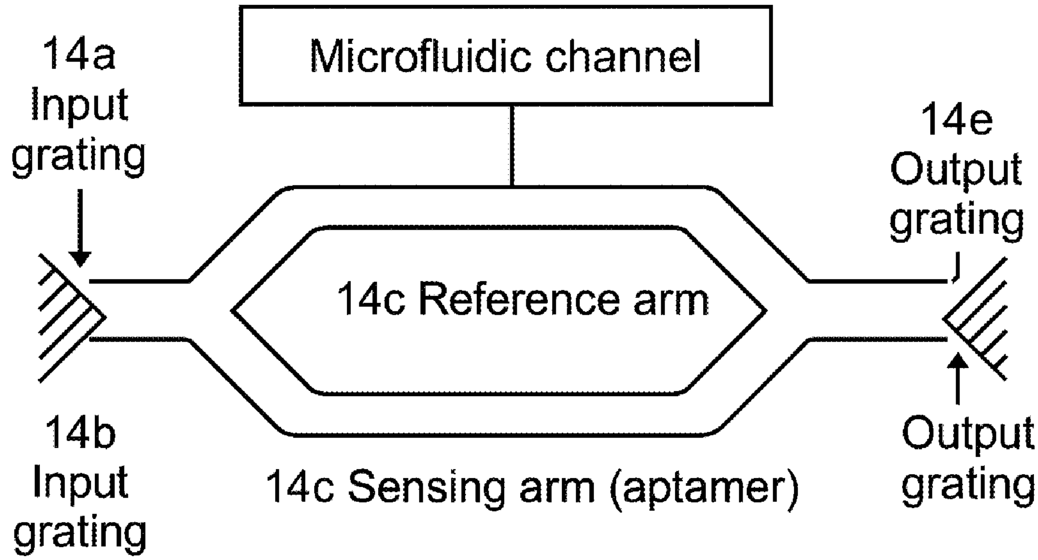


FIG. 14 Optical waveguide interferometric aptamer sensor

Each alternate embodiment couples to the same MX bus and obeys identical data-schema contracts; only columns 3-4 of TABLE 1 (sensor_modality, response_time) differ.

9.8 Advantages

1. Exchangeable consumable – aptamer degradation no longer mandates full hardware exchange; only a

References: Continuous Anti-Xa Sensor Module specifications above are supported by current research and best practices in microfluidic biosensing. Conventional anticoagulation monitoring is infrequent and labor-intensivepubmed.ncbi.nlm.nih.gov, motivating this real-time sensor approach. Prior art includes microfluidic anti-factor Xa assay chips for point-of-care useresearchprofiles.tudublin.ie and novel continuous heparin sensors (e.g. fiber-optic photoacoustic devices with LoD ~0.18 U/mL)pubmed.ncbi.nlm.nih.gov. The chosen aptamer-electrochemical method builds on demonstrated in vivo aptamer sensors capable of sub-minute resolution tracking of drugsresearchgate.net. The reversible aptamer switch mechanism underpins the continuous measurementresearchgate.net. Microfabrication techniques (gold microelectrodes in microchannels) are well-established for heparin sensingresearchgate.net, and protamine-based sensors have shown the feasibility of electrical heparin detection with high sensitivity researchgate.net. Advanced surface coatings now allow week-long in vivo sensor stability researchgate.net, aligning with the module's 5-day use. These sources and design elements confirm that the Continuous Anti-Xa Sensor Module is a feasible and innovative addition to the TraceLoop-MX closed-loop ICU system, merging state-of-the-art biosensor technology with robust safety and integration engineering.

Figures

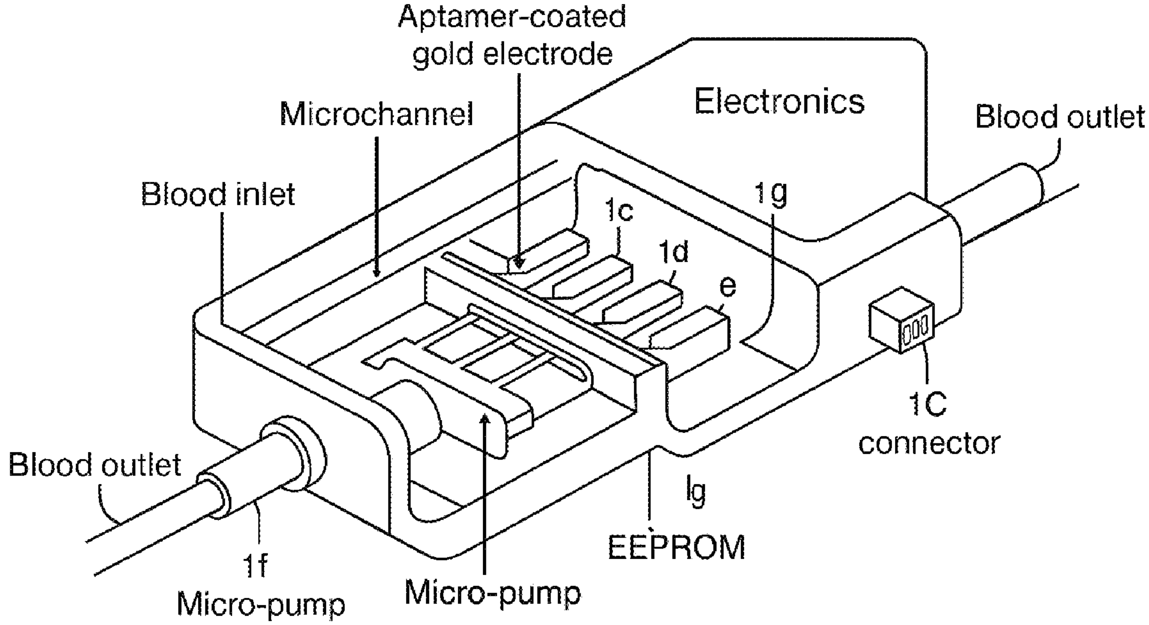
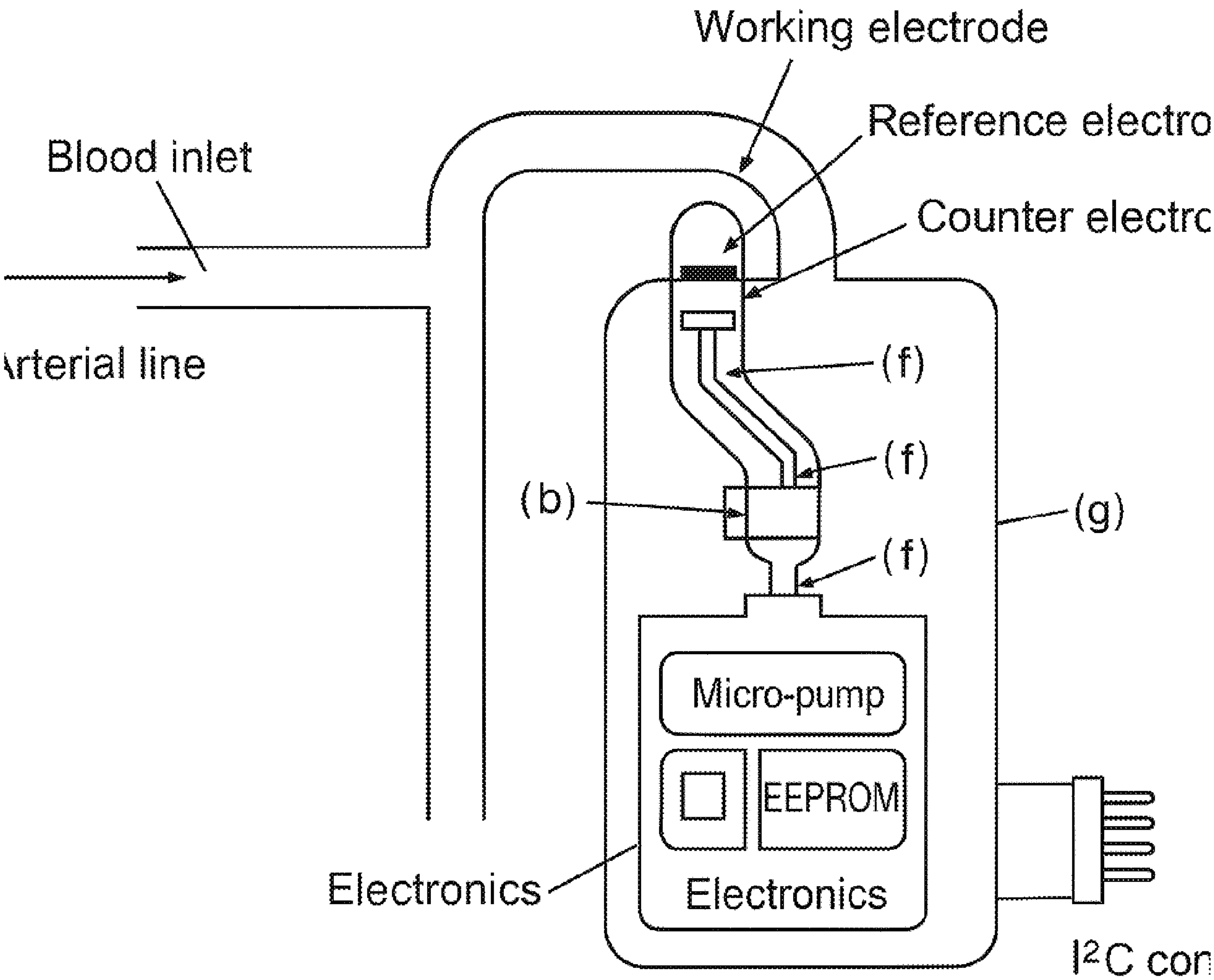


FIG. 1
Arterial-line microfluidic sensor cartr idge integrated



(1 Arterial-line microflui(dc sensor cartridge