

Non-Optical Bubble Sensing Methods

for

Electrically Conducting Liquids

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Goals for Bubble Sensing Devices:

1. Detect small bubbles in a small fluid channel without immersion of sensor parts in the channel
2. Differentiate between a gas filled channel and a fluid filled channel
3. Be sensitive to rather small gas fractions passing down the small fluid channel

Desirable Features:

1. Small and flat
2. Inexpensive
3. Reliable

Zen – No Sensor Sensor:

EIS

Magnetostatic Methods:

Magnetostatic Bubble Sensing – Impedance Method – 1 Coil

Magnetostatic Bubble Sensing – Transformer Method – 2 Coils

Magnetostatic Bubble Sensing – Gradiometer Method – 3 Coils

Galvanic Contact Methods:

Noble Metal Electrode Methods

Permittivity (Capacitive) Methods:

Absolute Capacitance

Differential Capacitance

Mass flow Methods:

Mechanical Resonance of Fluid Loaded Beams

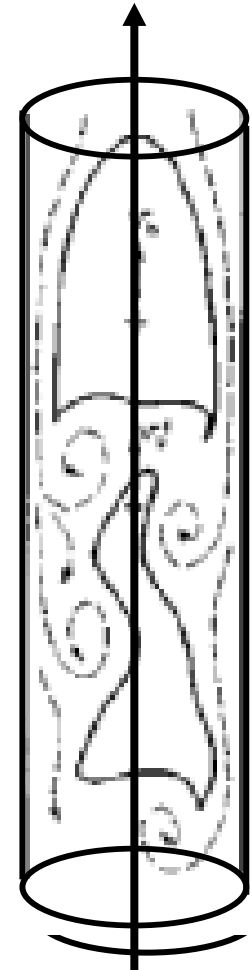
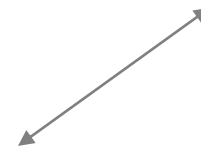
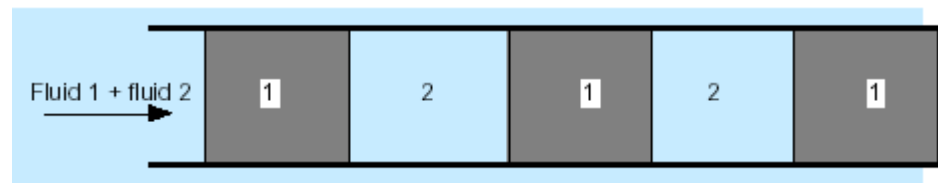
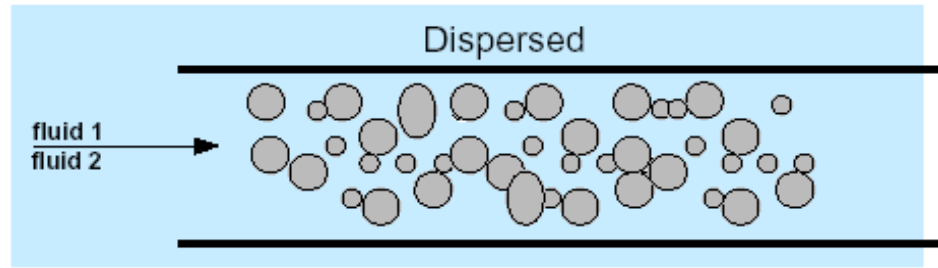
Ultrasonic Methods:

Pitch – Catch

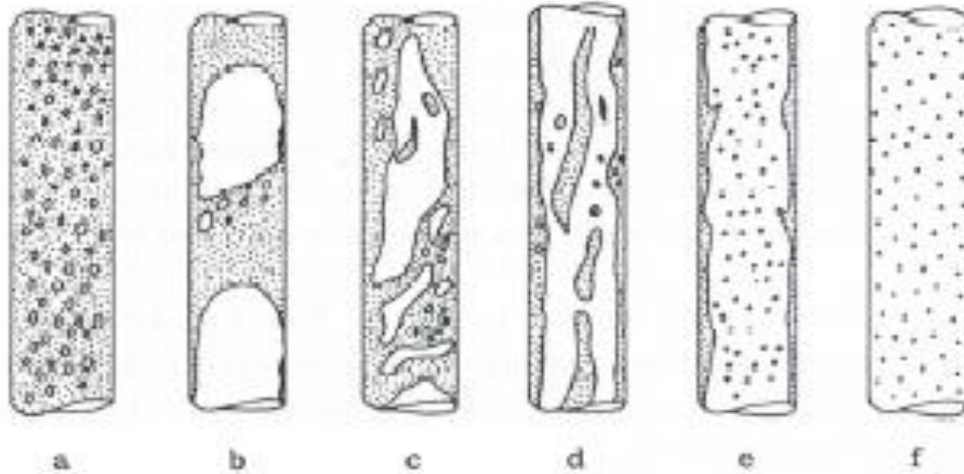
Mechanical Impedance

Nature of the Bubbles

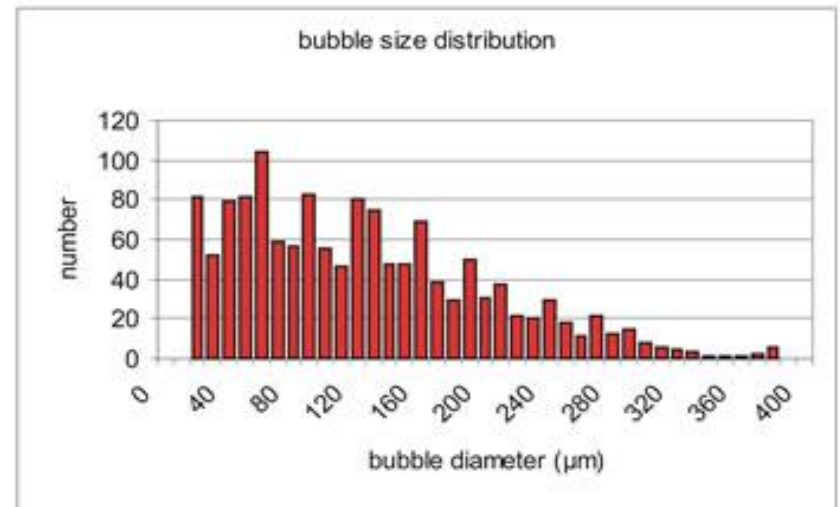
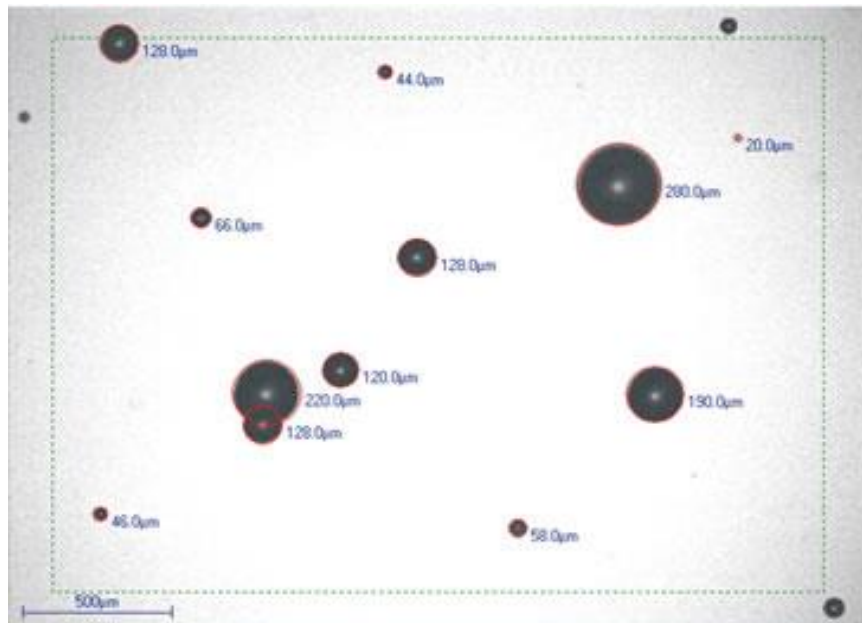
Nature of the Bubbles



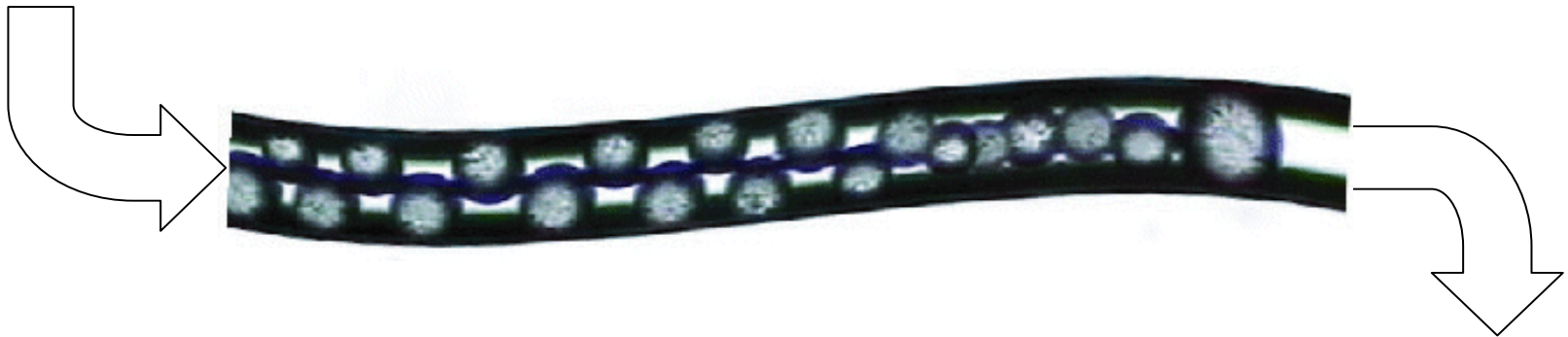
Nature of the Bubbles



Nature of the Bubbles



Nature of the Bubbles



Electrical Impedance Bubble Sensing

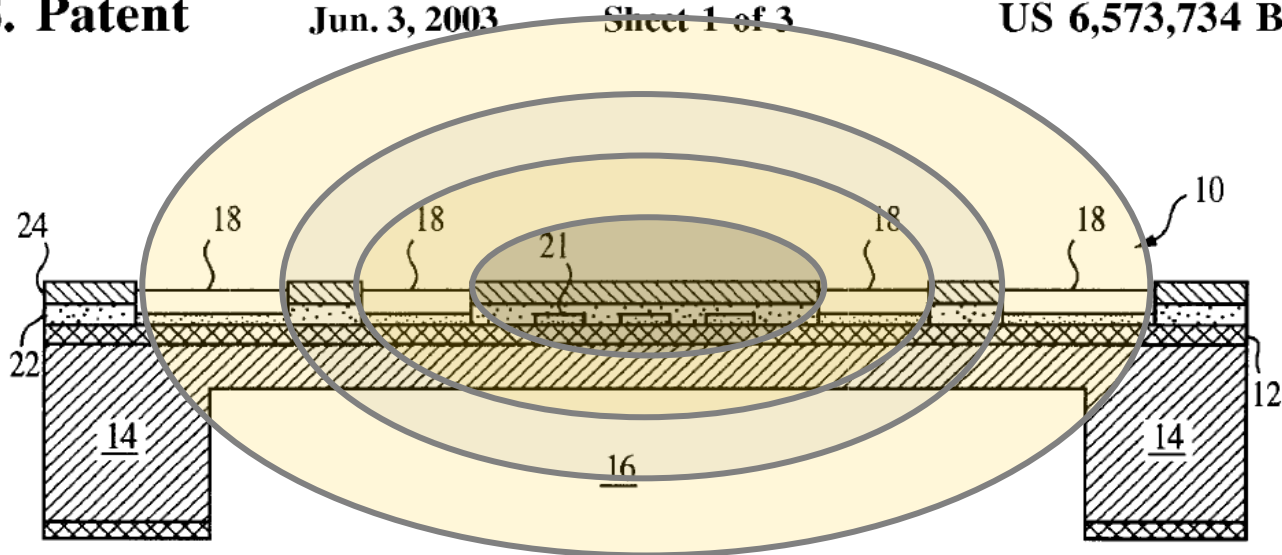
Electrode Bubble Sensing Methods - MEMS

U.S. Patent

Jun. 3, 2003

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US 6,573,734 B2



SILICON



THERMAL
OXIDE



NICKEL



GOLD



2ND SiN_x



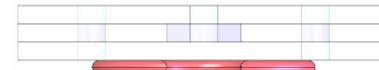
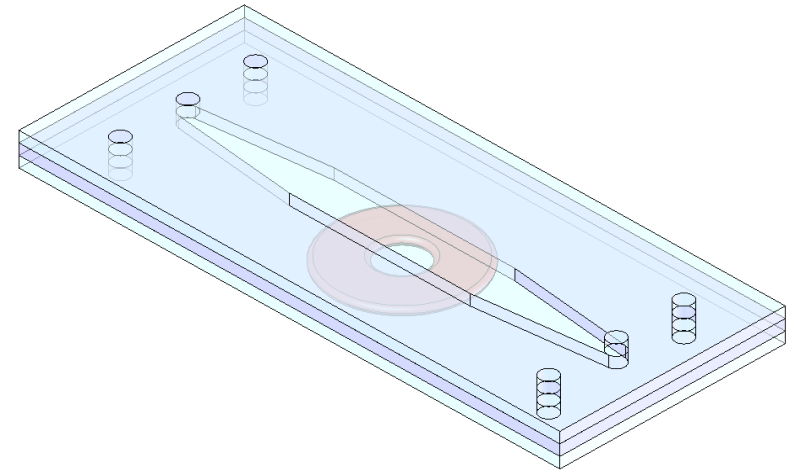
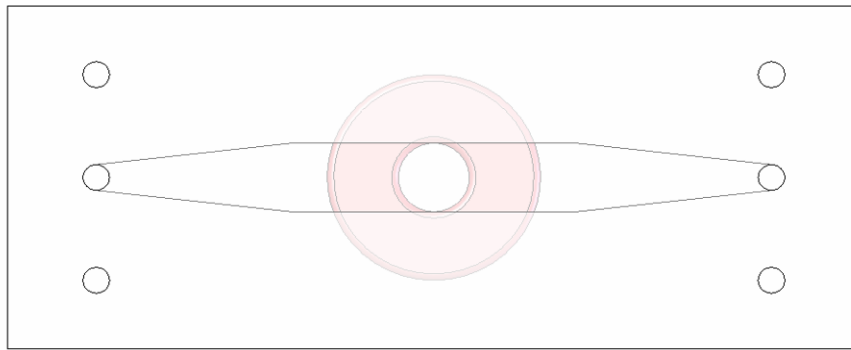
1ST SiN_x

Zen – No Sensor Sensor - EIS

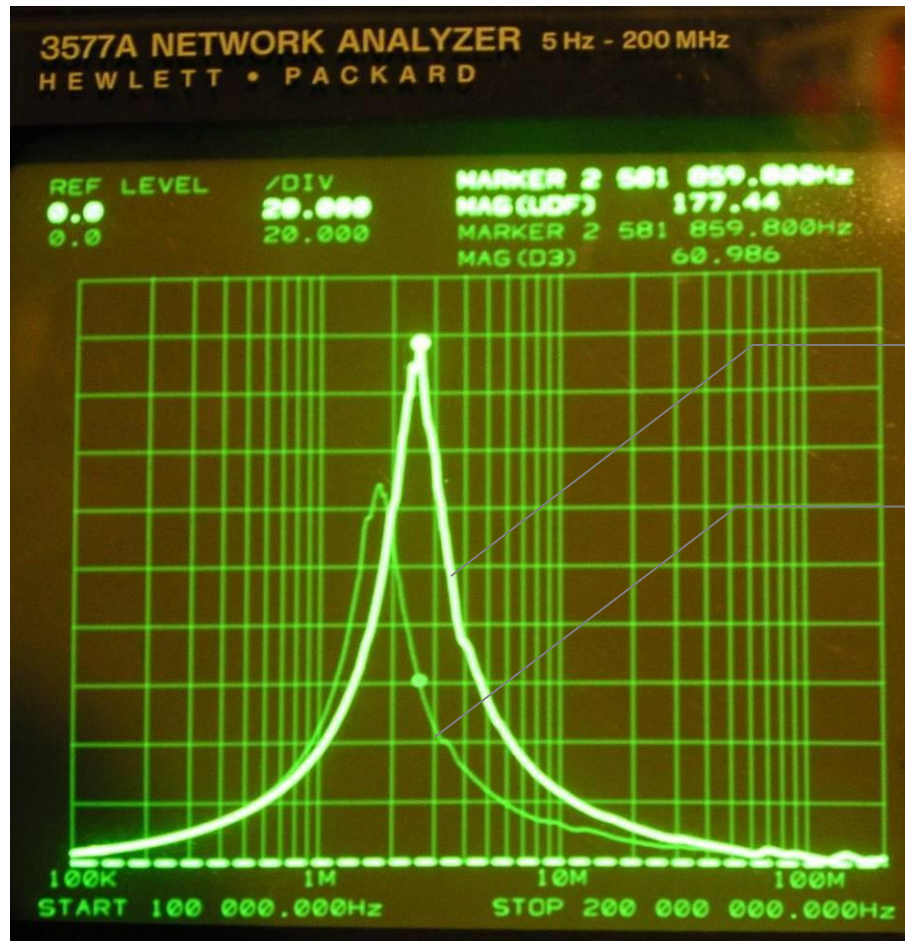
Measure the liquid electrical impedance using electrode already in place for other reasons.

Impedance Sensing – Single Coil

Impedance Sensing - Single Coil



Impedance Sensing - Single Coil

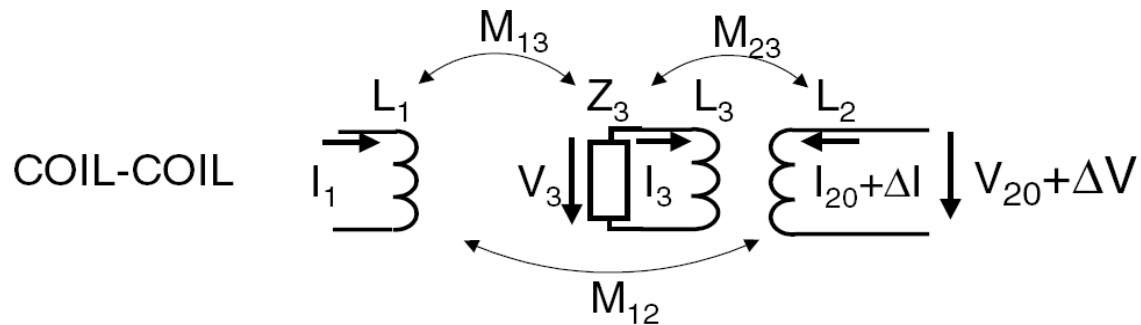


Coil by
itself

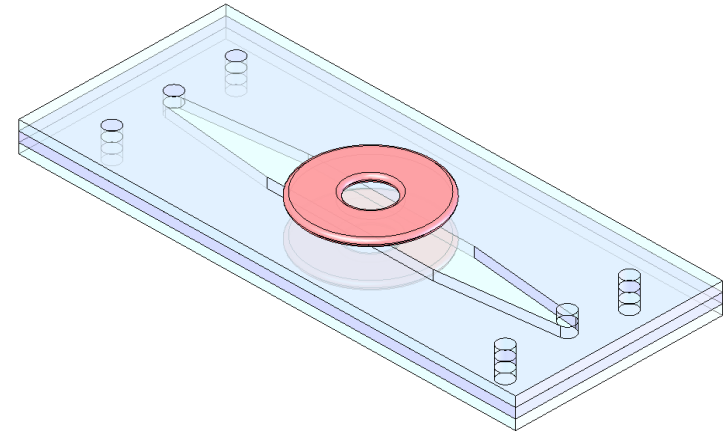
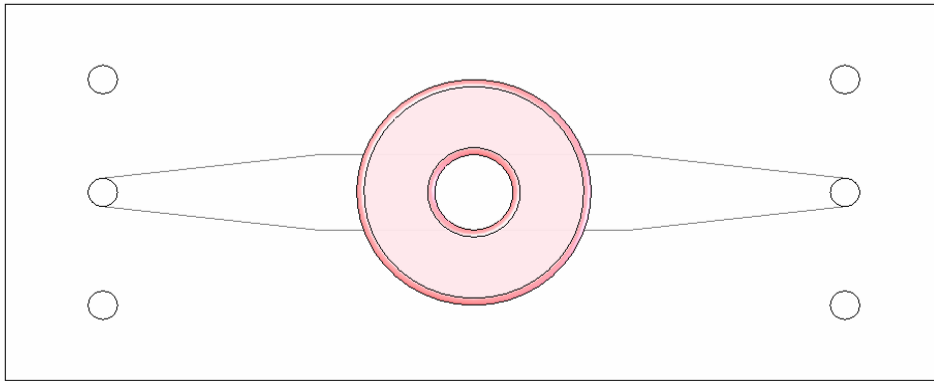
Coil with finger tips
pressed on it

Transformer Sensing – 2 Coils

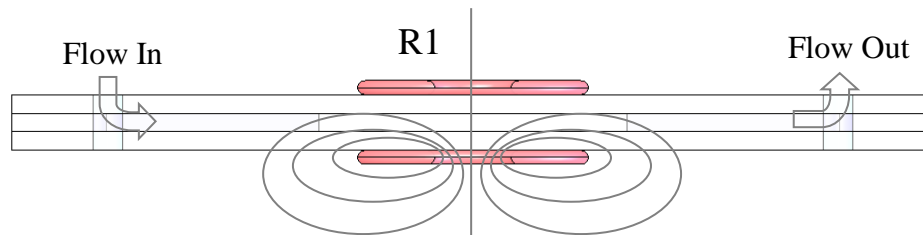
Transformer – 2 Coils – Circuit Viewpoint



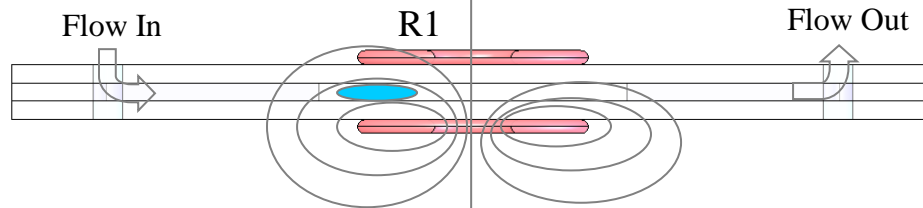
Transformer – 2 Coils - Narrow Channel



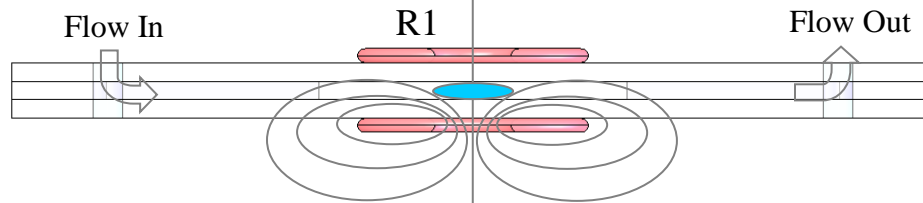
Transformer Bubble Sensing



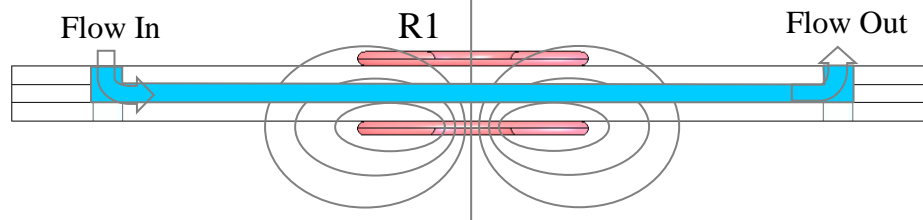
Electrolyte fills channel – no bubbles
R1 signal is attenuated for a long time



Small Bubble is in entry channel region
R1 is momentarily less attenuated



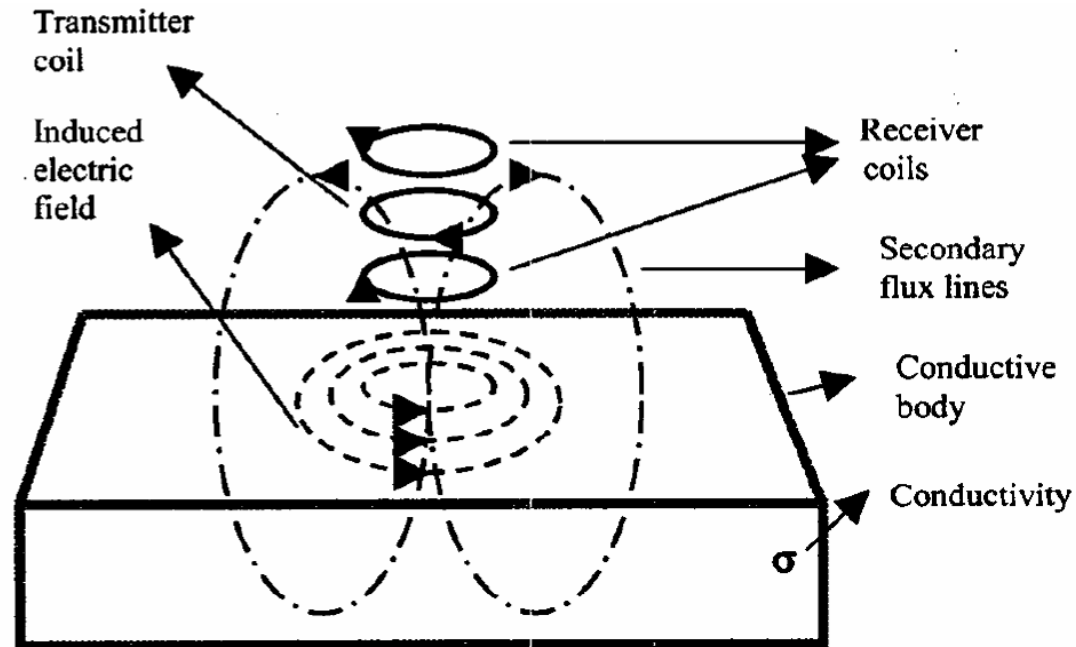
Small Bubble is in center of channel
R1 is attenuated for a short time



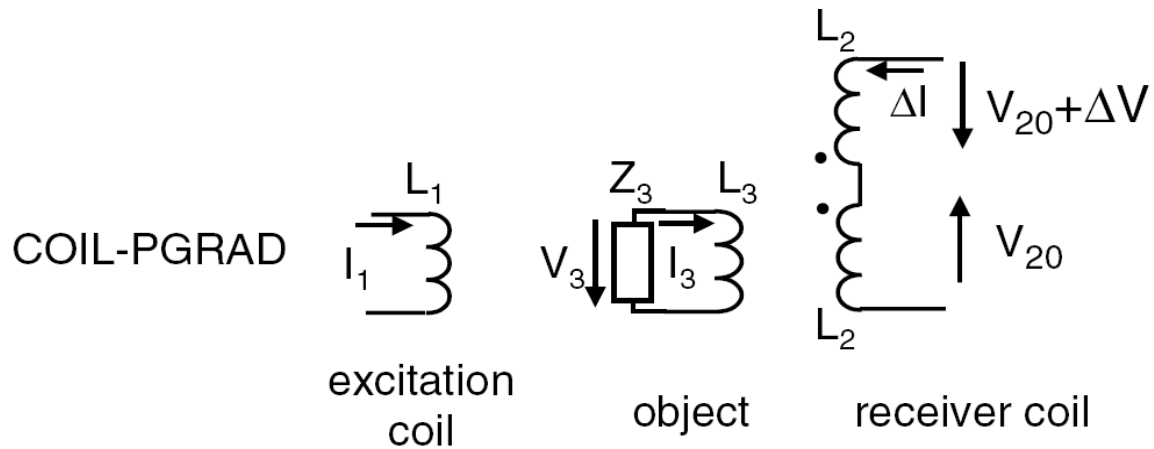
Gas fills the entire channel
R1 is less attenuated for a long time

Gradiometer Sensing – 3 Coils

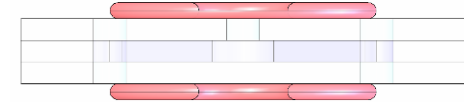
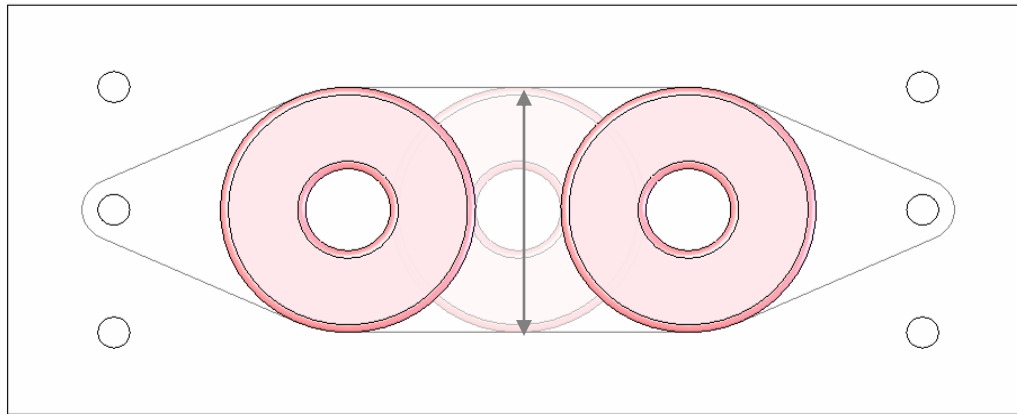
Gradiometer – 3 Coils – Physics Viewpoint



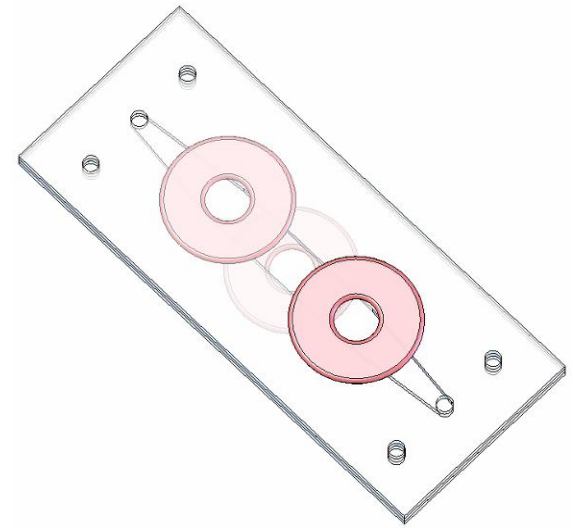
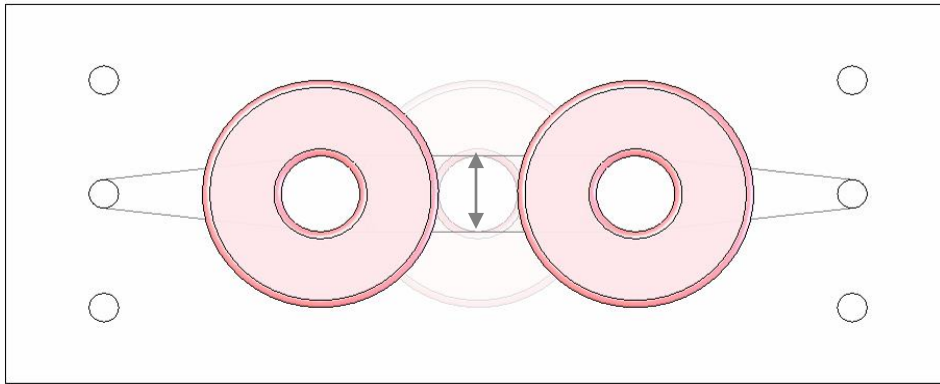
Gradiometer – 3 Coils – Circuit Viewpoint



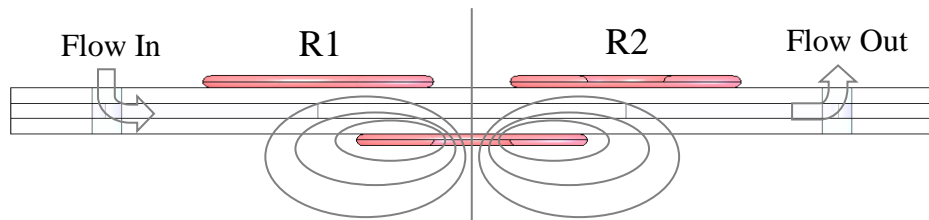
Gradiometer - 3 Coils - Wide Channel



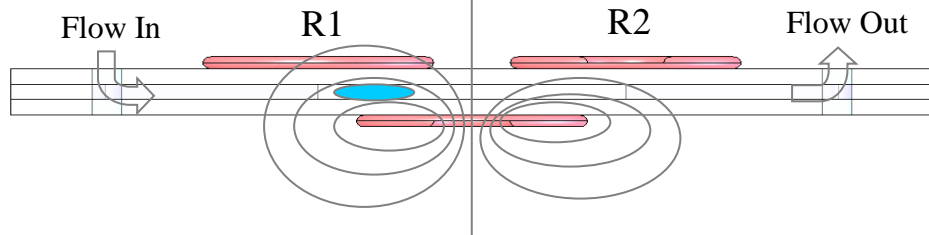
Gradiometer – 3 Coils - Narrow Channel



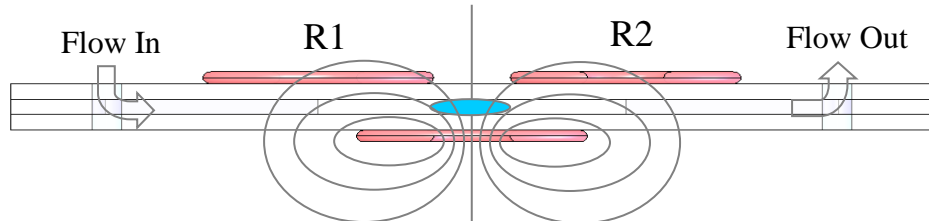
Gradiometer Bubble Sensing and Control Rule



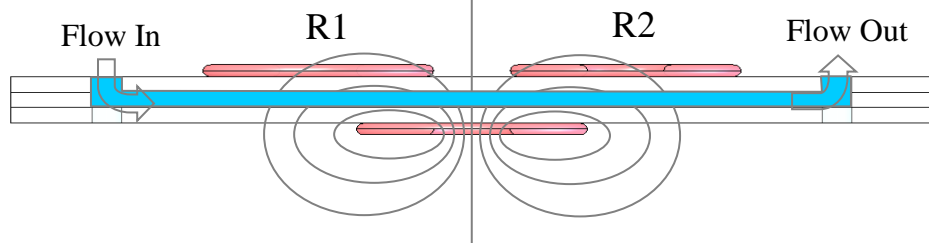
Electrolyte fills channel – no bubbles
R1 & R2 signal is attenuated



Small Bubble is in entry channel region
R1 is less attenuated – R2 is not affected



Small Bubble is in center of channel
R1 and R2 are less attenuated for a short time



Gas fills the entire channel
R1 and R2 are less attenuated for a long time

Other Bubble Sensing Schemes

Capacitive Bubble Sensing Methods

U.S. Patent

Apr. 10, 2001

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US 6,212,956 B1

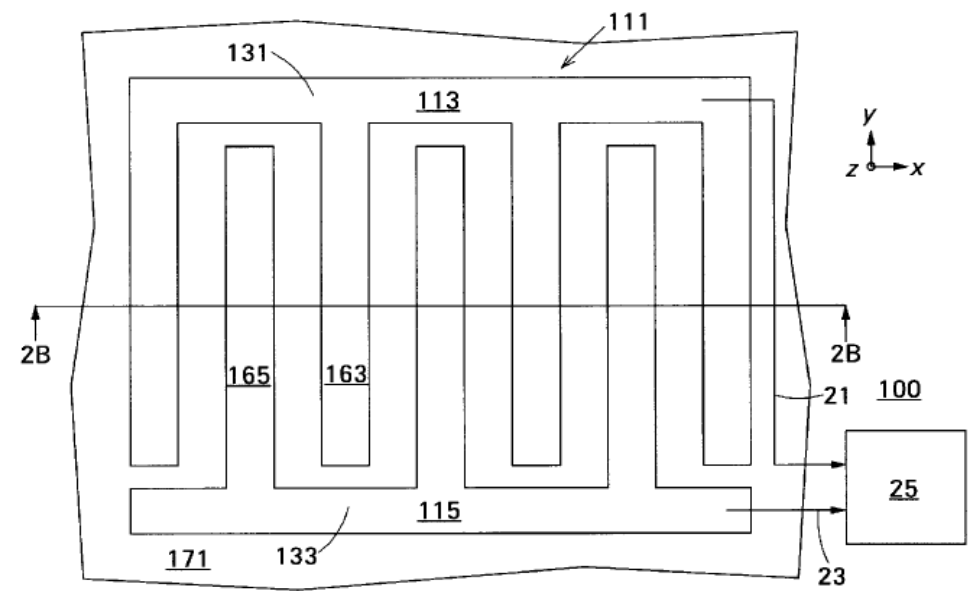


FIG. 2A

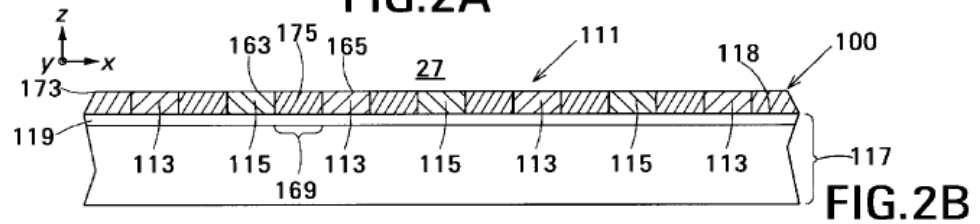
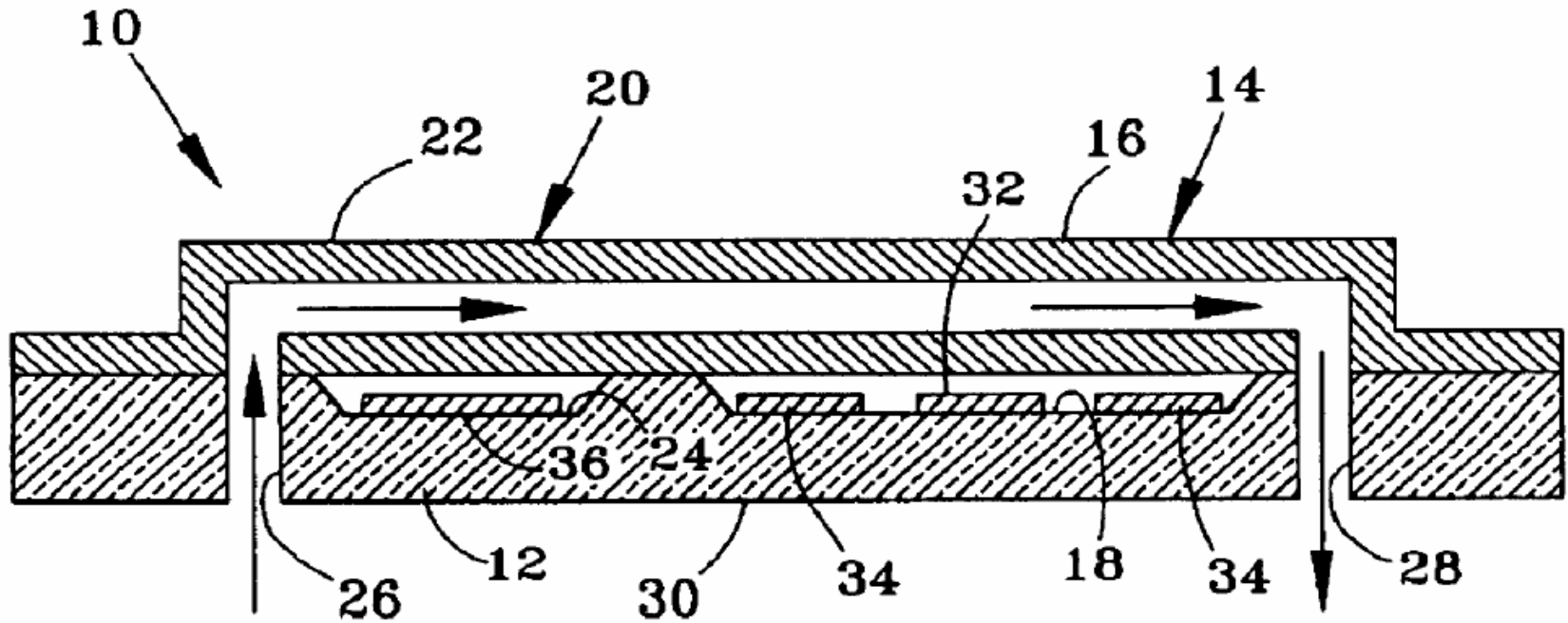


FIG. 2B

Mass Resonance Bubble Sensing - MEMS



Summary and Conclusions

A wide variety of bubble detection schemes suitable for use with conductive liquids have been introduced

Many of these are practical for miniature application

Microprocessor based electronic readouts for these sensing schemes
Are not complex or expensive