Pressure Measurement in the Hydrogen Industry

The case for Silicon-on-Sapphire Sensors

Part of the SUCO GROUP

ABSTRACT

The hydrogen industry has experienced rapid growth, driven by the global demand for clean energy. Precise and reliable pressure measurement is critical in hydrogen applications, ensuring the safe and efficient handling of hydrogen throughout its lifecycle. This white paper explores the challenges of pressure measurement in the hydrogen sector, highlights the limitations of traditional sensor technologies, and explains how silicon-on-sapphire (SoS) sensors, constructed with a specialist titanium alloy compatible with hydrogen, offer an optimal solution. These sensors' unique properties, including resilience to extreme pressures, exceptional chemical stability, and enhanced durability, make them indispensable in hydrogen environments.

1. INTRODUCTION

Hydrogen is a cornerstone of the transition to a low-carbon economy. As hydrogen production and utilisation expand, so does the demand for advanced pressure measurement technologies capable of addressing hydrogen's unique challenges. From production to storage, transportation, and application, accurate pressure measurement is crucial for safety and efficiency. The industry's challenges stem from hydrogen's high diffusivity, small molecular size, and potential to cause material embrittlement. Specialist solutions, such as silicon-on-sapphire (SoS) sensors constructed with a titanium alloy designed for hydrogen environments, provide high reliability under these demanding conditions.

2. IMPORTANCE OF PRESSURE MEASUREMENT IN THE HYDROGEN INDUSTRY

Pressure measurement is fundamental to ensuring the safe and efficient operation of hydrogen systems. Key applications include:

- **Hydrogen Production:** Accurate pressure monitoring is essential during electrolysis, steam methane reforming (SMR), and other production methods to optimise performance and ensure safety.
- **Hydrogen Storage:** High-pressure hydrogen storage, whether in tanks or underground facilities, requires precise pressure measurement to prevent leaks and optimise storage conditions.
- **Hydrogen Transportation:** Pipelines, transport vessels, and refuelling stations demand high-precision sensors to maintain safety and efficiency.
- **Hydrogen Fuel Cells:** Stable and accurate pressure control ensures the optimal performance and longevity of fuel cells, where hydrogen delivery is critical.

With pressures in hydrogen systems often reaching or exceeding 700 bar, sensors must demonstrate extreme accuracy, chemical compatibility, and long-term reliability.

3. CHALLENGES IN PRESSURE SENSING FOR HYDROGEN APPLICATIONS

Hydrogen's properties pose significant challenges for traditional pressure sensors:

- **High Diffusivity**: Hydrogen's small molecules can permeate many materials, leading to degradation over time.
- **Hydrogen Embrittlement:** Materials such as untreated stainless steel are prone to becoming brittle when exposed to hydrogen at high pressures, resulting in sensor failure.
- **High-Pressure Ranges:** Many sensors struggle to perform under the extreme pressures characteristic of hydrogen systems.
- **Temperature Extremes**: The hydrogen lifecycle involves temperatures ranging from cryogenic levels for liquid hydrogen to high temperatures during production processes.

Traditional technologies, such as piezoelectric and metal strain gauge sensors, often face material compatibility challenges, hydrogen permeability issues, and reduced durability at high pressures. SoS sensors, with titanium alloy construction, address these challenges effectively.

4. SILICON-ON-SAPPHIRE (SOS) TECHNOLOGY: A SUPERIOR SOLUTION

Silicon-on-sapphire sensors represent a leap forward in pressure sensing technology. These sensors integrate a thin layer of silicon on a sapphire substrate, further enhanced by a housing constructed from a titanium alloy known for its hydrogen resistance. This combination addresses the demanding conditions of hydrogen applications.

4.1 Key Features of Silicon-on-Sapphire Sensors with Titanium Alloy

1. **Titanium Alloy Construction**: The housing's titanium alloy provides superior resistance to hydrogen embrittlement and permeability, significantly enhancing the sensor's reliability and lifespan.

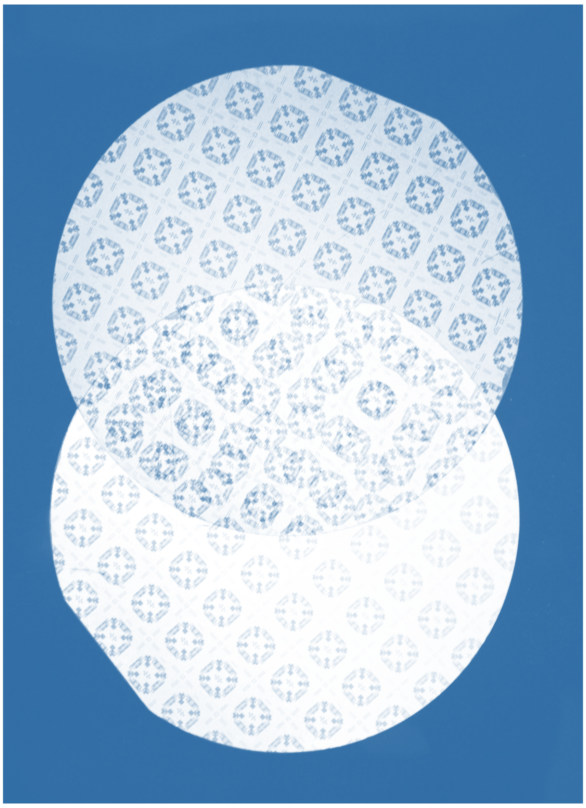
2. **High Strength and Durability:** Sapphire's robustness, combined with the titanium alloy's structural integrity, ensures exceptional resilience in high-pressure environments without deformation or failure.

3. **Thermal Stability:** Sapphire and titanium alloys offer thermal stability, enabling the sensor to function accurately across a wide temperature range, from cryogenic to elevated temperatures.

4. **Hydrogen Compatibility:** Sapphire is chemically inert and highly resistant to hydrogen degradation, while the titanium alloy housing resists hydrogen-induced damage, ensuring long-term stability.

5. **High-Resolution Measurements:** The silicon layer's integration with sapphire provides high sensitivity, enabling precise detection of pressure variations critical for hydrogen system management.

6. **Wide Pressure Range:** SoS sensors are capable of handling pressures from low levels in hydrogen pipelines to over 700 bar in storage and refuelling applications, depending on specific designs.



4.2 Benefits of SoS Sensors in Hydrogen Applications

• **Extended Lifespan:** Titanium alloy construction minimizes embrittlement risks, ensuring durability and reducing maintenance costs.

• **Exceptional Accuracy:** The combination of sapphire and titanium provides highly stable, drift-resistant measurements.

• **Enhanced Safety:** SoS sensors resist hydrogen's corrosive effects, improving system safety.

• **Cost-Effectiveness:** Long-term durability reduces replacement and recalibration frequency, minimizing operational costs.

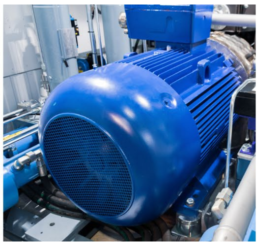
5. APPLICATIONS OF SOS SENSORS IN THE HYDROGEN INDUSTRY

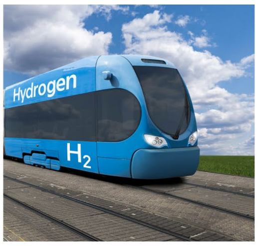
5.1 Production
In hydrogen production, pressure control during electrolysis and SMR is critical. SoS sensors' resistance to embrittlement and precision in high-pressure environments ensure optimal performance.

5.2 Storage and Distribution
For high-pressure storage and pipeline systems, SoS sensors, reinforced with titanium alloy housing, provide accurate and reliable measurements, reducing the risk of leaks and ensuring system integrity.

5.3 Refuelling Infrastructure
Hydrogen refuelling stations, where pressures exceed 700 bar, require sensors with exceptional durability and precision. SoS sensors enable real-time pressure monitoring, improving safety and efficiency during hydrogen dispensing.

5.4 Fuel Cell Systems
In fuel cells, precise pressure regulation is vital for maintaining efficiency and longevity. SoS sensors offer the reliability and sensitivity needed to ensure stable hydrogen delivery.






6. COMPARISON WITH OTHER SENSOR TECHNOLOGIES

FEATURE	SOS	METAL STRAIN GAUGE	PIEZORESISTIVE
H2 Compatibility	Excellent	Moderate	Moderate
High Pressure Capability	High	Moderate	Moderate
Temperature Stability	Excellent	Moderate	Moderate
Durability in Hydrogen	High	Low	Moderate
Hydrogen Permeability	Low	High	Moderate
Maintenance Requirements	Low	High	Moderate

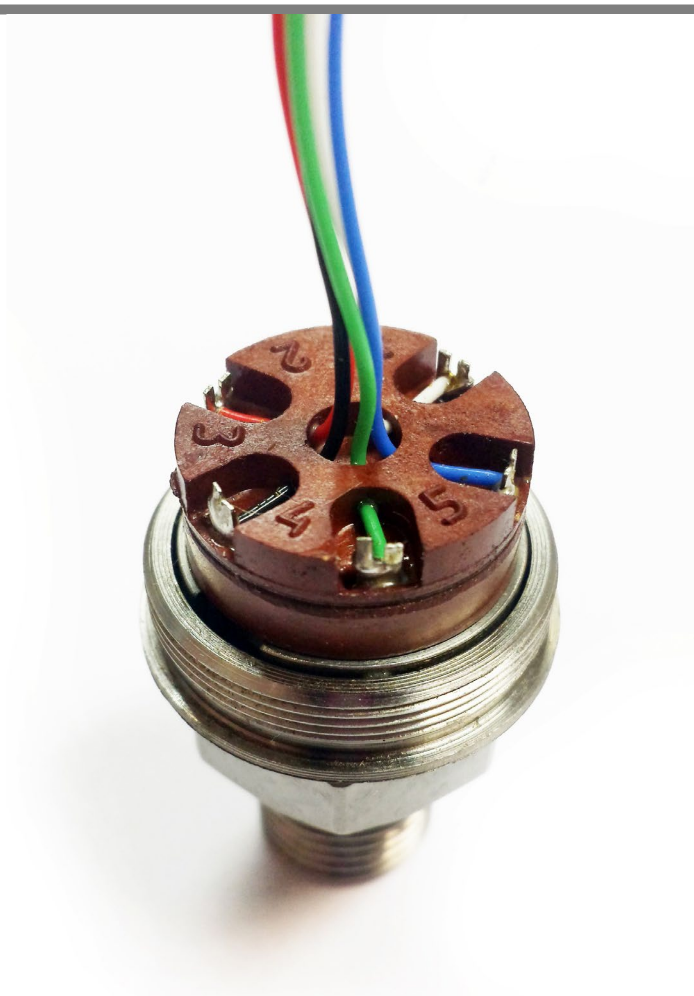
6.1 HYDROGEN PERMEABILITY: A CRITICAL CRITERION

Hydrogen permeability refers to the ability of materials to resist the infiltration of hydrogen molecules, which can degrade performance and structural integrity over time.

• **Silicon-on-Sapphire Sensors**: The sapphire substrate is chemically inert and highly resistant to hydrogen permeation. The titanium alloy housing further reduces the risk of hydrogen infiltration, ensuring exceptional durability and long-term performance in hydrogen environments.

• **Metal Strain Gauge Sensors:** The materials commonly used in these sensors, such as untreated stainless steel, are highly permeable to hydrogen. This leads to material degradation, embrittlement, and sensor failure under prolonged exposure.

• **Piezoelectric Sensors**: The permeability of piezoelectric sensors depends on the materials used in their housing and seals. While moderate improvements can be made with advanced materials, they generally offer less resistance to hydrogen permeation than SoS sensors.



7. TITANIUM ALLOY SENSORS VS GOLD-PLATED SENSORS

Titanium alloy sensors and gold-plated sensors are both used in hydrogen applications but differ significantly in performance and suitability based on their material properties. Titanium alloys are highly valued for their strength, corrosion resistance, and lightweight nature, making them ideal for demanding environments, such as those with high pressures or aggressive chemical exposure. Additionally, titanium alloys can endure prolonged contact with hydrogen without embrittlement, maintaining their structural integrity. Gold-plated sensors, on the other hand, offer exceptional conductivity and resistance to oxidation, which ensures precise signal transmission and measurement accuracy. However, gold is softer and more susceptible to wear, making gold-plated sensors less durable in abrasive or mechanical stress conditions compared to titanium. While gold excels in high-purity, controlled environments where sensitivity is critical, titanium alloy sensors are generally preferred in more rugged or high-stress hydrogen applications due to their robustness and versatility.

8. CONCLUSION

The hydrogen industry's rapid growth demands innovative solutions for pressure measurement. Silicon-on-sapphire sensors, with titanium alloy housings, offer significant advantages in hydrogen environments. Their resilience to hydrogen permeability, thermal stability, and durability under extreme pressures make them a reliable choice for hydrogen applications. By adopting SoS technology, the hydrogen sector can achieve enhanced safety, efficiency, and cost-effectiveness, supporting its vision for a sustainable energy future.

esi-tec.com

ESI Technology Ltd | +44 (0)1978 262255 | Sensor House, Wrexham Tech. Park, LL13 7YP

Part of the Suco GROUP