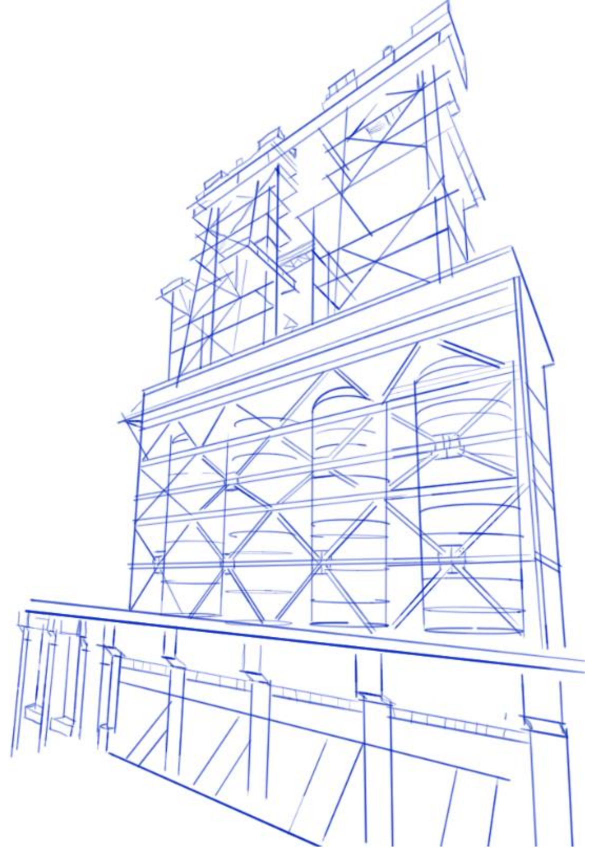

Laser Heated and Laser Measured Oil Fouling Thermal Probe

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Introduction

Fouling is the accumulation of unwanted material on solid surfaces to the detriment of function.

Fouling, of metal heat transfer surfaces used in crude oil refining operations, wastes millions of dollars annually as it requires cleaning, reduces thermal efficiency, and reduces process throughput. If fouling is effectively controlled a significant reduction in greenhouse gas emissions can be achieved through the increased efficiency of heating processes.

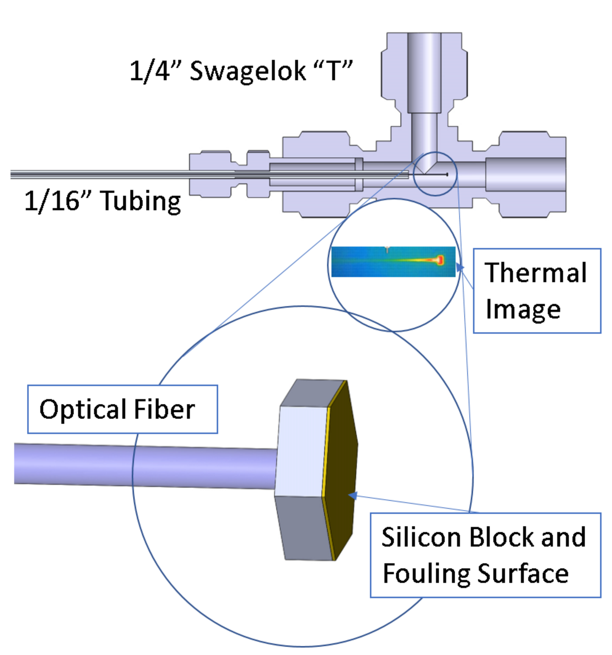
All optical fouling test system

- Intrinsically Safe Sensor (less than 1 watt and optical)
- High Precision and Electrical Noise Immune
- Water/Emulsion Tolerant
- Hostile Environment Ready (Silicon and Glass Construction)
  - 800°C / 2000psi / Acid / H_2S

Optical Sensor Design

A small block of silicon is fixed to the freshly cleaved end of a standard telecom optical fibre. The silicon becomes the heated fouling surface. The fibre can be threaded into stainless tubing. This tubing can then be integrated with a pressure system using standard Swagelok pressure fittings.

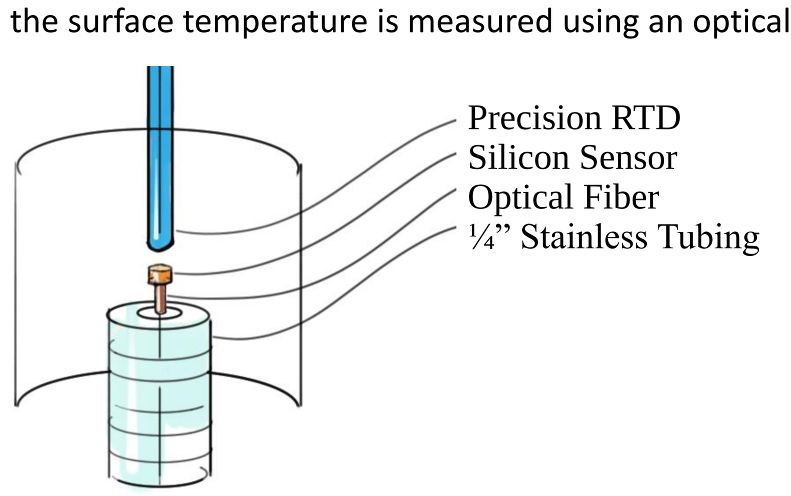
Because the heated surface is so small and only a single fibre is required to heat and measure this surface the test can be integrated into ¼" stainless steel tubing or Swagelok fittings themselves.



Fits in Swagelok Fittings

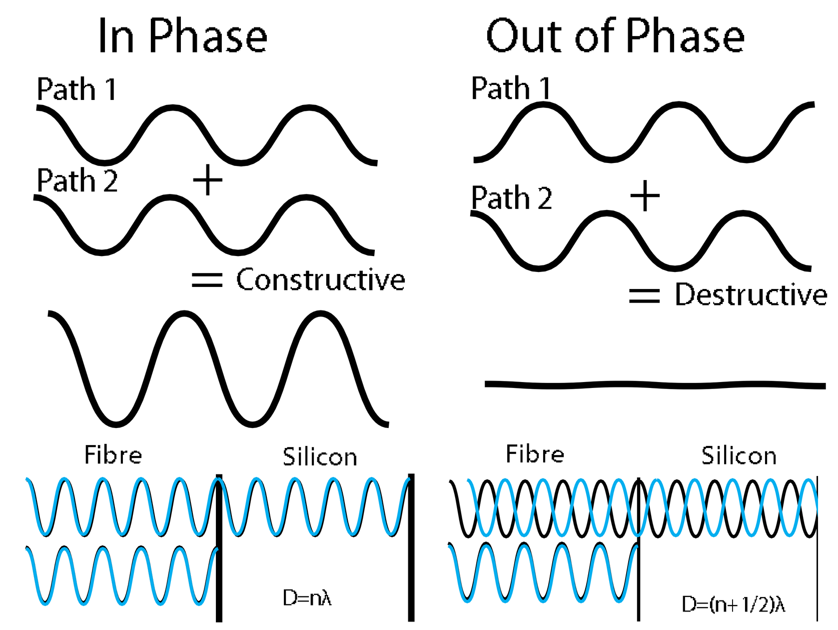
Single Fibre to Control Temperature

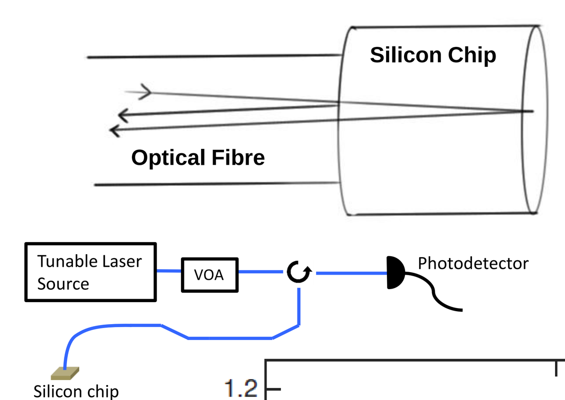
Two temperatures are required for the heat transport calculation to measure fouling factor: fluid temperature and surface temperature. The fluid temperature is measured by a precision Resistive Thermal Device (RTD) and the surface temperature is measured using an optical technique.



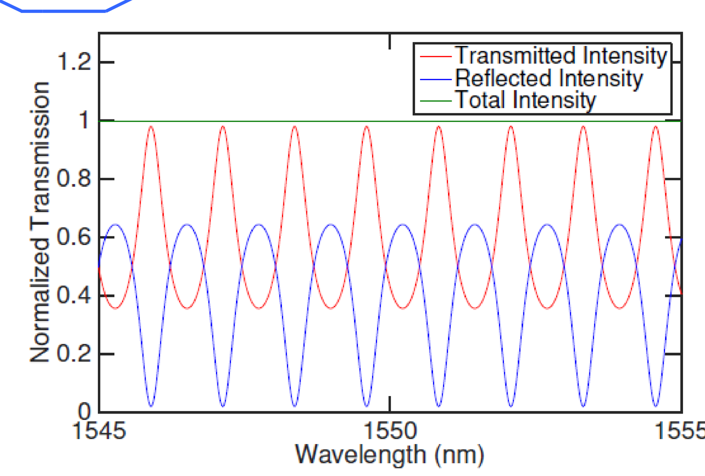
Optical Temperature Measurement

Temperature is measured using Interferometry. Light sent to the silicon block follows two paths. Both paths travel down the fibre where one reflects from the interface between the silicon and the fibre while the other reflects off of the end of the silicon. The physical length of these two paths is different by twice the length of the silicon block.

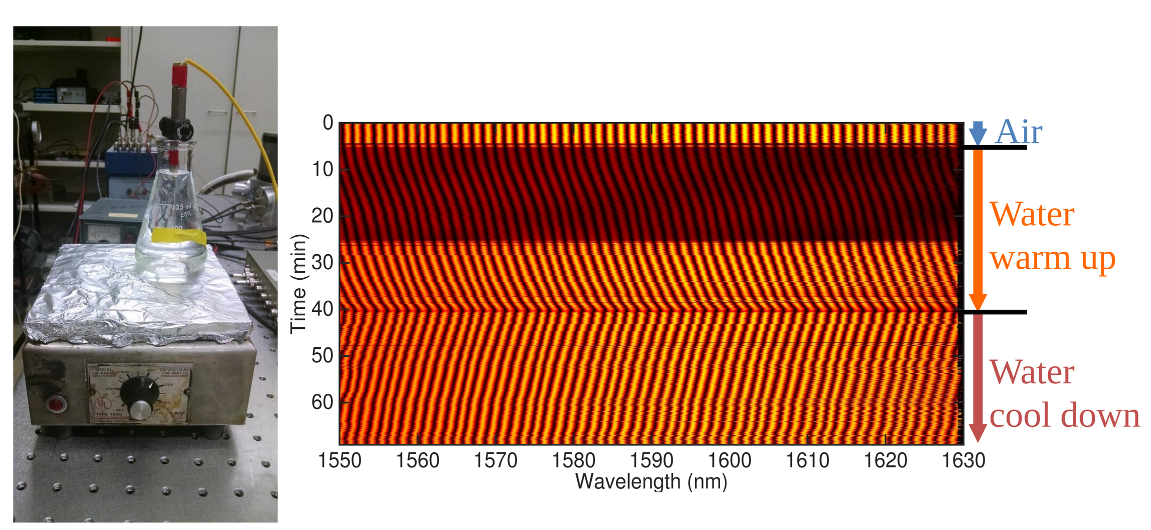




When the wavelength of light is swept from 1545nm to 1555nm an interference pattern is generated that depends upon the length of the silicon block.



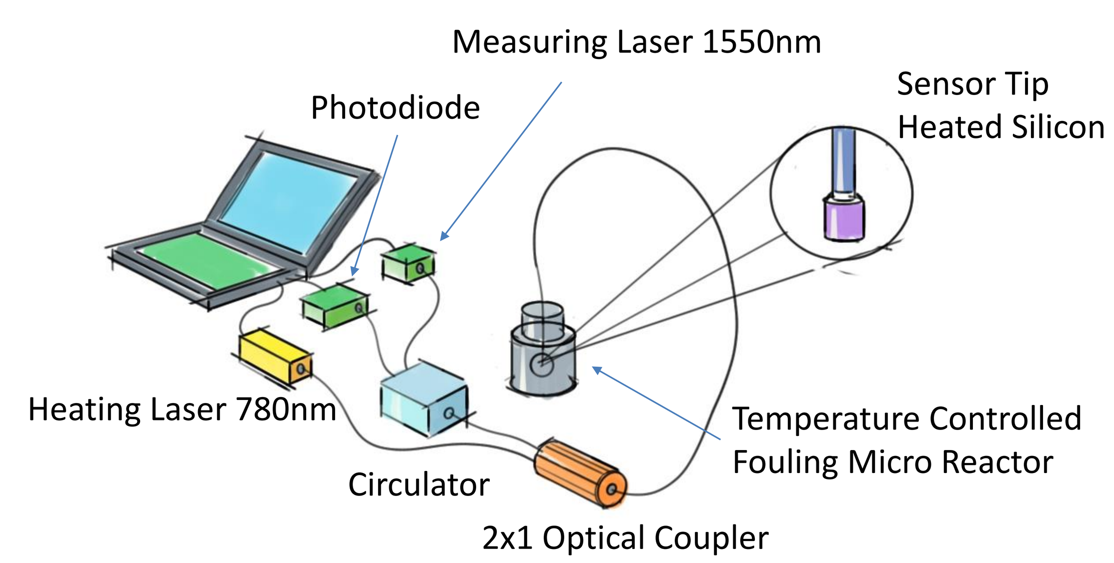
As the silicon block is heated the length increases which shifts the interference pattern. This shift is shown below as the sensor was heated to 100°C in water and then cooled back to room temperature.



If the temperature of the test chamber can be raised in a controlled manner, a swept laser source is not needed to measure the temperature. Instead sweeping the temperature while keeping track of the reflected power at a single wavelength is enough to measure the relationship of temperature to reflected power. This calibration can be used to determine the temperature with a fixed wavelength laser source.

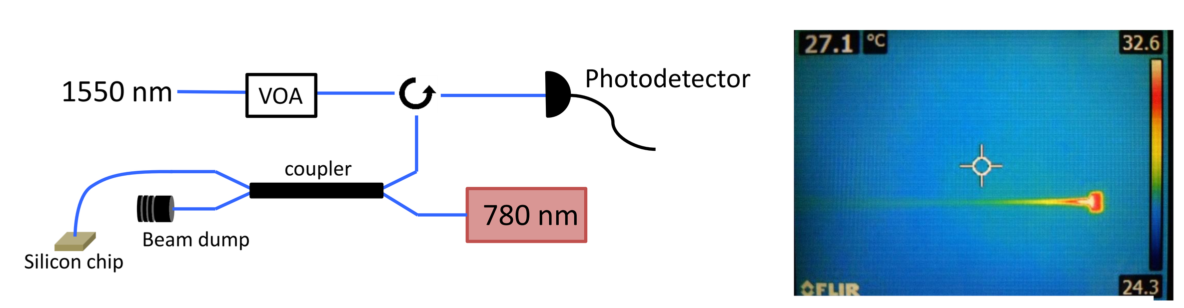
Controlled Optical Heating

A laser can be used to heat objects. The heating power is related to the power of the laser used for heating and the optical adsorption characteristics of the material. At 780nm light is absorbed into silicon and most of the light that reaches the silicon is used to heat the silicon up.

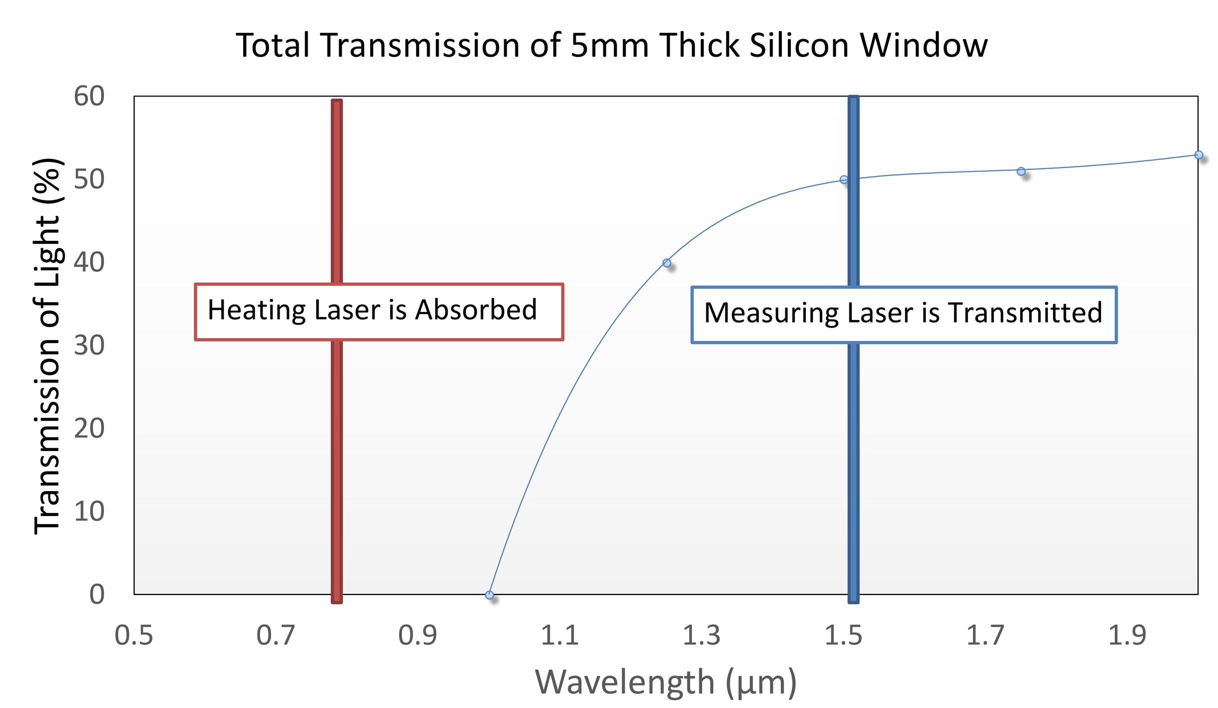


Putting the Two Together

The two optical systems can be combined using an optical coupler. The 780nm laser is used to heat the silicon surface, while the 1550nm laser is used to measure the temperature. Shown below is our first thermal camera image of the surface being heated in air and a system diagram showing the two systems coupled together.

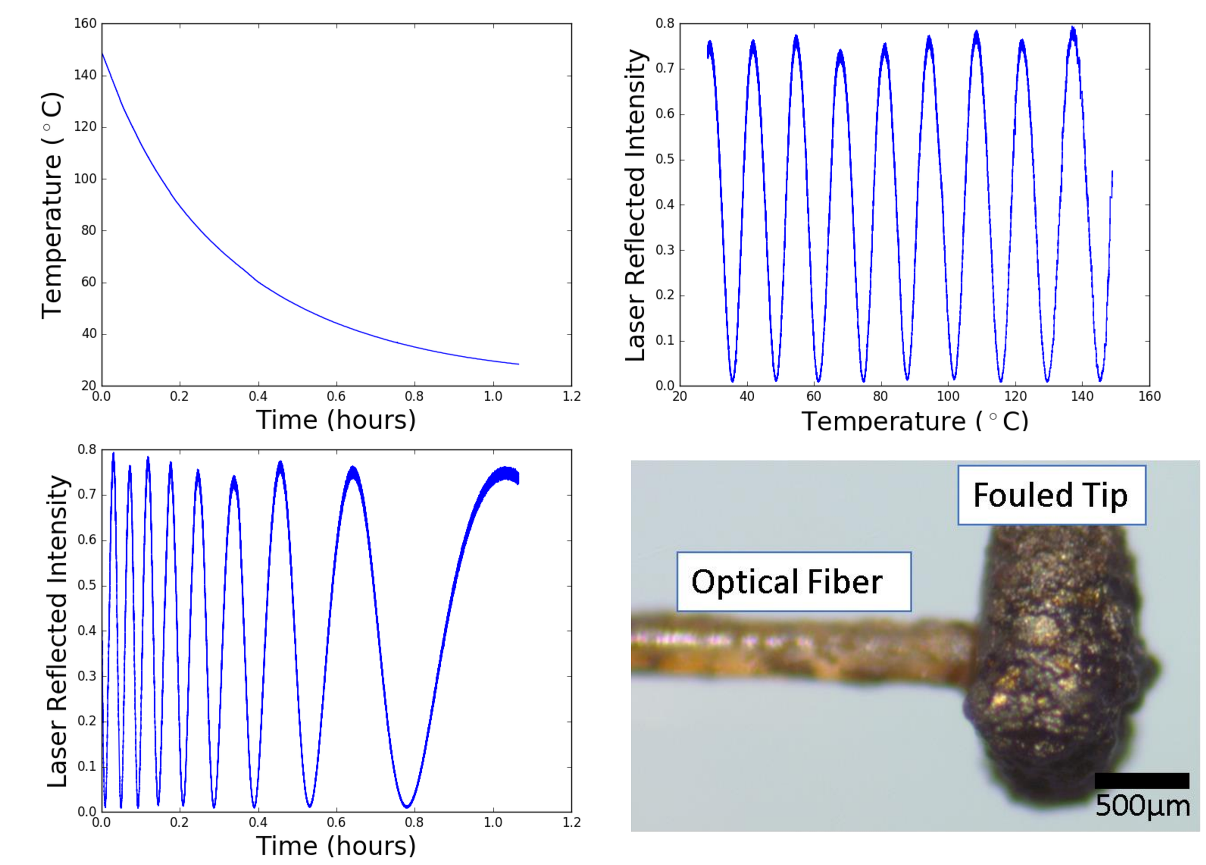


The optical absorption of silicon is uniquely suited for this application as silicon is opaque and can be heated by lasers below 900nm in wavelength and it is transparent and can be measured by light with a wavelength above 1500nm.

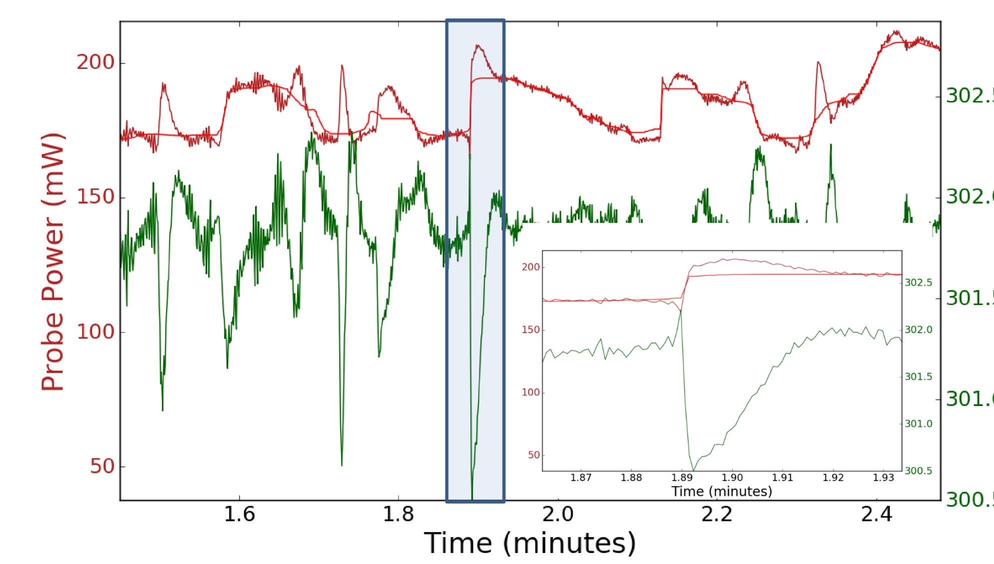


Calibration and Fouling Test

We calibrate the sensor temperature measurement using an external RTD with the heating laser turned off. The temperature is slowly adjusted and monitored while the reflection of light is monitored. As the length of the silicon changes the reflected intensity rises and falls through several constructive/destructive cycles. This can be used to generate a curve fit and calibration for the sensor temperature.



The probe was held for 24 hours at 300°C in 200°C light oil with unstable asphaltenes. At the end of the test the sensor was washed with acetone and observed under a stereo microscope showing fouling accumulated on the surface. The coating was quite uniform on the sides, top and bottom of the silicon block and there was very little fouling on the optical fiber surface. Temperature transients were observed during the test from bubbling at the surface. Temperature drops 1.5°C in 0.15sec and recovers 1.5°C in 1.5sec.



Conclusions

All optical oil fouling thermal probe designed, prototyped and tested

Temperature resolution:	**0.15 °C**
Power control resolution:	**0.1 mW**
Maximum Power:	**300 mW**
Measurement Rate:	**200 Samples/Second**

Silicon and glass construction enables operation at temperatures up to 800°C in many hostile environments including steam, acid, and H_2S.

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