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Functionalized Lateral Surface Coated Lasers for Chem-Bio Detection

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Summary

We present a class of compact, monolithic, photonic sensors that consist of multiple section edge emitting lasers (EELs) with lateral surface coatings that are functionalized to detect low levels of chemical or biological stimulants. Specifically, we discuss a 10μm x 1000μm H_2 sensor with a Pd coating and techniques to enhance the sensitivity by 35x and reduce the minimum detection limit (MDL) to 2ppm. Compared to conventional optical H_2 sensors that use fiber gratings, surface plasmon resonances, or surface reflectance, our sensors offer the advantages of smaller size, monolithic integration of laser source and detector, and 1-D scalability to an array of sensors that are functionalized to detect different agents.

Motivation

Our goal is to develop chip-scale sensor networks to detect and analyze unknown chemical and biological agents in-situ. Traditional optical sensors[1,2,3] can be difficult to integrate or array. Fig. 1 shows the layout for our generic class of enhanced sensors. The sensor is a multiple section 5μm x 1000μm EEL with a surface coating that extends 2.5μm laterally on either side. The waveguide mode has a small overlap, $\sim 10^{-4}$, with the thin coating. The coating's optical properties (e.g. extinction coefficient) change when molecules adsorb to the surface. For example, H_2 gas changes Pd to PdH and reduces the internal loss, α_i, from 57 cm^{-1} at a rate of 1.5cm^{-1} per percent H_2. Thus, the laser's output power varies in response to the concentration of adsorbed H_2. To maximize sensitivity, the laser is operated at the threshold knee. The MDL is determined by assuming the minimum easily measurable fractional power change, $\Delta P/P$, is 10^{-3}.

Results

A 1-D rate equation model, which was verified previously against experimental L-I data, was used to calculate the sensor response (see Fig. 2) for a Pd coated passive waveguide, a single section EEL, and a multiple section EEL that has a 50μm saturable absorber as the center section of Fig. 1. The saturable absorber amplifies the nonlinearity of the lasing knee according to the gain lever effect. The MDL of the three structures is predicted to be 70ppm, 12ppm, and 2ppm, respectively. Fig. 3 shows another class of generic sensors for higher sensitivity threshold detection. The multiple section EEL with lateral coatings is embedded inside slightly detuned DBR mirrors. As before H_2 reduces α_i and increases the circulating power, P_{circ}, which reduces the average carrier density, N_{avg}, due to increased stimulated emission. This changes the round-trip cavity phase. The phase shift is enhanced in multiple section lasers according to the gain-index lever[4] (see Fig. 4a). The cavity length is chosen such that the spacing of the wavelengths satisfying the round-trip phase condition is 1-2% smaller than the spacing of the gain peaks from the detuned DBR mirrors. This creates a Vernier effect (see Fig. 4b) which magnifies the phase shift[4] caused by the presence of H_2. When the H_2 concentration increases above a controllable threshold, the laser hops from λ_1 to λ_2. The specially designed DBR mirrors[4] (see Fig. 5) cause the highly reflective (HR) facet and antireflective (AR) facet to swap as the wavelength changes from λ_1 to λ_2. Thus, above the given H_2 threshold, the output from the left facet turns on. Course electronic control of this H_2 threshold level is possible by adjusting the biases on the slave and control sections since they determine the strength of the gain-index lever. Fine electronic control can be achieved by adjusting the bias on the phase section. If the phase in the absence of H_2 is set near the mode hop point, an extremely low MDL can be achieved, limited only by the stability of the drive currents and ambient environmental conditions.

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[2] C. Christofides and A. Mandelis, "Solid-state sensors for trace hydrogen detection," *J. Appl. Phys.*, p. R1 (1990).

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[4] L. Goddard *et. al*, "Rapidly reconfigurable all-optical universal logic gates," *Proc. SPIE*, pp. 63680H-1-13 (2006).

Figures

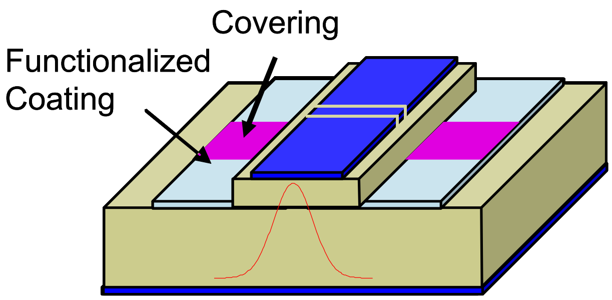


Fig. 1: Multiple section laser with Pd coating for H_2 sensing. A sensor array with various cover lengths enables compensation for system drift or temperature.

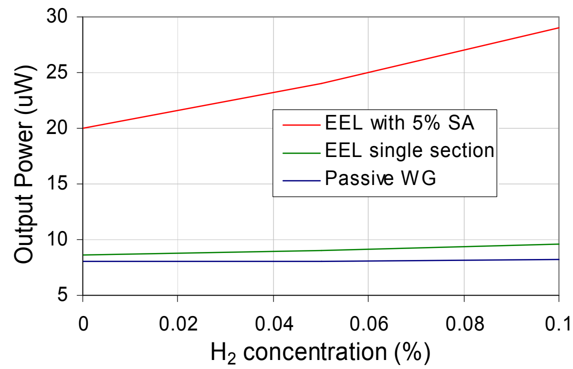


Fig. 2: Simulated sensor responses for Pd coated passive WG, single section EEL, and multi-section EEL (5% saturable absorber). H_2+Pd→PdH, reduces α_i and increases P_{out}.

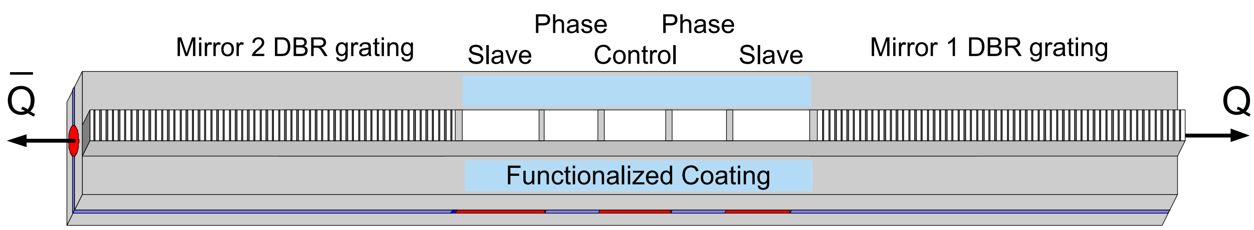
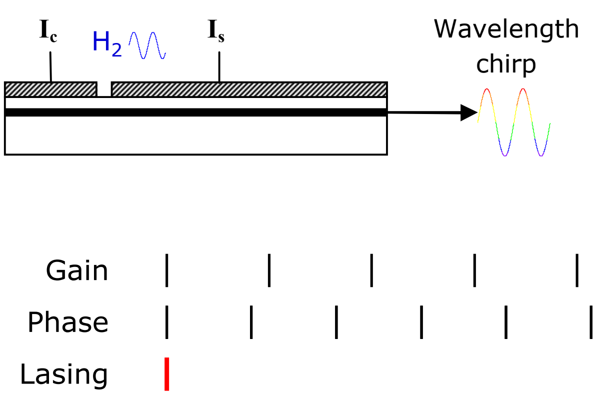


Fig. 3: Functionalized enhanced photonic sensor with threshold detection. Here, as H_2 reduces a_i, P_{circ} increases and N_{avg} decreases. The resulting cavity phase shift is enhanced by the gain-index lever and Vernier effects and causes the laser to hop to the mode that outputs light on the opposite side.



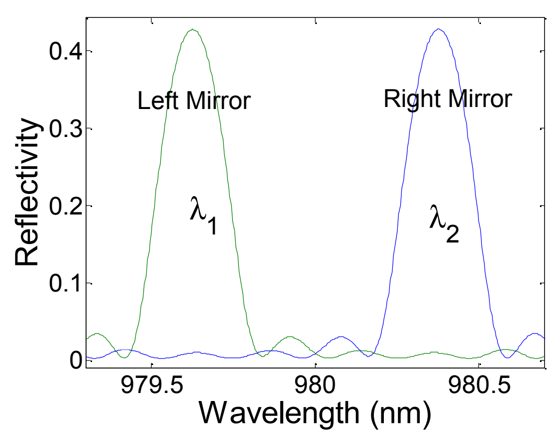


Fig. 4: **(a)** The gain-index lever in multiple section lasers is used to enhance the phase shift caused by the decrease in N_{avg} due to H_2. **(b)** The next mode is aligned using the Vernier effect, which magnifies the shift.

Fig. 5: Desired reflectivity profile for an alternating facet laser. At λ_1, the left mirror is HR and the right is AR so laser light exits the right facet. H_2 causes the mode to hop to λ_2 and switches the light to the left facet.

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