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Waveguide-Based Multi-Band Mid-IR Absorption Spectroscopy on Water-Containing Biofuel

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Abstract: Silicon waveguide structures with SiO_2 cladding and tapered on-chip couplers are fabricated on Si wafers for use in water-containing biofuel composition measurement in the 2.4-2.6 μm respectively 3.5-3.8 μm water and ethanol dominated absorption bands.

OCIS codes: (230.3990) Micro-optical devices; (230.7390) Waveguides, planar.

1. Introduction

Despite the waning public support, due to controversial aspects, such as the use of farmland for producing fuel rather than food [1], bioethanol-based fuel has become widely available. Gasoline engines can be operated with E10 fuel without modification, but the engine management system requires fuel composition information in case of E85 biofuel. Available capacitive probes measure the ethanol/gasoline ratio only, but can nevertheless be used in water-containing biofuel by assuming constant water content, which is corrected for in the measurement [2]. However, water content is, amongst others, depending on the source of biomass. Therefore, the water content in the ternary biofuel mixture has to be measured. The 230-280 nm band was found suitable for selective gasoline measurement by absorption spectroscopy in the UV [3], while ethanol and water have suitable absorption bands in the IR. The high absorbance favors the use of waveguide evanescence field coupling.

2. Concept and design

Silicon waveguiding structures with SiO_2 cladding on silicon wafers and tapered couplers for connecting to fibers as shown schematically in Fig. 1 have been designed and fabricated for use in water-containing biofuel composition measurement. Openings in the cladding enable exposure to the biofuel. The evanescence field attenuation is used in narrowband absorption spectroscopy for measuring the water and ethanol content.

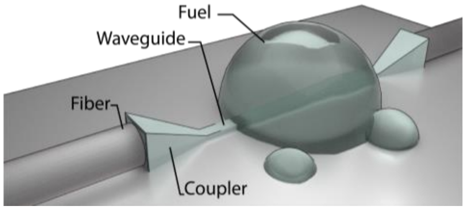

Fig. 1. Structure of the optical biofuel composition sensor.

The gasoline concentration is measured in the UV, but its presence in biofuel precludes the use of the distinctive features for ethanol and water in the 1.8-2.1 μm band, and the 2.4-2.6 μm and 3.5-3.8 μm bands are used instead.

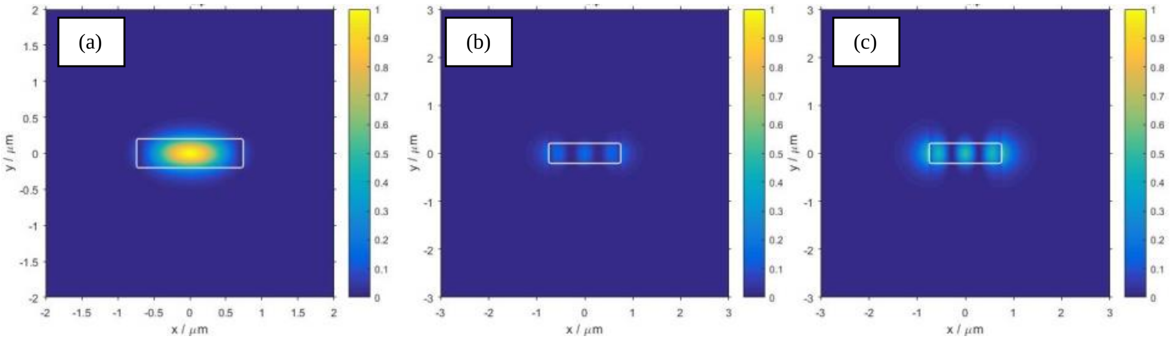

Fig. 2. Mode analysis for a 0.4 μm thick and 1.5 μm wide waveguide for: (a) 1st-order (b) 2nd- order and (c) 3rd-order at 2.6 μm wavelength.

The results of a mode-analysis for the 2.6-2.8 μm band shown in Fig. 2 indicate optimum waveguide cross-sectional dimensions of 1.5 μm × 0.4 μm for an efficient first-order propagation and a sufficiently suppressed higher order modes. A similar result is obtained for the 3.5-3.8 μm band. Fig.3 shows the absorption v. length, *z*, of the access slit for the 2.6-2.8 μm band, which clearly confirms the water- dominated absorption. For a maximum dynamic range of the optical transmission without saturation by water absorption, a window length of 100 μm was selected. A similar result was found for the ethanol-dominated band at 3.5-3.8 μm.

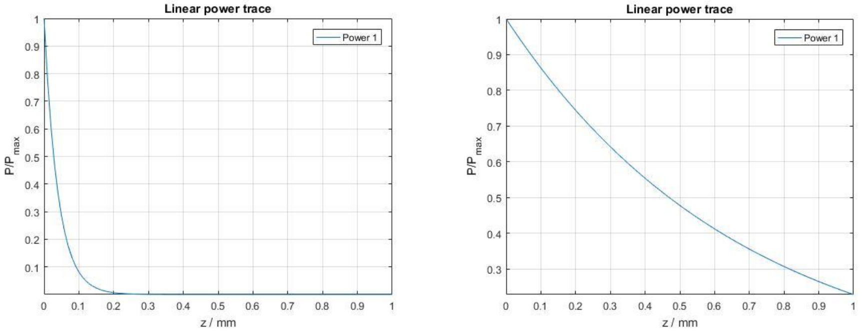

Fig. 3. Transmitted optical power at 2.8 μm for: (a) pure water and (b) pure ethanol.

3. Fabrication and validation

Waveguides of 3000 μm length, 1.5 μm width and 0.4 μm thickness ensure efficient first-order mode propagation only and are combined with 1500 μm long tapers from 9 μm to 0.4 μm thickness for in and outcoupling. The tapers are fabricated in silicon using a special pattern in resist, followed by resist reflow and transfer etch into polysilicon [4]. Initially, a 1 μm thick oxide layer is deposited to serve as the lower cladding. Subsequently, a polySi seed layer of 100 nm is deposited, followed by the epitaxial growth of 10 μm of polySi. The first mask is applied to result in a density-modulated trench pattern in the 6 μm thick resist with localized trench width-spacing that is a measure for the local mass removal and consequently determines the local height after reflow by design. In the next step this pattern is actually reflown in PGMEA at 70 °C and results in the taper in the resist with a bead at the edge, which results from the surface energy of the polysilicon. The taper is 1:2 transfer-etched into the polySi using a SF6/CHF4 plasma etch recipe. A short oxidation with isotropic oxide etch is applied to reduce the bead height, which would adversely affect the light coupling into the waveguide. Subsequently, the actual polySi waveguide layer is deposited and patterned, followed by the deposition of the 1 μm top cladding and the process is completed with the etching of the access holes to the fuel. Initial experiments confirm basic operation, but also reveal a few fabrication issues that are presently addressed.

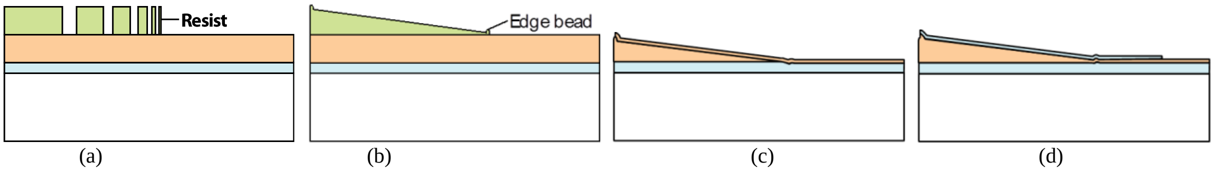

Fig. 3. Fabrication flow: (a) oxide and polySi deposition, followed by the pattern for reflow, (b) reflow, (c) deposition and patterning of polySi for the waveguide and (d) deposition of top cladding with etching of access windows.

5. References

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