Faraday Rotation Spectroscopy for Biomedical Sensing of Oxygen in Human Breath

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Oxygen level in exhaled air is a clinically significant measurement that demands a low-power, light-weight, and compact device that can deliver a sub one percent minimum detection level with 1 s time resolution. This requires a sensitive and selective measurement technique that can provide sensing specifications in a small form factor comparable to modern capnographs.

Faraday Rotation Spectroscopy is a laser based technique for the detection of paramagnetic gases based on the Faraday Effect, the observation that left and right hand circularly polarized light waves propagate at different speeds in the presence of an axial magnetic field and a paramagnetic medium like oxygen gas. The difference in propagation speeds changes the angle of polarization of the light as a whole to a degree directly proportional to the concentration of the paramagnetic species, the strength of the magnetic field, and the length of travel through the medium. By positioning polarizers on opposite sides of the medium, the change in polarization angle can be measured as a change in intensity using a photodetector. Faraday Rotation Spectroscopy is a promising technique for the sensing of paramagnetic molecules because there is no risk of interference from non-paramagnetic species and because it offers 2-3 orders of magnitude more sensitivity than direct absorption spectroscopy.

Previous work in the Princeton Laser Sensing Laboratory used a long path length (6.2 m) and large permanent magnets (over 1.8 kg in total) in order to achieve single ppm sensitivity in a low-power device, which is necessary for environmental and industrial applications. In this work, we have developed an optical benchtop prototype (shown schematically in Fig 1.A) that has a 28 mm path length, uses less than 0.1 kg of magnets, and is based on a low power VCSEL laser that ensures low power consumption. Using laser wavelength modulation FRS and a balanced detection scheme, an FRS spectrum of oxygen can be selectively acquired (see Fig. 1.B). We have achieved a bandwidth normalized minimum detection level of 0.2% / Hz¹/² of oxygen gas in air (by volume), which exceeds the sensitivity required for the biomedical sensing of oxygen in human breath.

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