
**CTh05**

Surface micromachined scanning confocal microscope

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Confocal scanning microscopy has recently emerged as a significant new technique, which exhibits several advantages over conventional optical microscopy. Because confocal images are devoid of out-of-focus blur it allows non-invasive, optical sectioning of intact specimens. There has been an ongoing effort to reduce the size of the imaging head, to enable its use in endoscopy, CD read heads, and in vivo medical imaging.

The confocal microscope system shown in Fig. 1 has a 0.65-μm laser diode as the light source. The beam on arriving at the chip passes through an aperture and a beam splitter and is then scanned in the x- and y-directions by two mirrors and is focused on the sample by an objective lens. The reflected light from the sample retraces the path and is reflected by the beam splitter into a confocal lens, which focuses the beam onto a detector. The presence of a pinhole aperture at the focusing spot of the second lens ensures the confocal operation of the microscope. The photocurrent from the detector is processed to produce an image.

Silicon surface micromachining has been used to fabricate the compact optical system incorporating low-inertia scanners. Figure 2 is a scanning electron microscope (SEM) photomicrograph showing a part of the system. Both scanning mirrors stand vertically on the silicon substrate and are actuated by comb-drive actuators. These MEMS structures were fabricated using the MCNC-MUMPS foundry process. The MUMPS process includes two structural layers of polysilicon on 2-μm-thick POLY1 layer and a 1.5-μm-thick POLY2 layer. The mirrors and the lenses are fabricated using a 3.3-μm-thick polyimide, whereas the beam splitter has only the POLY1 layer. Details of fabrication of scanning mirrors have already been published by Kim et al. and Gold is evaporated onto the surface of the mirrors to increase reflectivity.

Electrostatic comb-drive actuators are used as actuators as they provide high resonant frequencies. The x- and y- mirrors are 200 μm x 250 μm and 200 μm x 300 μm with resonant frequencies of 3.8 kHz and 2 kHz, respectively.

The maximum angular deflection of these mirrors, 1.5° and 3° respectively, was obtained with a 25 V difference applied to the two electrodes. The Fresnel lenses in this system have a numerical aperture of 0.16 and a focal length of 1 mm for the objective lens and 300 μm for the confocal lens. The spot size and depth of focus are 1 μm and 25 μm, respectively.

Images of metallic grating on glass substrates have been obtained using external lenses, instead of the on-chip Fresnel lenses; this allows the focusing of the laser beam to 1-μm spot size, efforts are underway to obtain images of integrated circuits and to fabricate a high-NA on-chip lens.

This system design, in conjunction with low temperature wafer bonding techniques, which can be used to bond the laser and the detector chip, can be used to develop an all-metallic micro-scanning confocal microscope on a Si-chip. Unlike previous designs, this system, being completely surface micromachined, provides ease of fabrication and allows mass production using conventional photolithography techniques.

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**CTh06**

Trace gas detection in ambient air with cw and pulsed QC lasers

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Recently developed quantum-cascade lasers have been shown to be useful tunable single-frequency light sources for laser-based absorption spectroscopy in the important mid-IR region. In this work, we demonstrate the application of cw and pulsed single-frequency QC-DFB lasers to the sensitive detection of CH4, CO, CO2, and CO2 (ethanol) and different isotopic species of H2O in ambient air will be reported. In order to determine the ethanol concentration from its dense infrared spectrum, a new approach based on a linear correlation technique was applied.

A schematic of the cw QC-DFB laser based gas sensor configuration is shown in Fig. 1. A commercial multiwire cell aligned for a 100-nm optical path was used. The pressure in the cell was set to 30–40 Torr. To improve the sensitivity, a "zero-air" background subtraction technique was also used. Spectra of ambient air and a pollutant-free "zero air" were alternatively taken with the sequential subtraction of the zero-air signal from the ambient air signal. In most of the measurements, pure air with an addition of 5% CO2 was used as a zero gas. The laser radiation was detected with a liquid nitrogen cooled photovoltaic MCT detector. The QC laser frequency was fast-tuned with current, which was supplied in 120–235-μs ramped pulses (quasi-cw operation) at a 800 to 1000 Hz repetition rate. Frequency scans were typically over 2 cm−1 range. The variation of the laser duty cycle resulted in a variation of laser operating temperature and frequency offset.

An example of the absorption spectrum of ambient air obtained with such a cw QC-based gas sensor is shown in Fig. 2. The estimated sensitivity is 2.5 ppb for CH4, 1.0 ppb for N2O, 63 ppb for 13CO2 and 125 ppb for C2H5OH. In experiments with a near-room-temperature pulsed QC laser, 7 to 10 ns current pulses were
A significant issue in urban air quality is the ability to measure particular trace and pollutant gases in real time with high sensitivity and specificity. One such species is HCO that, although at low concentrations of 2–20 ppb, is a precursor to atmospheric ozone production. HCO is produced by the photochemical breakdown of volatile organic carbon molecules and can also be a byproduct from incomplete combustion processes. In major urban environments, such as Los Angeles, New York and Houston, monitoring of HCO distribution and its daily concentration cycle is important in modeling complex ozone chemistry.

For high sensitivity optical monitoring of fundamental HCO ro-vibrational lines, cryogenically cooled Pb salt diode lasers operating near 2831 cm⁻¹ (3.5 μm) can be used. Although difference-frequency-based sensors have advantages such as nonresonant operation, intrinsic wavelength stability and high beam quality, their low cw power (<5 μW) has limited their detection sensitivities to date. To increase the difference-frequency power produced in such a sensor we have developed an architecture based on two frequency-stable diode lasers at 1.1 and 1.5 μm, which are amplified by high-power Yb and Er/Yb fiber amplifiers, respectively. To date we have generated up to 0.7 mW of narrow-band (<60 MHz) mid-infrared radiation. This higher power capability allows the use of an optical–noise-reducing dual-beam absorption configuration employing two DC-coupled Peltier-cooled HgCdTe detectors and an extended 100-μm absorption pathlength achieved with a low-volume Herriot cell.

Figure 1 is a schematic of the sensor configuration. The mixing lasers are a fiber-pumped 2-m 1561-nm DFB diode laser and a 50-mW 1083-nm DFB diode coupled into single-mode fiber. A 1-m²-doped fiber preamplifier increases the 1561-nm seed power to 30 mW to saturate the gain in the 0.6-W Yb/Er fiber amplifier while the 1083-nm diode directly seeds the 1.6-W Yb amplifier. To combine the two wavelength channels into a single fiber a wavelength division multiplexer (WDM) is used. The difference-frequency mixing occurs on a separate optical stage, where the fiber delivered beam is imaged into the 19-mm PPLN crystal (M = 11), by a 1-cm focal-length achromat. The primary beam is directed to a MCT detector after the multipass cell, and a reference beam incident on the second MCT is acquired from a ZnSe wedge placed in the beam before the multi-pass cell. This dual beam technique allows the strong reflections that arise from the lens and PPLN crystal in the difference-frequency mixing stage to be eliminated by rationing the two beams. The two channels are acquired simultaneously by the use of two A/D data acquisition cards. Spectral finescales are acquired by direct current modulation of the 1560-nm diode (triangular waveform at 0.1 to 1 kHz). This technique improves the absorption sensitivity to ~2 X 10⁻⁵. Figure 2 is a formaldehyde absorption spectrum near 2831.6 cm⁻¹ obtained from room air for a pathlength of 100 m, a pressure of 40 torr and an average of 3000 spectra acquired over 140 s. A Hitran 92 4.0 ppb HCO simulation is overlaid on the experimentally obtained spectrum. The residual displays a r of ~1.3 X 10⁻⁵, corresponding to a single shot detection sensitivity of ~0.4 ppb.

This work demonstrates a significant increase in both power and sensitivity over previously reported DWG based spectroscopic sources, and thereby will permit high sensitivity and real-time trace gas sensing.