applied to the laser. Fast frequency tuning was obtained using a sub-threshold ramped current, as in Ref. 5. The first experiments with a pulsed QC laser indicate a line broadening caused by frequency chirping due to the pulsed drive current. The narrowest laser linewidth was obtained with the shortest achievable pulses of 7 ns resulting in a FWHM of 0.016 cm$^{-1}$ (480 MHz).

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**CThO5 3:30 pm**

**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) photograph showing a part of the system. Both scanning mirrors stand vertically on the silicon substrate and are actuated by combdrives. These MEMS structures were fabricated using the MCNC-MUMPS foundry process. The MUMPS process includes two structural layers of polycrystalline silicon: a 2-μm-thick POLY1 layer and a 1.5-μm-thick POLY2 layer. The mirrors and the lenses are fabricated using a 3.5-μm-thick polysilicon, whereas the beam splitter has only the POLY1 layer. Details of fabrication of scanning mirrors have already been published by Kiang et al. 2 Gold is evaporated onto the surface of the mirrors to increase reflectivity.

Electrostatic combdrives are used as actuators as they provide high resonance frequencies. The x- and y-mirrors are 250 μm × 250 μm and 320 μm × 300 μm with resonant frequencies of 3.5 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 3 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, as 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 onto the chip, can be used to develop a monolithic 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 3:45 pm**

**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, N₂O, CO₂, H₂O (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 multipass cell aligned for a 100-m optical path was used. The pressure in the cell was set to 20–40 Torr. To improve the sensitivity, a "zero-air" back-ground 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 a 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 H₂O and 125 ppb for CO₂. In experiments with a near-room temperature pulsed QC laser, 7 to 10 ns current pulses were