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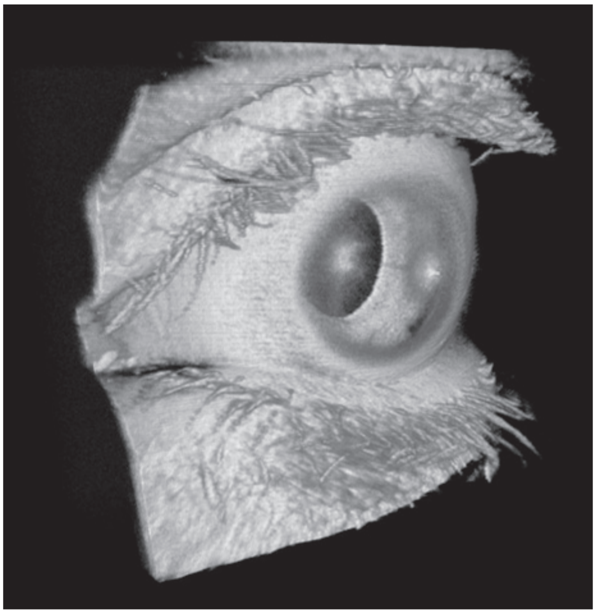
'High-sweep-rate 1310 nm MEMS-VCSEL with 150 nm continuous tuning range', V. Jayaraman, G.D. Cole, M. Robertson, A. Uddin and A. Cable

Record ultra-widely tunable semiconductor lasers look set to advance medical imaging and other applications

a clean sweep for MEMS-VCSELs*



ABOVE: Rendering of human anterior eye obtained using a 1310 nm MEMS-VCSEL in a VCSEL-based SS-OCT imaging system operating at 100,000 axial scans/sec. [Image courtesy of Massachusetts Institute of Technology]

ABOVE RIGHT: VCSELs are a potentially inexpensive swept source for measuring gas temperature in combustion systems such as automotive engines. A single VCSEL distributed to many locations by optical fibre can be used to spatially map temperature, as in this setup for tomographic temperature imaging. [Image courtesy of the University of Wisconsin]

RIGHT: Angiographic OCT fundus image of human retina obtained by SS-OCT using a 1050 nm MEMS-VCSEL. Retinal vasculature (red) is superimposed on rich choroidal vessels (green background). Total image size is 12X12 mm. No dye has been injected to obtain this image. [Image courtesy of Massachusetts Institute of Technology]

The first integrated 1310 nm wavelength MEMS-VCSELs have been reported in this issue of *Electronics Letters* by collaborating researchers in the US. Optimised specifically for swept-source optical coherence tomography (SS-OCT) applications, these MEMS-VCSELs can also be continuously tuned over 150 nm, which is the largest tuning range of any surface emitting diode lasers at any wavelength.

"MEMS-VCSELs have previously demonstrated speed and coherence length advantages for SS-OCT, but questions remained as to whether MEMS-VCSEL tuning range could compete with widely tunable external-cavity lasers," said Dr Vijaysekhar Jayaraman from Praevium Research who took the lead on the design and fabrication. "We believe that this work demonstrates for the first time that MEMS-VCSEL tuning range can be on a par with these other devices."

A flexible approach

MEMS-controlled VCSELs, which have their top mirror suspended on a flexible membrane to allow the cavity length and hence wavelength to be changed, first appeared in the mid-1990s. The target application initially was wavelength division multiplexed (WDM) systems, but grating-based edge-emitting lasers have tended to be used instead.

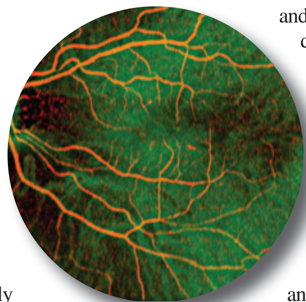
MEMS-VCSELs are still being pursued by some for short-haul communications, but interest in their development has now turned much more towards gas spectroscopy applications. The low cost, portability, wide and continuous mode-hop-free tunability and narrow line-width have made MEMS-VCSELs strong candidate sources in, for example, oxygen, ammonia and carbon monoxide sensing.

MEMS-VCSELs are also very attractive for SS-OCT as they combine a number of important performance features in a single device that are not simultaneously present in other tunable lasers. The wide continuous tuning range enabled by the short VCSEL cavity gives a high depth resolution in SS-OCT. A MHz range sweep speed allows real-time capture of large volume images, and is also important to reduce sensitivity to patient motion and for capturing time-varying biological processes. The long VCSEL coherence length allows a long imaging range that is useful for deep anatomic features. And finally, wafer-scale VCSEL fabrication can take advantage of volume manufacturing and reduce the cost.

A joint effort

The work reported in this issue is a small part of a multi-year multi-disciplinary effort in the development of MEMS-VCSELs for SS-OCT.

"Our hope is that the advantages of MEMS-VCSELs will combine to improve imaging performance and advance SS-OCT systems into a wider set of medical applications," said Jayaraman. "This in turn could aid in early diagnosis of a greater variety of diseases."



In the US-based collaboration, Praevium Research specialises in early stage development of wavelength flexible devices, and they are working with Advanced Optical Microsystems who have provided MEMS modelling, design and fabrication assistance, and Thorlabs who have funded most of the research and have also helped to guide the performance parameters towards SS-OCT and the designs towards manufacturability and scalability. Thorlabs will also manufacture devices at its Jessup, Maryland, facility, and lead commercialisation. Additional funding has also come from The National Cancer Institute in the US which is particularly interested in real-time SS-OCT cancer imaging with VCSELs. Massachusetts Institute of Technology (MIT), which invented OCT in the early 1990s, is also involved in validating the VCSEL for SS-OCT imaging.

The team realised their integrated MEMS-VCSEL with record tuning range by combining a long-wavelength indium-phosphide-based multi-quantum-well active region with a GaAs-based fully oxidised bottom mirror using wafer bonding. They also optimised the design of the micromachined electrostatic actuator, to allow them to sweep the emission wavelength over this ultra-wide tuning range at frequencies up to 500 kHz.

Increasing the range

To push the performance of their MEMS-VCSEL even further, the researchers have designs and ideas in progress to increase the tuning range and tuning speed. Other projects that they have underway include a MEMS-tunable VCSEL that operates at 1050 nm for ophthalmic SS-OCT imaging, and investigations into other wavelengths in the 400–2500 nm range.

The team have also devoted considerable effort to demonstrating manufacturability and scalability, as MEMS-VCSELs need a fairly advanced set of fabrication processes and materials, many of which differ from the processes and materials used in the established silicon MEMS industry. With these efforts they expect to enable commercialisation in the near future.

"We hope to see a renaissance in the MEMS-VCSEL field," said Jayaraman. "We anticipate new wavelength regimes and wider tuning ranges will be reported in the next few years, as well as new spectroscopic applications. We also anticipate significant cost reductions as we take advantage of Thorlabs' volume semiconductor manufacturing. We look forward to seeing MEMS-VCSELs become an established commercial product for both medical and spectroscopic applications over the next decade."