

COMPOUND SEMICONDUCTOR

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and SiC inverters cut
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Compound semiconductor MEMS community targets new applications

Today's III-V MEMS community is producing a wide variety of devices for applications as diverse as gas sensing, monitoring sugar levels in water, detecting explosives and reducing pollution from diesel engines. **Richard Stevenson** reports.

The multi-billion-dollar market for micro-electro-mechanical systems (MEMS) – devices containing micron-sized moving parts produced by photolithographic processes – is overwhelmingly dominated by silicon. However, this material is not suitable for the fabrication of certain devices, and academic institutions and company research labs are using various compound semiconductor materials to produce MEMS-based devices, including VCSELs, tunable filters, optical amplifiers, mechanical detectors and pressure sensors.

The last few years have seen growth in the development of wider bandgap semiconductor MEMS sensors for the relatively harsh automobile and aeronautical environments. French market analyst company Yole Développement predicts that this market could be worth about \$100 million for components manufacturers this year and \$300 million in 2010. The only factors expected to halt this revenue growth are a lack of progress relating to device metallization and packaging, or unexpectedly slow improvements to the SiC and GaN substrate cost and performance.

One company that is using SiC for MEMS devices is STMicroelectronics. The Switzerland-based semiconductor giant has developed a sensor that can help to reduce pollution from cars by monitoring the pressure within a diesel engine. Piezoelectric sensors incorporating resistors are arranged in a Wheatstone bridge configuration and then integrated within 4H SiC material, with a 100 μm thick membrane used to improve the device's sensitivity. Pressure changes deform the membrane, putting strain on the resistors, which modifies their resistance and leads to an unbalanced bridge that produces an output voltage.

Salvo Coffa, the research director of STMicroelectronics' soft computing, silicon optics and post-silicon technologies group, explained that SiC was selected for constructing the sensor because it can withstand high temperatures from both a mechanical and electrical perspective. He revealed that the company



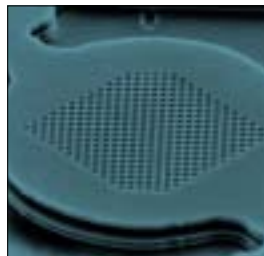
STMicroelectronics/BMW

also had to develop a metallization process for the sensor to produce contacts capable of operating at 800 °C, and an electrochemical etching process for SiC, because this material doesn't react with acids.

When the sensor is used in a "closed loop" configuration engine pollution is reduced because pressure measurements allow the timing of the ignition to be adjusted to ensure that all the fuel is burnt. Today the device is used as a lab sensor to provide information on the combustion of a specific engine, but the target of the project is to have it installed in cars. Although the device is competing against other pressure sensors that can be used in diesel engines, it is the only sensor that can be directly exposed to the environment. "Rival products require local cooling, which is expensive and limits their use to the research lab, or they need a transducer that removes the temperature from the sensor, but this approach reduces sensitivity and dynamic range," explained Coffa.

SiC pressure sensor development started three years ago. The first measurements on diesel engines were carried out last year, and Coffa expects that the devices will start appearing in cars within a couple of years. Although the current cost of these devices is roughly three times too high for mass deployment, Coffa says that the price is dominated by SiC substrate costs, and that the price of this material is falling substantially. According to him, the product's success will also depend on future European legislation regarding the permitted emission levels from cars, and the tightening of these laws could drive the uptake of these sensors.

STMicroelectronics has produced SiC-based MEMS pressure sensors (see inset) that can help reduce pollution levels by optimizing a diesel engine's combustion cycle.



Researchers in Lyon, France, have added a photonic bandgap structure to their tunable filters to make devices that can produce directive optical sources.

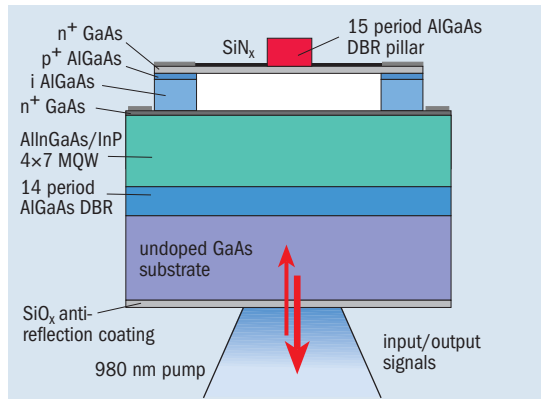


Fig. 1. The University of California, Santa Barbara's MEMS-tunable vertical-cavity semiconductor optical amplifiers have the potential to be deployed as wavelength-selective amplifiers in fiber and free-space networks. The devices are formed by bonding an active region containing four sets of seven 0.85% compressively strained AllnGaAs multiple quantum wells (MQW) grown by MOCVD on an InP wafer, to two distinct AlGaAs distributed Bragg reflector (DBR) mirrors grown by MBE on GaAs substrates. The top mirror is designed to have a reflectivity as close to 100% as possible and the bottom mirror targets 94% reflectivity. By pumping the amplifier with a 980 nm laser, 12 dB of on-chip gain can be produced over a 21 nm wavelength range.

Selective amplification

At the University of California, Santa Barbara (UCSB), John Bowers' group is producing MEMS-based vertical-cavity semiconductor optical amplifiers (VCISOAs) that deliver simultaneous optical amplification and tunable filtering (see figure 1). This property makes the devices suitable for wavelength-selective amplification in fiber-based networks, and free-space communication systems.

According to Garrett Cole, a former researcher in the group who is now heading tunable VCISOA development at start-up Aeriis Photonics, the VCISOAs face competition from fiber-based optical parametric amplifiers (OPAs), which can also combine tunable filtering and amplification. However, Cole says that the MEMS VCISOAs offer several advantages, including low pump and tuning powers, and straightforward integration with components such as lasers and detectors. "OPAs have extremely high gain, as well as continuous and very wide wavelength tuning ranges of nearly 200 nm, but these devices require extremely high pump power and a tunable pump laser to realize the wide wavelength tuning range of the gain spectrum." OPAs have other drawbacks too because they require the use of long lengths of specialty optical fiber, while MEMS-based VCISOAs have the potential to be produced as single-chip two-dimensional arrays.

UCSB's optical amplifier operates in reflection mode, with the input signal entering through a mirror with reduced reflectivity, and the amplified output exiting from the same side of the device. A circulator or coupler is required to separate the ingoing and outgoing light, and an optical source is needed to pump the cavity and enable amplification.

The researchers are still to determine what data rates

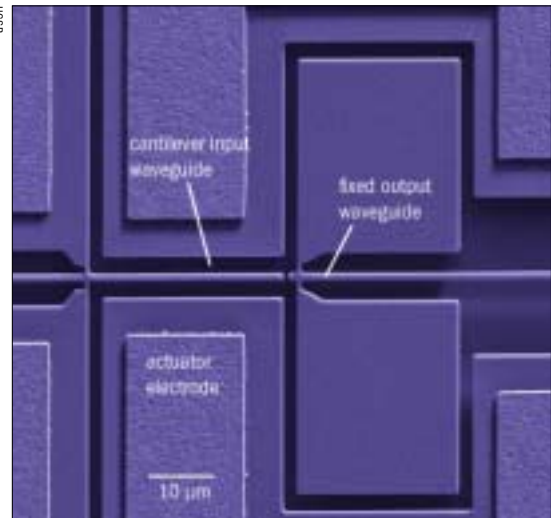


Fig. 2. The MEMS Sensors and Actuators Lab at the University of Maryland is developing cantilevers offering on-chip detection of explosive materials by monitoring the light transmitted between the cantilever and the fixed-output waveguide. The cantilever is coated with a thin chemically sensitive material that interacts with the material to be detected, leading to an increase in the cantilever's mass and a shift in its resonant frequency.

are possible with their MEMS VCISOA. However, they are optimistic that it will be capable of operating at high data rates because the device's structure is almost identical to the fixed-wavelength SOAs that the team has built in the past, which could operate at 20 Gb/s.

UCSB and Aeriis are continuing MEMS-based VCISOA development, with efforts being directed at producing electrically-injected devices, and counterparts that operate in transmission mode and are more suitable for network deployment. Both teams are also investigating the integration of VCISOAs with optical detectors in order to create integrated preamplifier receiver modules.

US universities are also responsible for producing the first InP optical waveguide MEMS switch, which came from Reza Ghodssi's group in the MEMS Sensors and Actuators Lab at the University of Maryland. Although these devices have insufficient switching speeds to route packets over optical networks, Ghodssi says that they are ideal for use in network restoration applications, where switching speeds are less stringent. The devices also offer lower static power consumption than traditional detector/emitter switches for these redundancy applications.

At present, though, the group is building InP MEMS environmental sensors with on-chip detection that share the same technology platform as the optical switches, but feature a cantilever coated with a thin chemically sensitive material and a fixed optical waveguide (see figure 2). Absorption of agents is revealed by a resonance frequency shift resulting from an increase in the mass of the cantilever, which can be identified by measuring the modulated optical power at the output waveguide.

"There has been a recent push to design devices that

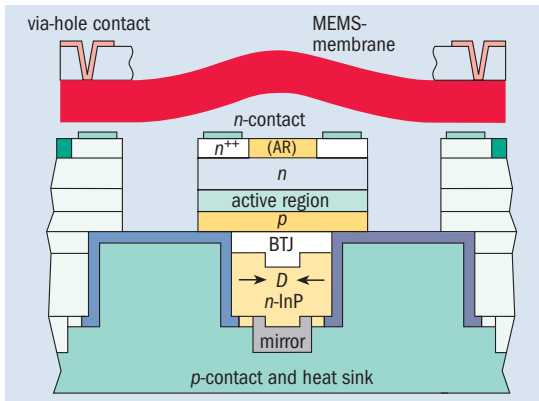


Fig. 3. The Walter Schottky Institute's tunable VCSELs can deliver an output of 1.7 mW. They are fabricated by bonding an active region grown on an InP substrate to a GaAs chip containing a distributed Bragg reflector mirror. The latest version also features an aluminum oxide anti-reflection (AR) layer, which has increased the tuning range from 43 to 60 nm. Tuning is achieved by injecting a current into the membrane through the via hole contacts, which causes thermal expansion of the material and changes the cavity's dimension. The laterally structured buried tunnel junction (BTJ) provides effective current confinement to the diameter (D).

can be placed in places such as airports to detect the presence of explosive material, bioagents, and other dangerous materials," remarked Ghodssi. According to him, various chemicals are known to react in a predictable way with these harmful substances, and the cantilever is coated with these reactive agents.

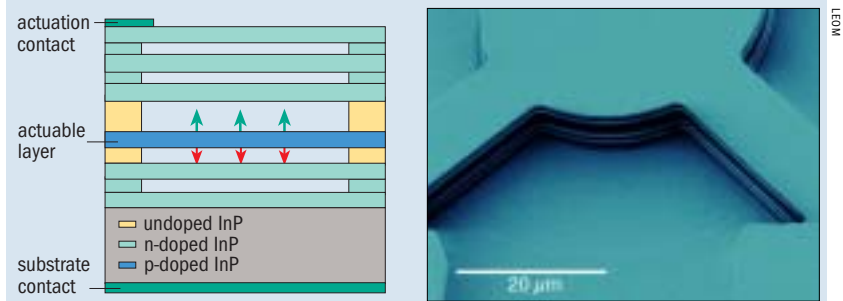
Tunable VCSEL progress

In Europe two companies, Switzerland-based Beam Express and Germany-based Vertilas, have recently developed InP MEMS tunable VCSELs that can be pumped electrically. These products are more mature than those made by the optically-pumped MEMS-tunable VCSEL company Coretek, which was bought by Nortel Networks in early 2000 for a staggering \$1.43 billion, and discarded two years later. Although the telecom market is not currently interested in buying these products, they offer an impressive collection of specifications. Unlike JDSU and Bookham's tunable edge-emitters that deliver a discrete set of wavelengths, these VCSELs offer wavelength tuning, highly efficient light coupling into a fiber and direct light modulation.

Markus-Christian Amann, chairman of the Semiconductor Technology Group at the Walter Schottky Institute in Garching, Germany, claims that the VCSELs, which have been developed in collaboration with Vertilas and the Technical University of Darmstadt, deliver the most advanced device performance in terms of tuning range and output power (see figure 3). "The VCSELs have a tuning range of up to 60 nm and operate at room temperature with single-mode performance," he said.

The VCSELs are still under development and have not been released for sampling. Although they are suitable for telecom applications, they can also play a role in gas sensing. The broad tuning range would allow a

LEOM's filters target sugar monitoring



The device shown on the left contains two back-to-back PIN junctions, enabling the actuated membrane layer to be displaced both upwards and downwards. Devices based on this design had a minimum linewidth ranging from 0.15 to 10 nm, depending on the number of membranes, and a typical tuning range of greater than 100 nm.

The latest tunable filters from the French government's optoelectronic, semiconductor and microsystems laboratory in Lyon are suitable for applications such as the detection of sugar levels in water (see above). The filters are constructed by growing an InP-InGaAs epitaxial structure by MOCVD, and then polishing the wafer's backside, fabricating ohmic contacts for actuation, vertically patterning the structure by reactive ion etching and selectively etching the InGaAs layers to produce suspended InP membranes.

mixture of gases to be monitored with just one MEMS VCSEL, says Amann, although he concedes that this may not be a cost-effective solution.

The French government's optoelectronic, semiconductor and microsystems laboratory (LEOM) in Lyon is also targeting non-telecoms applications. Senior scientist Michel Garrigues explained that the institute had previously worked on tunable VCSEL and filter development for telecom networks, but it is now developing tunable InP MEMS filters and detectors operating in the infrared region that could be used in spectrometers for chemical detection (see "LEOM's filters target sugar monitoring" box, above).

Garrigues explained that the laboratory has just started work on a project funded by the French National Research Agency that will aid the agricultural industry by developing an instrument containing tunable filters that can determine the sugar level in fruits or waste water. LEOM will be responsible for the design and micromachining process, the Alcatel-Thales III-V Lab will perform the epitaxy, SEM Datalink will construct the measurement system, and CEMAGREF, a public agricultural and environmental research institute, will build the analysis software and test the system.

The breadth of development of MEMS products, and the different markets that they serve, shows that these devices could feature in many of tomorrow's products. However, in many cases they are competing against rivals using alternative technologies, and it is this battleground that will determine the future revenue for the MEMS compound semiconductor industry. ●

“There has been a push towards devices that can detect explosives.”