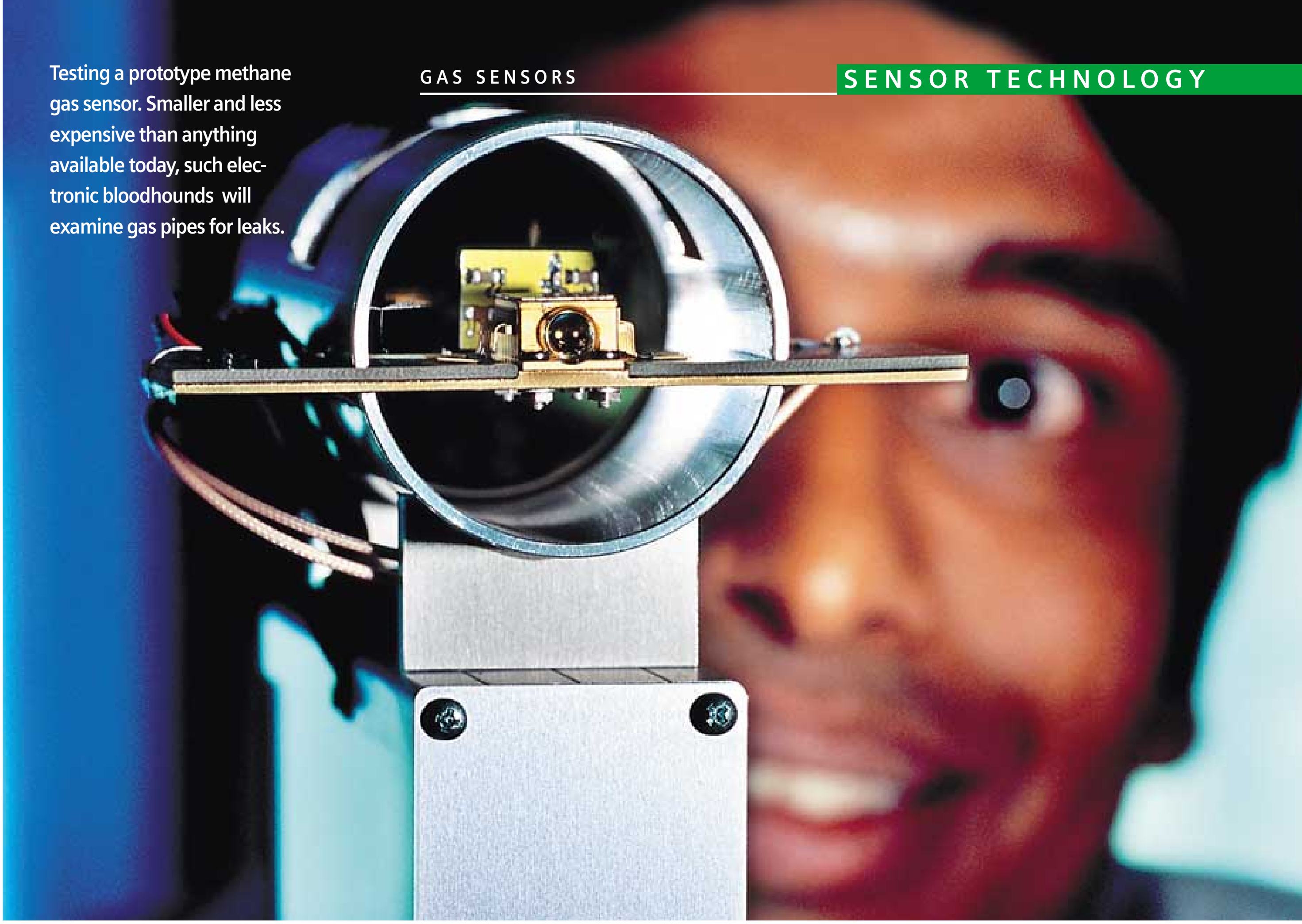


Testing a prototype methane gas sensor. Smaller and less expensive than anything available today, such electronic bloodhounds will examine gas pipes for leaks.

Digital Bloodhounds

The latest gas sensors are making our lives safer, industrial plants more efficient, and driving less risky. Reliable, fast and small, they range from methane sensors that can spot defects in gas pipes to an alcohol tester in a cell phone.

Driving and alcohol don't mix. But relying on electronic blood-alcohol test devices to determine whether you can get behind the wheel is not the solution. Not one of these devices measures actual blood-alcohol level precisely, according to a test conducted by the German automobile association ADAC early in 2004.

There are also very few methods today for measuring concentrations of other gases quickly and efficiently. "The devices are either too expensive and complicated to operate or, if they're simple and cheap, they don't yield reliable results," says U.S. scientist Allan Chen from Lawrence Berkeley Laboratory. This will soon change if Dr. Maximilian Fleischer from Siemens Corporate Technology (CT) in Munich achieves his goals. Here, in the laboratory of the Power and Sensor Systems Center at CT, a new generation of gas sensors is being developed. Fleischer, who heads the project, has electronic bloodhounds for the most diverse applications: He's got miniature sensors that fit into a cell phone, sensors that require hardly any electricity and powerful optical sensors for industrial applications.

Demand for small and inexpensive gas sensors is huge. Methane sensors could trigger an alarm when gas seeps into a house due to defective pipes, for example, while oxygen sensors could be used to optimize combustion in heating units, engines and power plants. Sensors that detect carbon dioxide (CO_2) could be used in air-conditioned buildings or vehicle interiors. Joggers could use ozone sensors to determine whether they should postpone their run. Finally, certain illnesses can be detected on the basis of trace gases on a person's breath.

However, detecting what are invisible and often odorless and volatile gas molecules is not easy. Although sophisticated methods of analysis, such as gaschromatography or mass spectrometry, can reliably identify even complicated molecules, such procedures are less suitable for rapid, mobile utilization, which requires small electronic components that immediately emit a signal as soon as the presence of a specific gas is detected. All currently known sensors for gases are based on changes in physical parameters that can be measured when molecules of a particular gas that are present in the air have bonded to a surface or reacted with other substances (see table). Fleischer believes that three types of sensors hold particular promise: those that function with metal oxides, field-effect transistors and lasers.

Hot Coating with Molecule Filters. Siemens researchers have succeeded in improving the type of sensor used for measuring blood-alcohol content. At the core of these so-called metal oxide semiconductor sensors is a tiny chip heated up to several 100 degrees Celsius, which also contains a thin layer of a semiconducting metal oxide. When a specific gas is present, the electric conductivity of the semiconducter is altered. There have been two problems with such sensors up until now: The first is that the metal oxide reacts to several different gases — for example, methane sensors also sound an alarm when alcohol is present. Such natural-gas warning units thus often set off false alarms when ethanol vapor (for instance, from cleaning agents) is present. The second problem became apparent when the ADAC tests of blood-alcohol measuring devices revealed that the devices only supplied stable results after a warm-up phase of an hour or more.

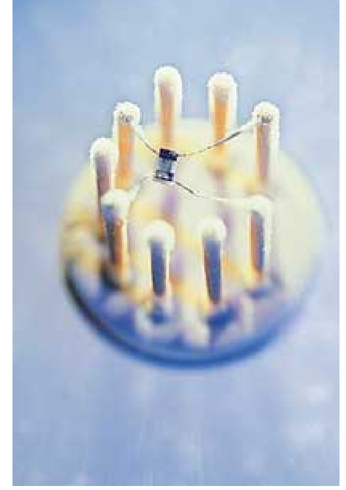
Siemens researchers have overcome both problems, however. Their sensors work with different materials and at higher temperatures than older models, which means they react much more quickly. Fleischer's team has also developed filters that keep unwanted gases away from the sensor surface. For example, their hydrogen sensor is sealed with a glass-like coating of silicon dioxide, through which only tiny hydrogen molecules can penetrate. The researchers also wrapped a porous layer around a methane sensor probe that breaks down any ethanol molecules present. "A particular advantage of the metal oxide sensors is that they're easy to miniaturize," says Fleischer. Because the sensor surface is only about as large as a grain of sand, it doesn't emit much heat, despite the high operating temperatures. This means that metal oxide sensors can be installed in portable devices such as cell phones and then used to measure alcohol on a person's breath or ozone in the air. The high temperatures even offer advantages in other applications, such as exhaust gas measurement for heating units or car engines.

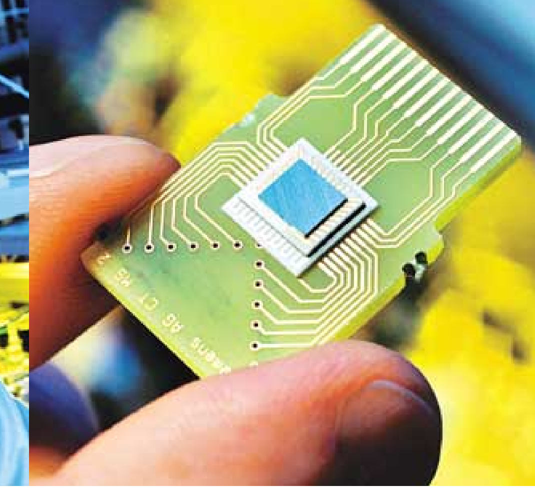
Cool Sensing. Fleischer is especially proud of his second group of sensors. Unlike the metal oxide sensors, these bloodhounds do not need to be heated up, which means they require less power to run. These devices are known by the name of field-effect transistor — or FET — gas sensors. Like the metal oxide sensors, they consist of a small plate with a chemically active layer whose surface adsorbs gases. This generates a voltage that is measured by the electric component — the FET. "What's great about these sensors," says Fleischer, „is that they work at room temeprature. That extends the range of applicable stable materials, thereby increasing the chances of finding the right material for each gas." The researchers use metals, salts, polymers, and even dyes for the sensitive coating. "These sensors have a tremendous future, but development is still in its infancy," says Fleischer.

However, Siemens researchers have used this technology to develop the first solid-state carbon-dioxide sensor. "There are a lot of applications for this type of sensor," says Fleischer's colleague Dr. Elfriede Simon. According to planned guidelines, new cars in the EU will have to use CO_2 as a coolant beginning in 2012. However, a leak in a vehicle's interior could be dangerous, since CO_2 inhalation causes fatigue. Drivers can lose consciousness if the gas exceeds a certain concentration. "CO_2 sensors would also be very useful for building-technology applications — for example, to regulate ventilation in conference rooms," Fleischer points out. Simon and Fleischer believe that FET sensors also have potential medical uses. Those who suffer from asthma, for example, could use such a sensor to check the nitrogen-oxide content of their exhaled air to identify a possible infection of lung tissue early on. This is crucial because the nitrogen-oxide level in exhaled air increases three to fivefold a few days before an asthma attack. At the moment, pulmonary clinics are only equipped with expensive and bulky stationary nitrogen-oxide measuring units. When technically fully developed, the sensor from Siemens might be able to fit into a handbag.

Remote Measurements. The third type of gas sensor from Siemens works with laser light, which takes measurements without making physical contact and can be guided to difficult-to-reach locations with glass fibers. Such sensors are thus very suitable for industrial applications. They function as follows: Most gases allow visible light to pass through but absorb certain light wavelengths in the infrared range. Conventional diode lasers, such as those used in communications technology, can be used to pinpoint individual absorption lines. If the gas in question is present, less light reaches the detector, and this information can be used to calculate gas concentration. Because each gas has its own absorption lines, there is no danger of the detector being confused by other gases or dust particles. Until now, it has been possible to use such sensors to measure oxygen, ammonia, water vapor, CO_2, methane and hydrogen sulfide. New laser technologies could enable the detection of other gases that absorb light in the mid-infrared region.

The main area of application for laser spectrometry is industry. The Swedish company AltOptronic developed this sensor technique for flue gas denitrogenization units at the end of the 1980s. Siemens acquired the





Siemens researcher Fleischer with sensors from his lab. A tiny metallic-oxide sensor measuring a few square millimeters detects alcohol on a person's breath — simulated here with dry ice (left). A FET sensor measures carbon dioxide (right).

ELIMINATING FALSE ALARMS

Where there's smoke is there also fire? Not always: Detecting a fire automatically is no easy feat. Many fire detectors can be set off by steam from the shower or kitchen, or by cigarette smoke. But not the Sinteso from Siemens Building Technologies (SBT). "Some of our customers think our fire detector doesn't really work right," says Enzo Peduzzi, head of Systems & Solutions at the Fire Safety unit in Männedorf, near Zurich. "Customers were used to three or four false alarms per week, so they were surprised when Sinteso never went off." The detecting abilities of the Sinteso fire alarm, which will be gradually launched in Europe in 2004, are even better than those of the predecessor model. At the core of the system is a sophisticated measuring chamber containing two optical sensors and two temperature sensors. The combination of the two optical sensors makes it possible to reliably differentiate between harmless particles, such as water droplets, and dangerous smoke. But the truly amazing part of the fire detector is its signal processing system. The unit more or less "knows" in what type of surroundings it is located and what types of signals to expect when something is burning. "What's more, the detector automatically increases its own sensitivity when it receives the first indications that a fire might have started," says Peduzzi. Sinteso is so foolproof that Siemens has pledged in many European countries to assume the costs if the fire department is forced to go into action due to a false alarm. The scientists in Männedorf are currently examining whether fires can be detected more rapidly with the help of additional gas sensors, since gases like carbon monoxide and nitrogen oxides are released even before temperatures rise and smoke begins to form. FET sensors from Siemens are most suitable for fire detection systems, as they require very little electrical power. "We're now conducting tests to see if they can be combined with our fire detectors," says Peduzzi.

MAJOR CATEGORIES OF GAS SENSORS

Sensor type	How it works	Example	Applications	Advantages/disadvantages
Conductometric gas sensors	Gas causes a change in the conductivity of a semiconductor	Metal oxide semiconductor	Broad area of application for nearly all gases, e.g. blood-alcohol,	+ Robust, long life, versatile, miniaturizable – Low selectivity, high power consumption
	Gas causes a change in the conductivity of a polymer	Conductive polymers	volatile organic molecules, food testing, use in arrays as an "electronic nose"	+ Broad selectivity, high sensitivity, operation at ambient temperature – Humidity interferes with the measurements, sensor could be "poisoned"
Amperometric gas sensors	Gas takes electrons from one electrode and passes them to the other. The current flow is a measure of the gas concentration.	Electrochemical cells	Applications: For example, monitoring the presence of toxic gases at the workplace, measurement of numerous inorganic and organic molecules	+ Versatile – Average level of selectivity, low lifespan, sensitive to high humidity and extreme temperatures
Potentiometric gas sensors	Electrical charge on an ion-conducting membrane	Lambda sensors	Measurement of oxygen content in vehicle exhaust or in metallurgical processes	+ Functions at high temperatures
Optical gas sensors	Gas absorbs light	Laser diode spectrometer	Simple gases such as O_2, CO_2, CH_4, HCl, HF	+ Very precise, selective – Gases require sharp absorption lines in the near IR, unsuitable for complex molecules
	Gas alters the transmission of light through a polymer layer	Optode	Fire detector	+ Miniaturizable, low power consumption
FET gas sensors	Gas is adsorbed on the surface, a voltage is generated		Still under development	+ Inexpensive, partially miniaturizable, rapid reaction, sensitive, selective

company in 2001. The Swedish team then got together with Siemens Automation and Drives in Karlsruhe, Germany, to rework their measuring device. The new version, presented as LDS 6 at the Hanover Trade Fair in 2004, is completely digital. It rapidly and accurately analyzes gas concentrations in smokestacks, combustion chambers and pipes at temperatures of up to 1,500 degrees Celsius. The system consists of a sensor and an analysis unit, which are linked to a glass fiber cable and can be separated by up to one kilometer.

LDS 6 can assist in the automatic control of combustion processes in power plants and other industrial facilities. "You can practically look into the combustion chamber and get results within seconds," says Stefan Lundqvist from Siemens Laser Analytics in Solna, Sweden. If the oxygen level is too high, the air inflow is automatically reduced, for example. "Up until now, many facilities have extracted the gas and then analyzed it — but that's too long if you want to control a facility efficiently," says Lundqvist. The LDS 6 is also used in petrochemical facilities to reduce the risk of explosion, and the spectrometer can also be found at engine test stands, where it supports catalytic converter research. Other conceivable areas of application include the medical sector and the food industry.

Multiple Sensitivity. The future, says Fleischer, lies in the combination of several sensors to create a type of "electronic nose." "At present, everyone is using a separate device for each application," he says. "But the goal must be to bring together the various measuring principles and integrate them into a single device." However, much development work still needs to be done before several sensor probes can be combined on one chip. Controlling them and processing their data represent further major challenges. If the scientists succeed, however, the measurement signal could not only be checked directly on the chip but also freed from interfering signals. Fleischer describes his vision as follows: "Future sensors should know what kind of device and environment they are in. And they'll be intelligent enough to do more than just take measurements." ■ *Ute Kehse*