Visit of Gas Sensing Solutions, Jan 6. 2015

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January 8., 2015

Abstract

GSS manufactures CO_2 sensors with mid-IR LEDs and photodiodes (PD). Our interest in these sensors is twofold. One is the low power consumption, the other is the robustness of the source.

I apologize in advance for the disgusting drawings.

1 The company

Founded in 2006 with an initial investment of $5M$ pounds, using the technology of a defence company (Kinetic). First production in 2008. Now sells in 46 countries through distributers or directly to customers for EOM applications.

Staff:
21 members, consiting of 7 engineers (incl. 2 PhDs in physics), 6 technicians for assembly and testing.

Markets:
- indoor air quality, driven by new legislation, both for public and residential buildings [1]
- safety equipment, e.g. scrubbers for diving
- process control, e.g. for the food industry
- medical, notably sports market (short time-to-market)
- automotive (large volumes)
- also grows epiwafers for other companies and universities (under the name Quantum Device Solutions)
- see big opportunities with methane (sensor under development)

Facilities and equipment:
- one facility run by two physicists, to grow the wafers. Since 2012, they own the system to epigrow the $3''$ and $4''$ wafers.
- one facility to manufacture the sensors, calibrate them and ship them.
- in total, very few square meters: $< 200\,m^2$ I guess, spread over both sites.

IP:
They have patents for the optical chamber and the growth processes. The rest (eletronics, signal processing, calibration) is not disclosed.

Supply chain:
PCBs are made in Corea, the optical chamber is made in China, the wafers are grown and hybridized at GSS and the edging of the wafers by CST.

Partnerships:
Has been working in colaboration with Schneider Electronics for the past 10 years:
- ultra low power sensor (10 years autonomy with one AA battery and one measurement every two minutes)

[1] He mentioned that the concept of "comfort meter" is big in China.

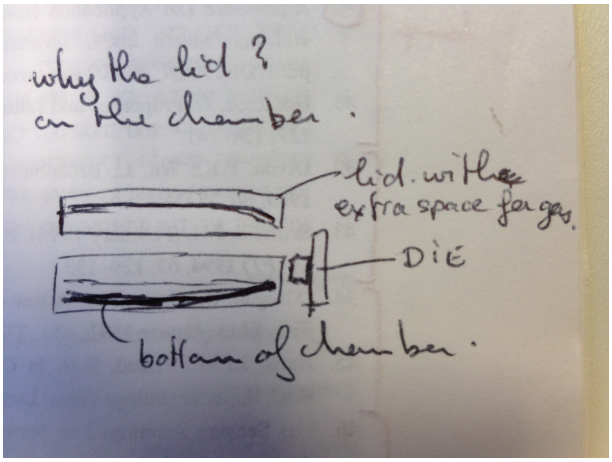

Figure 1: Cut of the optical chamber showing the variable section over the first cm or so. The waveguide is symetrical w.r.t. the axis normal to the surface of the LED and PD.

- sensors for metabolism estimate (sports market)
Tight connections with a couple of university labs.

Competitors:
The Russian company MIRDOG uses a different technology whereby the mid-IR light is inderectly produced after emission of a first wavelength.

2 The technology and the sensor

The sensor is described in [1].

2.1 Epigrowth

The LED and PD are made by epitaxic growth on a wafer. They use a unique composition of gasses to tune the bandwidth for a given gas detector: Al, Ga, In, As, and Sb, with specific mixtures and layer thickness.

It takes about $5h30$ to grow a wafer for LEDs, and $7h$ for the PDs (longer because the layers are thicker), one wafer at a time. A calibration of the system is also necessary before each growth because the rate of material flow changes. So a chamber can only produce two wafers a day. A second chamber should become operational within 6 months. In addition, also within that time window, the supplier of wafers will be able to produce $4''$ wafers. A $3''$ wafer produces 1400 dyes, a $4''$ wafer produces 2500 dyes. Hence by that time, production could scale up to $10\,k/day$.

2.2 Quality

The company is ISO8001. The quality manager controls the quality of each wafer. They check the emission bandwidth of the sensors by photoluminescence. They impose hard limits on the central wavelength. The allowed excurtion is $0.15\mu m$ from wide to side.

2.3 The optical chamber

See pictures on wishare/research/CO2/benchmark/cozir_GSS/ and fig 1. The chamber is produced using injected moulded plastic platted with pure gold. Mixtures of gold with other metals are less reflective. The reflectivity also depends on the details of the evaporation process, but I do not have details.

They had difficulties finding a manufacturer in China working with pure gold.

GSS designed their own chamber using Zemax. No prototype is made, the simulation is usually right (which means that they know what they are doing). I asked how they handle the partial reflectivity with

Zemax. They "have a way" of doing it, but would not tell which one. They could design a chamber for us. The cost would be similar to the one for a plastic mould.

There are engineering constrains to the design of the chamber. First it is $70\,mm$ long in order to reach the resolution for ambiant air control. Second, because of LED and the PD are inefficient, and because of the losses at each reflection (reflectivity of the pure gold coating is about 98.5%), it is imperative to collimate as much as possible the light from the LED. This is achieved with a waveguide of variable cross-section, with a a segment more or less of the form of a parabola. That is why the sensor is $9\,mm$ thick. It is "very challenging" to conceive a waveguide which collimates the light within a thickness of $6\,mm$.

2.4 Calibration

Each sensor is calibrated against CO_2 and temperature. The dependence on T is so large that this double calibration is mendatory. For instance, the readings of the sensor could go from $1000\,ppm$ at ambiant temperature to tens of thousands at $40°C$.

The calibration is fully automated. The sensors, mounted on a PCBs with the full electronics (STM32F100), is placed on a rack inside a box of about $25 \times 15 \times 5\,cm^3$, with a gas inlet and a gas outlet. There are 24 sensors per box. The boxes are placed in ovens. They have two ovens with a capacity of 8 boxes, and one oven accepting 3 boxes.

The calibration concists of the following sequence:
- fix a temperature T_1,
- measure at 3 different concentrations
- flush the boxes with nitrogen
- go to T_2 , and so on

Five temperatures between -10 to $55°C$ are thus calibrated. For a range of 10 to $40°C$, 3 temperatures could suffice. Verification consists also of 3 different gas concentrations at only one temperature. One calibration-verification cycle takes $24h$. So with their three ovens, that makes about 450 sensors calibrated per day.

The gas concentration is controled by gas blenders (Environics - Series 4040). They use a self-made software to operate them.

They save the calibration table of each sensor, labeled by their serial number, in a database.

I asked if it was possible to model the temperature dependence of the sensors. They said they tried and failed.

2.5 Operation and particularities of the sensor

The LED it lit by $5\,ms$ trains of pulses at about $10\,kHz$ with a duty cycle of 50%. The output of one measurement is the average of two trains seperated by $500\,ms$.

The LED and PD are very inefficient. The ratio of the output electrical power (to operate the LED) to the input electrical power (from the PD) is 10^{-5}, the losses coming from the LED, the PD, and the chamber (reflections). Thus there are two important elements in the design of the sensor. One is the optical chamber, which has to collimate the light from the LED as much as possible in order to reduce the losses through reflections. The other is the first amplification stage of the photodiode which must have a very low noise. Since the input electrical power is $10\,mW$, the output is of the order of $100\,nW$.

One alleged advantage of this source is its robustness. They claim its spectrum does not change in time, and it sustains well shocks, see however the next section. They confirmed that the troubles with incandescent lamps come from the filament, whose emission spectrum changes with time because of electrochemical reactions, and because of chocks.

Second, the power consumption makes one's head spin. The module, with complete electronics, is operated at $3.3\,V$. The average current during measurement is $30\,mA$, so the power is $10\,mW$, but the measurement, from swithing on to swithing off lasts for about $1.2\,s$, which makes an energy consumtion of $E \simeq 12\,mJ$. This means in turn an average charge consumption per measurement of $10\,\mu A \cdot h$.

There is actually much room for improvement since the sensor they designed for Schneider reaches $1\,\mu A \cdot h$ per measurement. The improvements are simple: minimize energy losses (in particular due to capacitance), optimize the way the MCU handles the tasks, and increase the SNR by increasing the operating frequency (to reduce the $1/f$ noise). One measurement lasts $10\,ms$ from switch on to switch off, reaching an autonomy of 10 years with one AA battery and one measurement every two minutes. This sensor is for Schneider's use only.

2.6 Autocalibration

The sensor needs to be periodically "self-calibrated". As we do, the sensor uses the minimal concentration over a sliding window of 7 days. **The autocalibration consists in redefining the base of the absorption curve** [2]. Thus if no autocalibration were done, one would see both an offset and a change of gain because the absorption is not a linear function of the concentration [3].

But I do not understand why this autocalibration is necessary, since the LED is supposed to be stable appart from the temperature dependence.

2.7 Development of new sensors

R&D is mostly done internally. They also work with partner laboratories from the university who have expertise in the design of LEDs and PDs. But that is only at an initial stage of some R&D projects. They eventually take over because they are the only ones to work with these gases for the epitaxi.

The bandwidth of a LED or PD is adjusted by modulating the composition of the mixtures and layers thickness. The range of wavelength covered is 2.1 to $5.5\,\mu m$. I asked about the possibility to manufacture sources and sensors in the range 1.4 to $2.1\,\mu m$. That would require different materials, more expansive.

3 The proposition for the business partnership

The first round for quotation is summarized in this table:

option	quotation for $300k$ in USD
COZIR module	37
LED and PD bonded to PCB + optical chamber	15.5
LED and PD diced but not bonded on PCB	~ 10
LED and PD edged on wafer	?

To get a hope of bringing the price down to 5 USD, I had to resort to:
1) strip the sensor to the bare minimum, that is the LED and the PD, with 3 options. In the order of increasing cost: hybridised wafer; dyes edged on wafer; dyes bonded on a PCB.
2) allure them with the perspective of a ramp up from $300\,k/yr$ in the first year to $1\,M$ over a period of 18-24 months. To reach these volumes they would have to invest.

In other words, in this proposition we would have to:
- design a chamber
- desing an electronics
- come up with an algorithm
- calibrate the sensors in CO_2 and temperature

This deal would include a technology transfer. This option is conceivable for them only in so far as the sensors will be integrated into our products and will not sell them to third parties. If we find a cheaper way to produce the sensors, they could also by some units from us [4].

There are three difficulties with manufacturing these sensors.
1) the design of the optical chamber and of the amplification stage.
2) the calibration at the factury. This means an investment, and a lot of work to automatize the process as well as to design and build the equipment.
3) the overall cost.

The first point is hard work but not an issue, except if we insist of the thickness of $6\,mm$. We could try at first a similar design by making the variable section in a plane parallel to the plane of the PCB instead of

[2] I new it !
[3] Sounds familliar ?
[4] Irony of the market economy.

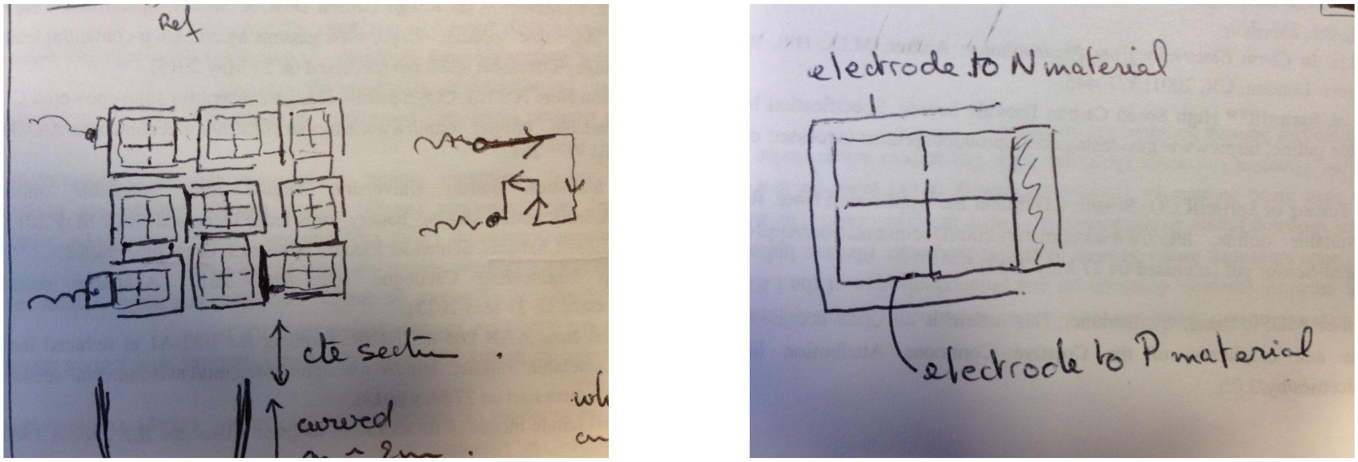

Figure 2: Right panel: Schematics of the segmented LED (same for the PD). The segments are in series. Left panel: detail of one electrode. The U shaped electrode is electrically linked to the n-doped layer. The squared surface loved inside the U is the p-doped surface (the cross are the electrodes).

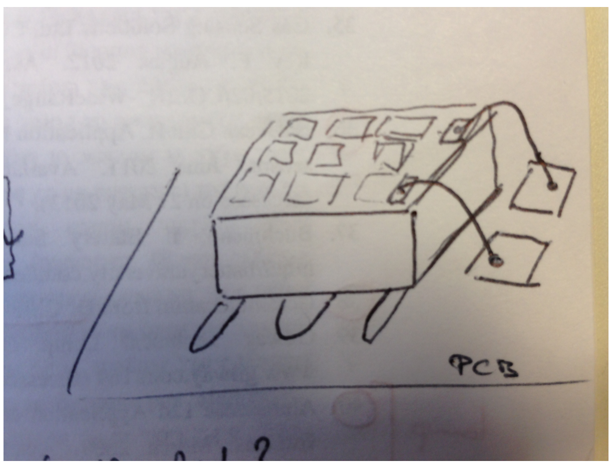

Figure 3: Schematics of the segmented LED (same for the PD) bonded to the PCB.

an orthogonal plane. The calibration is a real challenge for the production. It would be greatly simplified if we could model the temperature dependence of the sensor. This is by no means garanteed, so a serious experimentation plan would have to be carried through (on say a 100 units) before making any commitment. It is probably a necessary condition to keep the costs under acceptable limits because then we would not need to invest in any heavy equipement.

In conclusion I do not think it a reasonable option for the next product. But the technology is promissing and I think investing time to try and master it might turn out to be a good investment.

A Description of LED and PD

The LED and PD are segmented in a 3×3 matrix. They are assembled in series in order to increase the voltage to $3.3\,V$ and lower the drive curent of the LEDs, see figures 2 and 3.

References

[1] D. Gibson and C. MacGregor, *A novel solid state non-dispersive infrared CO_2 gas sensor compatible with wireless and portable deployment*, Sensors 2013, 13, 7079-7103.