Edited transcript of EPIC Online Technology Meeting on VCSEL Technology and Applications, 29 May 2020

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Introduction

The EPIC Online Technology Meeting on VCSEL Technology and Applications was held on 29 May 2020 to discuss the requirements in the design, fabrication, and packaging of VCSELS for volume applications. The event was moderated by Jose Pozo, CTO at EPIC and Ana Gonzalez, R&D Manager at EPIC, with contribution from the following speakers:

Speaker 1: Christian Neumeyer, CEO at Vertilas

Vertilas is a producer and developer of long-wavelength VCSEL, from 1.3 µm to over 2µm. We have a special indium phosphide-based design that allows us to cover everything from 1270 nm all the way up to 2.3 µm.

Today we produce on 2-inch and 3-inch wafers and we can produce over 40,000 lasers with the current die size of 250 µm² on a 3-inch wafer.

The main applications that our technology is addressing today are:

Near infrared sensing: Tuneable diode laser spectroscopy, allowing you to measure gases that are in the environment. It works on open path systems, where the transmitter and the receiver could be up to 100 meters in distance. Typical applications include measuring poisonous or explosive gases on oil platforms or oil refineries, portable devices for methane detection or other gases. It’s a very wide field where you need many different wavelengths to measure many different gases.

Optical communications: Mostly applied for intra- and inter- data centre connections, as well as in metro networks. This is where our laser technology is able to meet the different requirements which are in the O band for 1.3 µm, C band and L band around 1.55 µm to 1.6 µm.
The laser performance:

**Near-infrared gas analysis**: You can see the LI and VI performance curves of our lasers. The VI curve shows that our lasers usually consume less than 1.5 volt, and a bias current, depending on the application, between 5 and 10 milliamps, so the laser is a very power efficient. What’s very important is for the gas sensing market is the tuneability of the laser. The chart at bottom left shows that you can tune our lasers with the bias current, so by setting the bias current to certain operating point you can tune wavelength, and that allows you to scan across the so-called absorption lines for the sensing market.

**Communications lasers**: They are also very power efficient. Our fastest lasers have a 3 dB bandwidth of around 17-18 GHz, and it has been shown that our lasers have been modulated up to 40 gigabit per second on on-off keying (OOK). You can also do this with DMT or other kinds of modulation formats. These are single mode lasers, and we typically have a side mode suppression ratio of 40 dB or more.

**Our outlook and roadmap**:

- High-power two-dimensional VCSEL array: We have developed prototypes with over 1,000 emitters on one chip, allowing us to have several watts of CW power and modulated operation.
- Integration with silicon photonics: We are working very actively with partners from all over the world, and especially in Europe, for example with VTT. The advantages are very high data rate very highly integrated silicon photonic integrated solutions.
- Development of long wavelength VCSELs based on gallium antimonide. This allows us to also go beyond 2.3 µm
- Wide tuneable laser: We have developed prototypes which can be tuned over 100 nm with the MEMS VCSEL approach.

**Questions**

Ana: Maybe this would be a good time for you to elaborate more on your role in Passion?
Christian: In passion, we are developing a terabit integrated solution. It’s a single chip with two terabits of throughput, and we supply VCSELs in the c-band to cover over 48 channels in the ITU-DWDM grid. We are the supplier of the laser technologies and we supply 40 different wavelengths which are integrated on a single silicon photonics chip from VTT.

Phonex: What is the present achievable wavelength tuneability range for telecom and what is the plan to increase it?

Christian: Today, with the so-called standard VCSEL approach, we can tune several nm, so a range of 3 to 4 nm. However, we also have the MEMS approach, where we try to tune 50 nm up to 100 nm in the future.

Photonics 42: What is the development status of single mode VCSELs at a 1550 nm?

Christian: We’re in the final qualification phase, we have age all data of over 40,000 hours and we have an accelerated aging campaign of over 10,000 hours, so our goal is to fully qualify and finish qualification in 2020, and then start regular production towards the end of this year.

Photonics 42: What are the market requests for these 1550 nm VCSELs for communications applications?

Christian: Firstly, to cover several ITU channels, to have certain optical power, especially also at high temperatures, so that we can supply a power of around 1.5 to 2 mW even at 80 or 90 degrees. At 50 degrees the lasers are about 3 mW optical power. What’s also important is the data rate, so we have two product versions: one is for 10 gigabit and the other one is for 25 gigabit and more. We also have a side mode suppression ratio of 35 dB or more.

Dominic Gallagher (Photonic Design): I was impressed you said your VCSELs are single mode, that usually makes them inefficient. What is the differential quantum efficiency you achieve in single mode regime?

Christian: I wouldn't say that having a single mode laser makes it inefficient, it’s a trade-off between the optical power that you get from your device and the single mode performance. , if you have a wider active area, you can get more optical power, but typically a wall plug efficiency is in the range of 15 to 20 percent roughly.

Ahmad Atich (Optiwave): Our software tool has many components which model VCSELs, and we hope that we can get experimental data to be able to implement it and give better modelling for these VCSELs, how open would you be to share that data with us?

Christian: I think we need to talk about the details as to what we can share, but if it’s just like measured data there's no problem to share that.

Sergei Tsarev (Astrum LT): Are you limited to single mode or can you offer arrays?

Christian: We have a two-dimensional array that can have over 1,000 emitters on one chip, so we can do one dimensional arrays like for optical communications, like for 10 channels 12 channels and for parallel interconnects or for more powerful or high power applications we can have 2D VCSEL arrays which can be addressed either together, so they all emit light together or we can also have like certain parts of the chip being addressed separately.

Wilfried Noell (SUSS): You used to be purely on the component side, but it seems that you are now also going towards sub-assemblies, is that true or is that still more on your client side?
Christian: Vertilas is mostly a components company, so our core competency is really the design of lasers and the manufacturing and testing of the lasers, but we are also more and more getting into the assembly techniques, especially together with silicon photonics, we really need to fully understand the requirements. We have packaged lasers in more regular TO-type packages, and also transmit optical assemblies for SFP+ modules or pigtail applications, fiberized applications, but we are also now working with partners to offer optical engines in the future, at least have a reference design so people know how to take our lasers and integrate them with silicon photonics in the future.

Speaker 2: Julien Boucart, Director of Product Management at II-VI Laser Enterprise

Technologies for 3D mapping:

Time of flight based: They tend to be used in applications such as augmented reality, boke effects, so that’s the blurring of the background when you take a picture so that the subject pops out, auto focus, virtual shopping and they branch out into two subcategories:

- **Direct time of flight**, where you send a pulse of light and you directly measure how much time it takes to come back, but because you rely on the speed of light, the electronics requirements are very demanding, you need fast modulation, you need fast detectors.
- **Indirect TOF measurement**: Instead of measuring the pulse of light round-trip time directly, you measure the phase shift, for example, so you will modulate the light with a known modulation pattern, and you measure by how much the phase is shifted. This reduces the requirement on demodulation, because now you’re only looking at the comparison of the phase shift on the modulation signal, so you’re still pretty fast but not as demanding as what you get in a direct time of flight.

The advantage of a direct time-of-flight compared to an indirect time-of-flight is that with direct measurement you will get rid of the thermal effects. What it means for a VCSEL is that you can get more power out from a certain unit area of semiconductor, so you can overdrive the VCSEL. This improves the signal to noise ratio.

Time of flight has **advantages and disadvantages**:

- The concept is **very simple**, so from the software side it’s not very demanding. That means that the computational requirements aren’t so high, which also reduces the thermal load and the energy load on your mobile device.
- You **don’t need parallax**, that means you can have a compact illumination and sensor, they can even be in the same in the same module or subassembly, which is very attractive for mobile devices.
- As you go further out to measure longer depth, the noise only increases linearly, and it that’s in contrast to the triangle made triangulation method where it increases quadratically. That’s why time-of-flight tends to be used for long range applications.
- There are some **disadvantages**, and one of them is that it requires a dedicated VCSEL technology, you cannot use your standard CMOS sensors. Those VCSEL are not as mature, and they tend to be big, which means that altogether the sensor you will have a lower spatial resolution. Therefore, what drives the use of the time of flight technology are applications in which you don’t require high resolution, but you need long-range. When you need high spatial resolution in short-range, then you tend to find structured light.
Structured light is similar to stereo vision, the same as human vision, we have two eyes and from the parallax, the fact that we don’t look at a target from the same angle, we convert the depth information into a spatial shift. That’s stereoscopic vision, and structured light is very similar, instead of fusing two detectors, you have one illumination source which projects a known pattern and the detector is looking at the parallax, looking at the shift of your known pattern and from there it can infer the depth information.

The advantages are:

- It uses standard CMOS, so you can get very high spatial resolution.
- The depth resolution can be very good, but it doesn’t have to be. It’s related to the distance between the detector and the illumination. You can get good spatial resolution but that means that in order to get any depth information you need to split your illumination and your sensor, which means that you cannot make a compact system anymore, which is a disadvantage for mobile applications.
- The baseline distance between the illumination and the sensor is very critical, which means you need to know it at any given time, so the assembly for the illumination and for the sensor needs to be very robust, and you need to monitor it.
- On the reliability side, because the pattern is used to get the depth information, if you use a VCSEL emitter as your dot in your pattern, if the VCSEL emitter is dying, you lose depth information, so the requirements on the VCSEL are much greater in the structured light system than in time of flight.

If we go a bit more generic and we look at what you want from a VCSEL:

- You want it to be small and low-cost, and that means that in general we will try to drive the size down and increase the power per unit area.
- The reliability is very critical, both for TOF and Structured light. You want to push the end of life of a certain VCSEL array to well after the product lifetime.
- The modulation speed is very important, especially for direct time of light.
- The system needs to deal with the electromagnetic radiation it generates.
- The power efficiency of your VCSEL is directly driving battery life, so it is very important, but it will also drive the heating of your VCSEL.
- The beam shaping is something that you want to match the output of your elimination module to the camera system that you’re using, so you want to have a good matching between the two systems.
- A mobile device will be used in all kinds of conditions and operations, so it needs to remain eye-safe 100% of the time.
What we can offer: We can make VCSELs, for direct and indirect TOF, consumer applications, even datacom. We can also customize solutions for your problem.

What we need: There is still a lot to be improved, we require fast electronics, faster testing solutions, so here I’m interested in understanding the ecosystem around direct TOF and the partnerships that we can form around this characterization of this mode of operation.

Questions

Reto Keller (Optics Balzers): Julien mentioned that it is extremely important to ensure eye safety, is there some feature that comes with your VCSEL package to address that or is it up to your customer to solve that into their modules?

Julien: We are supplying VCSELs in different forms, we can supply chips and in general it tends to be that chips by themselves or not eye safe. We are also providing packages, and we provide a certain level of eye safety, but it cannot cover all the cases, like damage, so it still needs to be guaranteed by the end customer.

Jörg Smolenski (Nanoscribe): What are the beam shaping methods used in TOF and what are the trends?

Julien: I would say I don’t see that the trends have changed that much, so we still use diffractive optical elements to shape the beam, so that would be typically diffusers. Probably at the next level they would have more insight into the beam shaping.

Bendix de Meulemeester (Umicore): You need a lot of VCSELS to get to a high power for LiDAR, are they ever going to be cost competitive with edge emitting lasers?

Julien: I think in the end if you just need war power it would be very difficult, because the fill factor of an edge emitter can be much higher than on a VCSEL. However, there are some features of the VCSEL, like vertical emission, the wavelength versus temperature and the modulation speed that make it attractive, but I would probably agree with Christian’s statement that long range is for edge emitters and short range is where pixels can be comparable.

How do you check for eye safety?
Julien: The method that we’re using is to place at 10 centimetres an aperture of 7 millimetre, which corresponds to the iris of the eye, and then we check for the power density on the surface that replicates the retina.

Speaker 3: Simon Schwinger, Senior Manager of Business Development at Jabil

We are integrating not only different light sources into various systems but also taking those into mass production.

Our general task to design smart and small dot projector modules, and principally the way it’s been done you have a light source which is defined by the number of emitters, the beam parameters, and you end up with deciding between edge emitters and VCSELs. Then you have some lens system that defines dot size, the angular spread and the focus.

This beam delivery usually goes into diffractive optics that define the dot number, density, efficiency as well as the energy distribution and finally that’s what the customers and system integrators are interested in. This is all accompanied by the acceptance of distortion, which is always different from system to system, so that’s kind of the basic set up.

Focusing more on the light source, one of our projector modules consists of different RGB cameras and the laser projection. As it is a near field applications or close operation mode, we are considering VCSELs because we consider them to be available in higher power and we have the possibility to set up arrays of VCSELs and go into the hundreds of mV, that’s what we are looking for. Plus, you have the option to have pulse operation which increases the power as well. What we found interesting is the wavelength stability, which is superior to an edge emitter’s. We see a higher sensitivity and the possibility to have a very narrow spectral line width, which is important also in the applications we are serving.

From a system design view, you can direct the projection and there is a lower power consumption on the VCSEL, which is very important in consumer applications.

This is what a conceptual VCSEL-based setup looks like. The VCSEL array is combined with the micro lens array, so the collimation of each VCSEL emitter separately by a corresponding micro optical
element. The micro optical elements could also be stacked directly to the VCSEL array, for increased optimization, which allows of more flexible access to new design concepts.

The next element is the DOE, the diffractive optical element, sometimes combined with a Fourier lens. In this setup the DOE acts as an optical grating, influencing the optical spread, depending on the period. The field of view depends on the feature size and gradients of the profile, and the energetic distribution then depends on the high profile of the period.

The dot patterns are the replication of the VCSEL arrays in the detector plane, and they can see a lot of the optical effects that we are faced with and that need to be compensated or eliminated. The working range is decisive in this system: if you look at 200, 600, 1000 millimetre working ranges, you need to decide where you optimize the system. For 600 millimetres, you come across so-called tessellation effects that originate from the finite extent of the VCSEL source and depend on the working range in the overall system.

There are also additional considerations we are taking when deciding about utilizing edge emitters vs VCSELS. The arrangement of the VCSELS offers flexibility regarding the point cloud, distance needs to be used for the separation, focal length of a micro lenses influences the definition of the divergence. If there’s a small low divergence on system level you look at a good collimation for a good point separation, which is decisive for the projection afterwards. Very importantly, custom design of VCSEL arrays are required. There are vendors out there for standard designs, but we are looking for custom designs and we see an increase in need for close cooperation of optical design, the VCSEL manufacturers the software providers, in order to provide the best results.

Looking at applications, I focused on the ones that we are mainly involved in, so face ID, gesture recognition, 3D sensing, distance sensing, automation control, lidar (both automotive as well as industrial), robotics, driver monitoring, collision avoidance, heating systems, etc. A few designs mentioned here that we have already taken into mass production are illumination for driver monitoring cameras, light sources for 270-degree time of flight camera systems, and flood light emulation for 3D sensing.

What we can offer: Even though Jabil is focused on the high-volume, we see that the photonics market is highly fragmented, so there are a lot of small companies in niche applications. We have capabilities here in Germany and Vienna to incubate such kinds of business prototyping, low volume assembly, the capability to incubate until it’s ready for mass production.

What we need: The challenges are many, such as the VCSEL itself, the customization in terms of wavelength and power, so we are also looking at higher wavelengths like 1200-1300 nm, while maintaining a good portion of power on that side. Another aspect we usually collaborate on is software, specifically on the system level.

Questions:

Bernd Grammer (SABIC): Which kind of lens material do you consider?

Simon: We handle glass polymers, so we are independent from the optical material, we can handle all of it and we are highly involved in all of our designs to work with innovative materials.

Jörg Smolenski (Nanoscribe): As building space is getting smaller, is the angle out of the DOE something which is critical for you?
Simon: For the moment we feel that this is a manageable task, but since the system size has continued to be decreased, that might become an issue, so if you have ideas and input on that it would be interesting.

Speaker 4: Mary Hibbs-Brenner, CEO at Vixar – subsidiary of Osram

Vixar is a subsidiary of Osram and we make a range of VCSELs that go from 660 nm up to 980 nm. We also have a single mode single VCSELs up to large arrays of multi-mode devices.

Today I’m going to focus on VCSEL illumination for 3D sensing, and in particular I’m going to talk about the time-of-flight applications. Everyone's aware that VCSELs were first incorporated into mobile phones by Apple, and their approach was to use a structured light approach. More recently, time-of-flight has been adapted, particularly in some of the Android platforms like Huawei and Samsung. In the consumer market, there's interest in putting 3D sensing into AR and VR systems to be able to add sort of situational awareness. In the industrial market, 3D imaging is being used in things like autonomous delivery vehicles, robots in warehouses and drones, as well as in sensors, for safety systems.

There’s also now design activities going on to put 3D sensors into the automotive, both in the interior, where they’re being used for things like occupancy sensing, driver monitoring, gesture recognition, as well as the exterior.

In the consumer market, it's really power consumption and size that are critical. When you get to longer distances, now the need is not so much for size but rather for very high peak power and minimizing the drag current.

Recent developments

I’m going to focus on a couple of advances that have occurred over the past year in time-of-flight 3D sensing. For consumer solutions, where the size is key, and one of the developments has been to make integrated illumination modules that incorporate multiple features, so it has a high-efficiency VCSEL but the driver chip is now being incorporated into the same module, and that not only helps reduce the footprint of the solution, but it also reduces the inductance that you have between the driver and the VCSEL. This has yielded rise times substantially less than five hundred picoseconds.

Eye-safety has come up previously in this meeting, and incorporated into the module is also a photodetector, for monitoring the output power, as well as an interlock that would detect if, for instance, the lid were to fall off the module. There’s also an optic element in the lid that creates the desired field of view. These are being shipped now in significant volumes.

Another development over the past year has been in a multi-junction VCSEL. This is particularly useful at the LiDAR end of the time of flight range, where you need a lot of power. This is not a new idea, but it can be difficult to implement, and we have some recent results that are very promising. The VCSEL is pretty close to standard, it has a top mirror and a bottom mirror and an active region in between. The difference is that, instead of a single PN Junction, there are multiple forward-biased PN junctions, to multiply the amount of output power that one can achieve. In between the forward bias junctions you need tunnel junctions, which are now reverse biased, and because of the high doping in those tunnel junctions, they have a very low breakdown voltage and so you can get current passing through those in a way that looks almost ohmic.
Here are some results from some multi-junction VCSELs. Across the top we have the performance attributes comparison of a single junction, three junctions and five junctions. On the left is plotted output power versus current, and you can see that, for a given current, you really do multiply the output power. In fact, it’s proportional to the number of junctions in the device. However, this has to come at a cost, you’ve added additional junctions in your device and so that adds voltage. But, we also see an overall power conversion efficiency advantage from the structure, and we have seen in excess of 60% electrical to optical power conversion from the structure.

The data on the top is from a single VCSEL that is tested CW at room temperature. One can then take this kind of structure and put it into an array, just like you can with a single junction, and the data on the bottom shows the kind of pulse performance that has been achieved. So it’s a chip that’s 940 nm, pulsed with 3.6 nanosecond pulses at 0.1% duty cycle, and from this chip we’ve seen peak powers of 147 watts for a 64 amp peak current. Given the active area, that's about the equivalent of 281 watts per square millimetre, so this starts to get us into the range that becomes interesting for LiDAR and external sensing in automotive.

What we can offer: We are always happy to provide VCSELs to people and there are cases where we’re certainly open to doing custom designs, but it has to be a good business case, it either needs to be some high-value product or a high-volume.

What we need: I think in the area of high pulse power for LiDAR, there's a real need for testing, it would be nice if there were some turnkey flexible testing systems for doing this pulse testing. Optics continues to be a challenge for these integrated modules, we need high performance, high temperature, the ability for the optics to survive a solder reflow, but we want it to cost nothing at the same time.

Questions

Julien Bolkart (II-VI): Do you think that the stacked active regions with the turn junction is better suited for DTOF than for ITOF?

Mary: It certainly is very beneficial for DTOF, but I think we see some advantages for ITOF as well, you can get more power out of a smaller area, a lower current can also help to reduce the size of the driver that's required. The only issue is that often in consumer systems you have a limit on the voltage that you can use, so it may limit you to two junctions or maybe three.
Wenjuan Fan (Texas Instruments): Is there any reliability data or concern because of the multi-junctions in the VCSEL?

Mary: We’re in the middle of reliability evaluation or the qualification of these devices, and so far we don’t see any big issues with reliability I don’t think we have data that we can share quite yet but we will when it’s ready. I think what we’re doing is pushing the limits of what peak power we can achieve with good reliability, but we're understanding the trade-offs right now.

Speaker 5: Simone Lavizzari, Director of Product Marketing & Innovation at PROPHESEE

We design neuromorphic sensors and the artificial intelligence algorithms for those sensors. A neuromorphic sensor is designed to mimic the human retina, which means that every pixel in the sensor is independent and activates itself intelligently and asynchronously, depending on the number of photons that are present in the scene. What triggers this pixel is a change in contrast or light intensity. The change can be either positive or negative, and we map that with a colour, so you see white and black and black dots.

As you may understand, this is a way to mimic the retina, and it's a way to automatically extract what is relevant in the scene. Obviously, if you are interested in looking at something that changes over time, because if everything is static then there is no point, there are other benefits. The pixels are very fast, so our time resolution goes down to one microsecond. We don't have an exposure time or frame rate, so we are not blind in between the two frames.

By construction, the pixel allows for a very high dynamic range, more than 120 dB, and we tested the low-light performance and saw that the low-light cut off is at around 0.4-0.7 mini lux. Since we are extracting only what is relevant in the scenes, we also generate less data than a standard frame-based sensor.

We are presenting in this webinar because there are many applications for this technology, but if you combine these meta-vision sensors with a VCSEL projector, we can realize a novel structured light 3D sensor.

The applications of neuromorphic sensing are high precision depth sensing, which is also very fast, roughly 50 times faster than a standard structured light frame-based system or time-of-flight. This has many applications, face scanning, we can also imagine virtual chat rooms, so not only video, also a 3D presence. We can use these to do gesture control, but also for 3D awareness or if you want medium-range 3D reconstruction that can be used by robots or appliances to navigate or to recognize objects and people.
Here are a few examples of the output of our sensor. The top left is a 3D reconstruction of a face, you can also see an example of the 3D reconstruction of a marble circuit, you can notice the details that we were able to capture. Unfortunately, we were not allowed to put video, but it is nice because this game has marbles that flow at a certain speed, and we can follow them in real-time. I also want to point out that, despite the fact that the output of the structure light even base is a standard 3D point of cloud, and here in the bottom you see a construction using kinetic fusion, so we took our output and we plugged it into an existing software, which is plug in play.

We think we can break the trade-off between the exposure time, the accuracy and the robustness that is present in all 3D systems, either stereo, active or passive, time of flight and standard frame-based structured light. I’m not going to go into the details on how we do it, because this is proprietary, but if you are interested you can definitely get in contact with me. The basic concept is that, like in structured light, we project a pattern, so there is a triangulation, but the pattern is not static, it’s modulated in time. Thanks to the fact that we are very good at capturing what is moving in time, we can recognize this pattern and from this we can triangulate and reconstruct the 3D image.

**What we can offer:** Today we can offer state-of-the-art accuracy with respect to a structure light system, and we can speed up the acquisition time 50 times, typically we can go to 1 millisecond for the full 3D point of cloud. We can reduce the software complexity significantly, because we don’t have to match the pattern in a post process mode, ideally we can match this pattern inside the sensor directly. There is no motion blur when we capture the 3D scene, because it’s very fast in the acquisition, and we can also be compatible with outdoor applications if we use very fast pulses with high power.

**What we need:** We design the sensor and we produce the algorithm, but what we don’t do are the VCSELs, so we are looking for a partner or a supplier of VCSELs that are relatively high power, we don’t need 140 watts, fast pulses, in the order of microseconds and we have a wavelength in the 940 nm space.

**Questions**

Simon Schwinger (JABIL): What’s the sensor size?

Simone: This depends on the generation, the latest we have is 1 million pixel for less than 1/2 inch.
And what is the level of maturity?

Simone: We have four generations of the sensor. The generation 3, which is a much bigger VGA, it’s 3/4 inch to be precise, this is available and in mass production, so you can order it in quantity.

Generation four, which is the one we were using for structured light with a million pixels, we developed it in collaboration with Sony, the one we have is the engineering sample and will be available in small quantities this year. The mass production is foreseen to happen end of 2021.

Speaker 6: Ignazio Piacentini, Principal – Photonics Testing at ficonTEC

If we talk about volume applications, then we need to talk about wafer level testing and high-volume testing. VCSELs are used in many different applications, and I took two examples far apart in size and current. One is a data pump telecom VCSEL with 250 µm pitch. The other one is a module of high-power VCSELs.

Talking about testing, if you consider that now you can get a six-inch gallium arsenide wafer, with a 250 µm pitch you’re talking about a quarter of a million VCSEL per wafer. In this case, cost and speed become a major issue in testing.

Testing what? Well, differentiating between R&D and production, you want to test as much as you want in R&D and as least as possible in production. Primarily, you test energy and spectral properties, but additionally you may want to also delve into near field-far field, modulation, burn in and so forth.

LAV and spectral measurement can now be achieved in a few tens of milliseconds, but if you want to move on reliably, and let’s use the 250 µm pitch as an example, then the mechanics takes a bit longer, so if you consider one second per VCSEL, on a six inch wafer with 250.000 devices, you’re talking about 70 hours per wafer, so obviously that is not the way to go.

The way to go is parallel, and ficonTEC has been working now for a while on multi-site optical-electrical probe heads, and so this solution increases the overall speed, while removing some stress and extending the lifetime of mechanical components. Think also of the tips of the electrical probe part. In a typical semiconductors wafer probe, one medium touchdown is a pretty good result, but if you
have a quarter of a million VCSELs, you'll be replacing your needle tips quite frequently, unless you can reduce the number of overall touchdowns.

We've been involved in a horizontal cavity edge emitting laser for quite a while, either single emitters or bars, and typically we used an integrating sphere, but these will not really fit very well for wafer level scale testing. However, we have done some preliminary tests on fibre-optics based probe heads, and we have validated that you can really replace and calibrate it for the implementation of the of the probe heads.

You can go parallel with the probe heads, but this has an impact on instrumentation, so now we move the problem to cost-effective instrumentation, which means modular instrumentation. We've been working on PICs, and PICs and pixels are really two different games in photonics testing, but again, we need a better and more modular instrumentation for photonics testing.

Our goal is to offer fully integrated wafer level testing solutions, which means mechanics, probe heads, instrumentation and user-configurable software that drives it.

**What we can offer:** We can build the machines to test your devices, we are not going to test them ourselves, we're going to give you fast machines to test them.

**What we need:** Right now, I'm trying to optimize some of the ideas that go into the probe heads. The mechanics is fairly simple, we've been doing precision mechanics for 20 years, the instrumentation is a matter of getting the interest of some vendors and optimizing the front-end, but what you can really do for us is to help us harmonise, collected ideas and provide a supply chain for the probe heads, they need to be adapted to different devices, very much the same that happens in conventional silicon.

**Questions**

**Bendix de Meulemeester (Umicore):** We're making germanium semiconductor wafers, and at this moment there's interest in trying to do VCSELs on germanium, which can reach 8 inch and 12-inch diameters. Would you be able to do eight-inch testing and even going beyond that?

**Ignazio:** I think we can, and in fact I've been mentioning 3/4 inch for VCSELs, but for PICs we are already supplying machines for 8 inch and 12 inch wafers.

**Björn Hoffmann (RoodMicrotec):** Do you build systems for reliability tests on wafer level?

**Ignazio:** I should answer no, but I'd be interested to hear more because it is a challenge to do burning tests in large scales, due to power dissipation.

**Plasma Technology:** With time, as the manufacturing process, materials and the yield improve, we can expect that vessel manufactures might not be checking the full area of the wafer. Could you maybe share whether you've seen a trend towards the reduction of testing percentages?

**Ignazio:** My real headache is to test efficiently under percent. For complex structures, 100% testing is definitely a must, that is what is required from us. If in the volume process we'll be able to remove some of the testing, that means that we will relax a bit on the way we build the machines, so for sure going from 100% testing to reduced testing will be a push from the manufacturers.
Speaker 7: Simon Rankel, LED Business Development Manager at Ophir Spiricon Europe

Ophir is part of MKS instruments, which is a global provider of instruments and process control solutions. Our portfolio consists of laser and LED measuring products, so sensors in imaging, but also other high performance IR and visible optical elements and also replacement and OEM for high-quality optics for CO2 or other high power fibre laser materials.

In the laser world we have sensors from 5 watt to 100 kilowatt lasers, as well as sensing and imaging. We are also being more and more involved in testing for VCSELs. The main important points that we want to address, because we think that sensors and imaging is one of the main forces behind the research and use of VCSELs, and as VCSELs are becoming more powerful, I think the key points remain: Eye safety, energy efficiency and optimal beam power and beam profiling.

To stay within the safety limits for eye safety, we really need to precisely determine the average power and pulse energy. In order to minimize the consumption, the laser beam power, the profile noise and everything, all the other parameters have to be tested to ensure that they strictly comply with all the specifications.

How to choose the optimal technology for measuring the VCSELs is the main question, and I think it’s important to understand the measurement principles we want to employ, as well as the boundary conditions that apply to testing. VCSELs are often operated in pulse mode, and passive or scanning optics can be also used, so these are all the important factors contributing to the choice of the real measurement system.

For power measurement, at Ophir we are offering integrating spheres with different wavelengths, from 600 to up to 1500. We also offer the special adapters that can be used for wider beam angles, so up to 60 degrees, but we have also special gold-plated adapters for up to 170-degree beam angles of the light source.

The power ranges for integrating spheres can range from few microwatts to 30 watts, but we can also use the thermo-pile sensors or the VCSELs that could be used with also with spectral sensitivity.

What we can offer: The beam form of the VCSEL source is really important, and I think the geometry of the beam is really essential to find the best optimal solution. I would like to mention different options that we offer at Ophir near-field beam profiling, where we use a microscope lens to get all the
precise pictures of the VCSELs from up close. We also offer far field beam profiling, either directly, where the laser beam is directly pictured on the CCD camera or indirectly, which is specially used for VCSELs, where the beam is projected on a diffuser, and we analyse the beam heading into the camera with a special lens.

One of our latest solutions is a small integrating sphere sensor, which allows multifunctionality, because the three different measurements can be simultaneously performed, so we can measure power, we can detect the pulse shape and also the spectrometer can be easily connected to the system via SMA fiber adapter.

We know that calibration and accuracy are the main points, so we can really calibrate the slow photodiode attached to the sensor, and with this one we allow to calibrate the fast photo diodes. The design of this 1.5 integrating sphere results in superfast rise and fall times. The quite large aperture of two centimetres also allows working at some distance, and with this sphere we can get good measurements for the divergent angles of VCSEL lasers up to sixty degrees.

**What we offer:** Our range of measurement sensors goes from power measurements to fast pulse characterization up to beam profiling.

**What we need:** We need further input and feedback from you, so VCSEL manufacturers, system integrators and end-users. We want to know about the exact measurement requirements that you have, and we will be interested in creating a strategic partnership to develop the innovative solutions that you need. I think that there are significant opportunities that require cooperative efforts to find appropriate solutions.

**Speaker 8: Björn Hoffmann, Optoelectronics & Innovation Manager at RoodMicrotec**

We are a German company and we have 50 years of experience as a service supplier for semiconductor parts and also for testing. Our focus is on automotive, industrial, healthcare and datacom. We have a strong background in datacom qualification, because our company in Stuttgart has a long history with Alcatel, so many people and equipment is coming from the datacom industry.

Our labs are certified according to ISO 9001 and we are also an accredited lab, so we definitely offer top quality services. In general, we can cover most of the Telcordia GR-468-CORE requirements for reliability tests on optical components. We have a dedicated life test system from Yelo, and we have several humidity chambers to perform temperature humidity biased or biased damp heat. These are very stressful tests for devices, where they degrade very quickly.

Especially for photo diodes, we offer high temperature reverse bias tests, this typically runs for one or two thousand hours at up 200º C. A very new development that we now have is HTOL tests for electro modulated edge emitting devices. This is a pretty complex topic, because you need to drive the lasers and you also need to control the modulator and that all needs to go into an oven.

We also do tests such as temperature cycling, ESD tests, with the human body model or machine model tests. Our failure analysis lab is able to perform die sheer tests and wire bond strength tests. In my department, we have a lab for mechanical shock and vibration tests, so if you need to shake something really hard or vibrate it, we can do those tests according to all the relevant standards. We also have all the characterization equipment, so we are able to perform eye safety estimations or
evaluations. We can also perform laser classifications, so if you need something like that, we could be your partner.

Our specialty is not only doing these standard tests, one of our really strong points is that we can design custom electronics or adaptive holders, and we have intelligent test programs that are tailored to your demands. We are working together with several datacom players right now, and I just want to give you a few examples.

For VCSEL THB tests, where the devices degrade very fast, we have developed safe stabilizing current sources, so they always keep their current stable even though the device is degrading. We can also put up to 128 VCSELs on one PCB and this is then that coupled with eight current sources.

Recently, we have modified a Newport Laser Lifetest system to enable the control of the modulator. Another thing that we have done is we have put a photodiode on an XY scanning system and put it in vacuum, so now we’re able to scan across arrays of devices for fully automatic LIV characterization or spectral characterization, which is needed especially for the THB tests.

What we can offer: We can take care of your reliability tests, either once, if you have just a capacity problem, or in a long-term partnership if you are not able to do the tests on your own or if you are a start-up and don’t have the equipment.

A good argument for us is that we have the tailored hardware, we have a very motivated team that is working on very specialized solutions.

What we need: Contact us if you need a partner for reliability testing, either the single tests or if you need an automotive qualification like the AECQ. If you are developing new test scenarios or devices, just contact us if you need some help, or if we could go into a public funded project.

We have a lot of experience in single emitters, but we haven’t worked a lot on VCSEL arrays, so we would love to get into that field more.

Questions

Vito Roppo (3SP Technologies): Which support do you use for reliability tests on VCSELs?
Björn: Typically, we tend to use TO 46, because that’s where the modules from our yellow system are made for, but we can put round about 400 TO cans into that life test system, and that’s also why we usually put the VCSELs in the same package for the other tests too.

We also work at sub mount level to be able to test laser diodes, for example, so we could also think of sub mount testing for VCSELs, but we are not doing any wafer level testing so far.

We are just focusing on small amount tests, so just a few hundred of devices. When we have to test four thousand devices, for example, in life test or random failure test, then we go to a partner.

**Speaker 9: Ahmad Atieh, VP – Optical Systems at Optiwave Systems**

Optiwave is a Canadian company that mainly develops software for designing, simulation and optimization for components, systems and network. This software can give users a competitive advantage by shortening the product time introduction through simulation, which could provide savings on cost and enhancing their productivity.

I’m going to talk about the main products of Optiwave at system level, called OptiSystem and Optispice. At component level, we have different products, such as OptiBPM (Beam Propagation Method), OptiFDTD, OptiFiber and OptiGrating. Next month we will be introducing our newest software, OptiInstrument. This will enable users to remotely control and communicate with instruments, set up parameters, automate testing and characterization and allow users to view generated signals, extract data and process the data remotely.

The main capabilities of OptiSystem, which is the main software which addresses the VCSEL market. OptiSystem has the capability to simulate opto-electronic circuits, networks and amplifiers, it also provides advanced modulation schemes, wireless communication systems, it can do sensors. The rest of our software package can also offer finite time difference methods, beam propagation methods, optical grating and optical fibre, as well as mode solving methods for photonic crystal fibres.

Our capabilities are applied to optic systems in a range of systems:

- **Wireless communication** market, where we address LiFi, Free Space Optics, visible light communication, and this is because we offer lots library components in microwave photonics for modulators, lasers, filters, designs and characterization.
- **LiDAR** market, we offer different simulations for time-of-flight range measurements, as well as the Frequency Modulation Continuous Wave methods. We also offer sensors for using gratings or gyroscopes or OTDRs.
- We offer **DSP** components, which can do signal processing for the systems
- **Advanced coherent modulation**

We have four different VCSEL components, one of them is for single mode application and then others for multi-mode applications. For single mode applications we have the VCSEL laser, which includes thermal models, parameter fitting based on measurements of LI and IV curves, so you can extract the data from measurements and then plug it into the components, and then eventually you can do this simulation on a system level.

There is a second VCSEL component called VCSEL Laser Measured, which has more functionalities beside the ones described before, and allows the user to extract laser rate parameters from measurements of threshold current, optical power, resonance frequency and damping factors.
For multimode applications we have the Spatial VCSELs, which can also be spatial-temporal VCSELs which supports 2D spatially-dependent rate equations and accounts dynamically for spatial interaction between optical fields and carrier distribution in the active layers.

This is an example of the GUI with multi-mode VCSELs used for transmission of BAM signals. If you double-click on a component you can see the parameters, you can set up thermal effects, you can set the physical dimensions of the component, so there’s lots of flexibility in the model, and you also have lots of visualization modes, so you can see time domain, frequency domain, and it’s easy to use, it’s just only dragging components or from libraries into the layout.

**What we can offer:** We offer 30-day free trials for anyone who wants to try the software, and we are looking into collaboration with different people in the meeting here to work on simulating and implementing our different software solutions in their design and in their manufacturing floors.

**What we need:** We want to collaborate with manufacturers and design houses to be able to use our tools in their facilities, to be able to simplify the designs and study the different system parameter variations and the effects that they have on the system and the components.

We would also like to get a collaboration with several fabs, to get data from them and then plug it into the simulation tool to tune it to give more realistic models for the simulation.