Continuous-Wave LiDAR: The Next Big Wave in Self-Driving Technology

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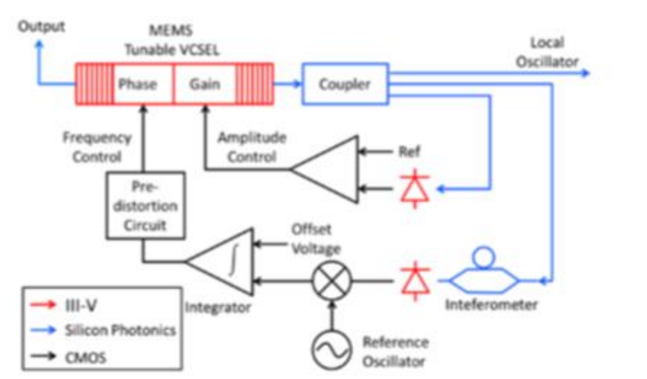
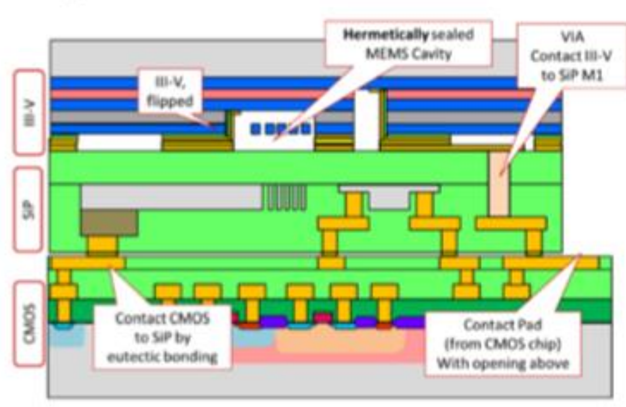
Chip Construction and Design

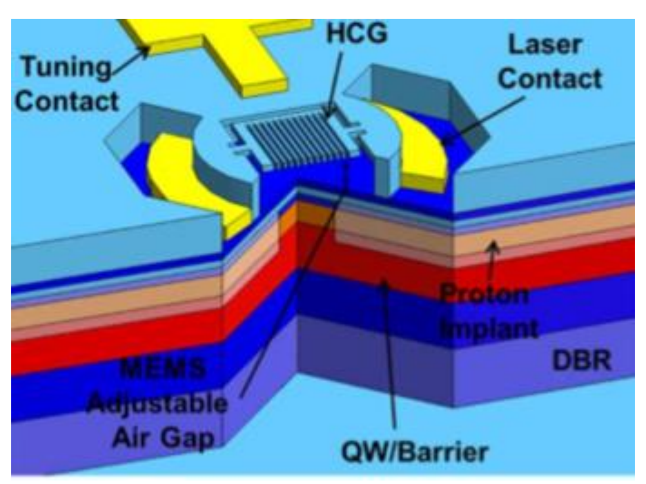
The way LiDAR systems work is by creating a beat frequency between the source laser and the reflection off the target onto the local oscillator to calculate the distance between the target object and the detector. The circuit diagram to the right shows the Optoelectronic Phase Locked Loop (OPLL) that is a schematic representation of the way frequency-modulated continuous-wave LiDAR works. The Vertical Cavity Surface Emitting Laser (VSCEL) generates a frequency swept signal that is fed through the Silicon Photonics Mach-Zehnder-Interferometer (MZI) to produce a sinusoidal output at the detector until it creates a DC signal. The CMOS integrates this signal to form a linear ramp which accounts for the nonlinear characteristics of the VSCEL frequency.

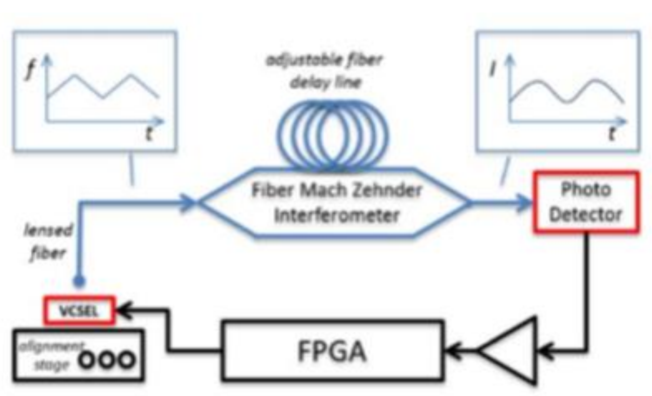




A way to fabricate the OPLL circuit is seen in the figure to the left. The III-V stack corresponds with the VCSEL components, the SiP section correlates with the MZI, and the CMOS parts complete the stack. To build this chip, the SiP and CMOS wafers will come from foundry shuttle runs and/or wafer runs. The III-V stack is processed onto an Indium Phosphide wafer, and the Silicon Photonics and CMOS will be bonded together by Through Silicon Via and contact opening. To connect the first stack to the other two, wafer alignment and wafer stack with electrical contacting and wire bonding will be used.

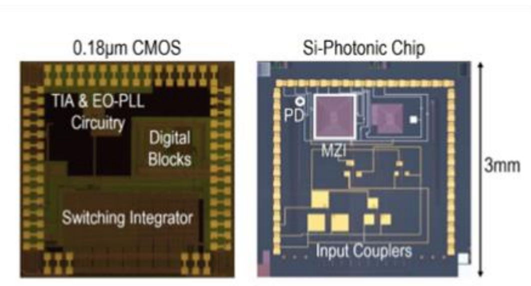
A schematic of the VCSEL mentioned above can be seen to the right. Its frequency is controlled by changing the cavity length of the laser by electrostatic tuning of a MEMS high contrast grating (HCG) which in the figure is a highly reflective mirror. Because of its low mass, the HCG allows for a high tuning speed, such as resonance frequencies above MHz. The VSCELs have a wide range of tunability, from 15 nm to +11 nm.



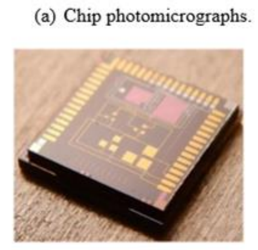


In an experiment carried out by the University of California, Berkeley, the OPLL model used can be seen to the left. It uses an electrostatically actuated tunable VCSEL, fiber optics components, and a Field Programmable Gate Array (FPGA). The FPGA contains mixing with a reference oscillator, an integrator, and a pre-distortion circuit. The OPLL produces the desired repetition frequency by inverting the ramp slope.

Depicted in the figure to the right is the CMOS technology and Silicon-Photonic Chip integration done by Dr. Baghmisheh from the University of California, Berkeley. Taking all components of the Electro-Optical Phase Locked Loop, he was able to integrate them onto a single chip-scale platform, except for the tunable laser. His electronic circuits are created in 0.18 micrometer CMOS technology with the MZI and photodiode are implemented on a SiP chip. Both chips occupy 3x3 mm^2 and utilize stack integration with TSVs. Both the chips and the stack integration can be seen in the figure to the right.

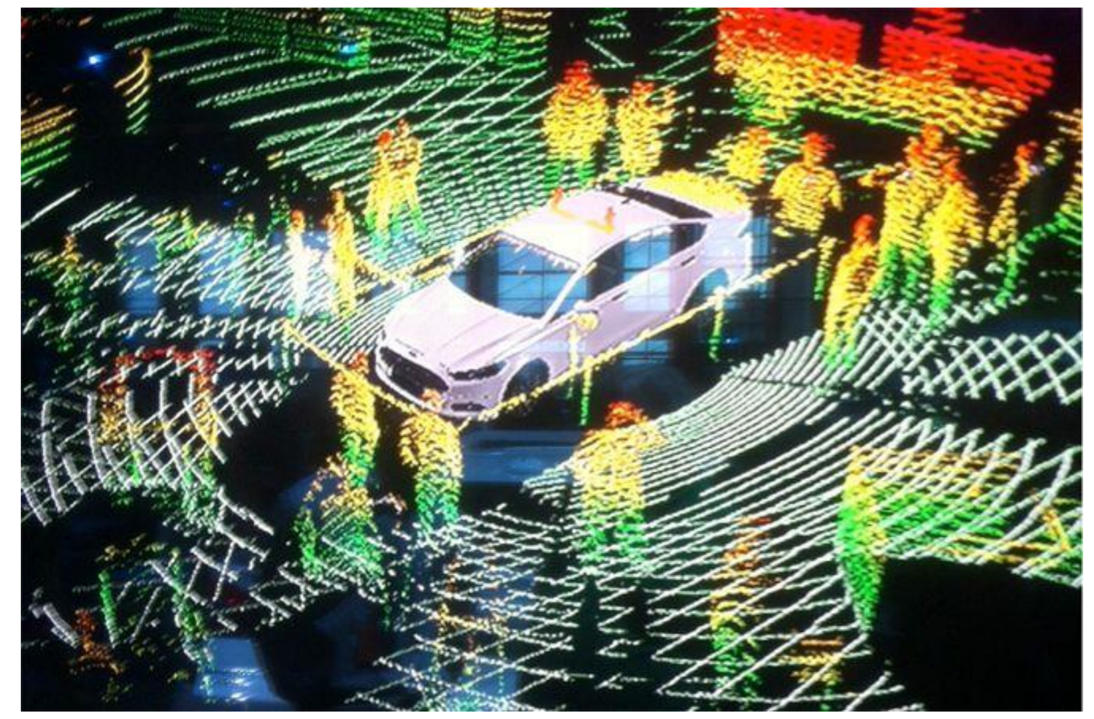


(a) Chip photomicrographs.



(b) Photograph of the integrated stack.

The Need for a Better Lidar



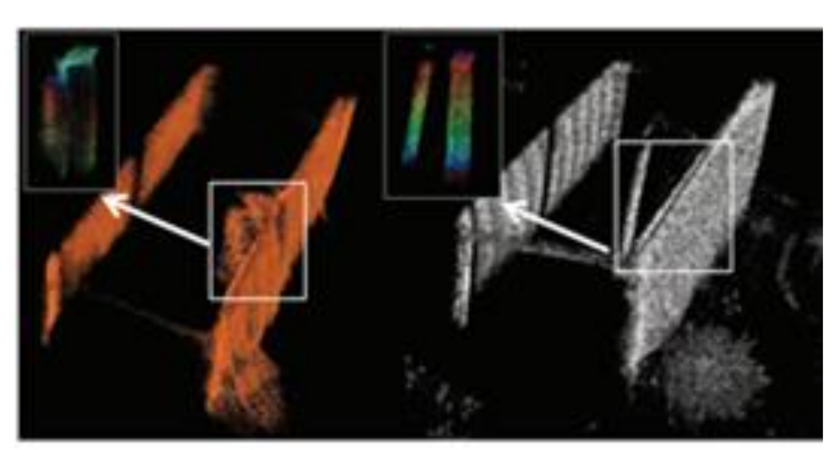
Recently, an incident occurred in Tempe, AZ involving one of Uber's self-driving Volvo SUVs. A woman was killed on March 26, 2018 as she was crossing the street; this is the only reported case of a fatal accident between pedestrian and a self-driving vehicle. The LiDAR technology within the car was still the top-mounted rotating piece made of mechanical parts. It utilized pulsing LiDAR technology, displaying a fatal example of the faultiness that comes with that type of LiDAR. This has a massive impact on cities, such as Oakland and Pittsburgh, because on a college campus pedestrians rarely follow the rules of the road. It is often left to up to the driver to react and overcome the mistakes of pedestrians, or they face the potential of hitting them. Mistakes by both drivers and old LiDAR technology alike is exactly why continuous-wave LiDAR is necessary for engineering autonomous driving.

A Look Behind the Curtain of FCMW Technology

In order to provide a better understanding of this technology, a brief explanation of how frequency-modulated-continuous-wave (FMCW) LiDAR works will be given here. The chip sends out a chirp and when it is reflected back to the LiDAR it mixes with a local oscillator to create an understandable signal for the unit to read. The frequency created by these chirps "directly yield the object's velocity as well as distance," which allows the car to calculate how fast it's approaching a truck or sign and how far away it is. This allows the car to recalculate its own speed and when to apply the brakes to avoid hitting the object in its way. As we mentioned earlier, CCL needs to give off a very low noise and linear chirp to work, and Strobe accomplished this by combining a "diode laser with millimeter-scale whispering-gallery-mode resonator." The laser is the one sending out the chirps and the resonator creates a sphere of light around it and when the chirp is reflected back it hits the sphere of light, creating a sensor that detects distance and speed.

Continuous-Wave LiDAR In Action

To prove that continuous-wave is actually more accurate than pulsing LiDAR, the US Army Corps of Engineers carried out a study in 2014 to directly compare the quality and accuracy of digital landscapes produced by the two different systems. At the end of the experiment, the continuous-wave LiDAR was clearly superior in all three of the characteristics that were compared: range ambiguity, obscurant penetration, and maximum range. One of the best examples of the difference between the two systems with respect to range ambiguity were the images captured of the very first target tested. This first target consisted of a few wooden supports and a background board, all covered by netting. The researchers plotted out the number of data points collected versus the distance of those points onto a histogram and compared it to the actual distances of the objects that made up Target 1. To put it simply, the VZ pulsing LiDAR was able to detect the objects within Target 1, but not without hundreds of stray points within the two targets. The HRS-3D continuous wave system not only detected the two objects with hundreds more points, but had barely any stray points in between.



This image displays one of the objects each LiDAR unit had to scan. The pulsing unit's image is on the left continuous-wave on the right. Note the errant cloud of nonexistent points picked up by the pulsing LiDAR.

Long-term Effects of Effects of CCL Technology

The most obvious and most important effect of self-driving cars on society would be the huge improvement in automobile safety. Cars and computer systems aren't able to become fatigued, distracted, or inebriated, and therefore are much safer than human drivers. Since 2008, the US has averaged roughly 35,000 vehicle-related fatalities a year. Current self-driving cars have an accident rate about a tenth of the safest driving demographic. (60-70 year olds) This gives them the potential to prevent roughly 31,000 deaths a year.

Year	Automobile-Related Fatalities
2008	37,423
2009	33,883
2010	32,999
2011	32,749
2012	33,782
2013	32,893
2014	32,744
2015	35,485
2016	37,461

One best-case scenario estimate by ClimateWire suggest that if self-driving cars were to shed some unnecessary weight and incorporate more fuel-conscious driving algorithms, that a world made up entirely of self-driving cars could cut down car emissions by up to 94%. This is a best-case scenario, but if 94% is the ceiling, even a portion of that would still be a huge turnaround for world pollution.