

# **RED CREAMERY**

**A LIDAR for L3/L5: ultra-high-resolution with  
“mechanically-modulated” CW laser**

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**DVN Lidar Conference 2022**

# “Holy Grail” LIDAR Requirements

- Existing LIDAR systems easily meet SOME of these requirements, but not ALL of them together
- Lots of samples needed:  
 $120^{\circ}\text{H} * 30^{\circ}\text{V} / (0.1^{\circ})^2 * 20$   
fps = 7.2 MSPS
- Typically, full resolution, or full range, or both are only available within smaller ROI

Range $\geq$ 200 m at 10% reflectivity (R)
Field-of-view (FOV) $\geq$ 120° horizontal and 30° vertical
Distance accuracy $\leq$ 10 cm
Angular resolution $\leq$ 0.1° horizontal and 0.1° vertical
Frame rate $\geq$ 20 Hz
Power consumption $\leq$ 10 W; maximum 100 W
Infrared wavelength $\geq$ 850 nm
Unit price $\leq$ \$200 for mass production
<b>Typical requirements of lidar products for L3, L4 and L5 autonomous driving</b>

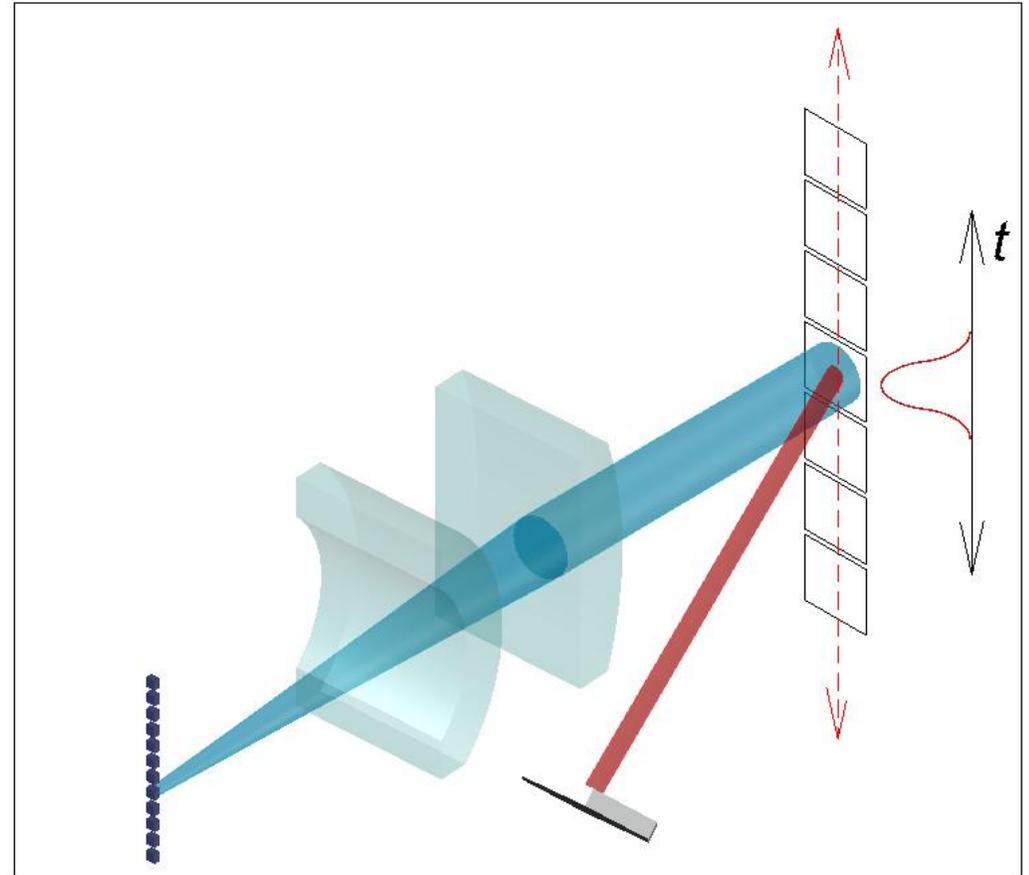
From “Lidar 2020-2030: Technologies, Players, Markets & Forecasts”, By Dr Nilushi Wijeyasinghe and Dr Khasha Ghaffarzadeh, Copyright © IDTechEx

# Lots of Pixels – Lots of Laser Power

- A  $\phi 40$  mm lens collects only about one photon out of a billion from a 10%-reflective Lambertian target 200 meters away, with no atmospheric loss
- If 1000 collected photons is needed per each of 7.2M samples, that's  $\sim 7.2 \times 10^{18}$  emitted photons per second, assuming no other losses. That's  $\sim 1.5$  W of AVERAGE laser power @1550 nm.
- Flash LIDAR with short-duty-cycle light source would need enormous instantaneous power
- On the other hand, sequential acquisition LIDAR would bump into ambiguity limit: 7.2 MSPS corresponds to  $\sim 0.14$  us/per sample, or only  $\sim 20$  m of unambiguous range

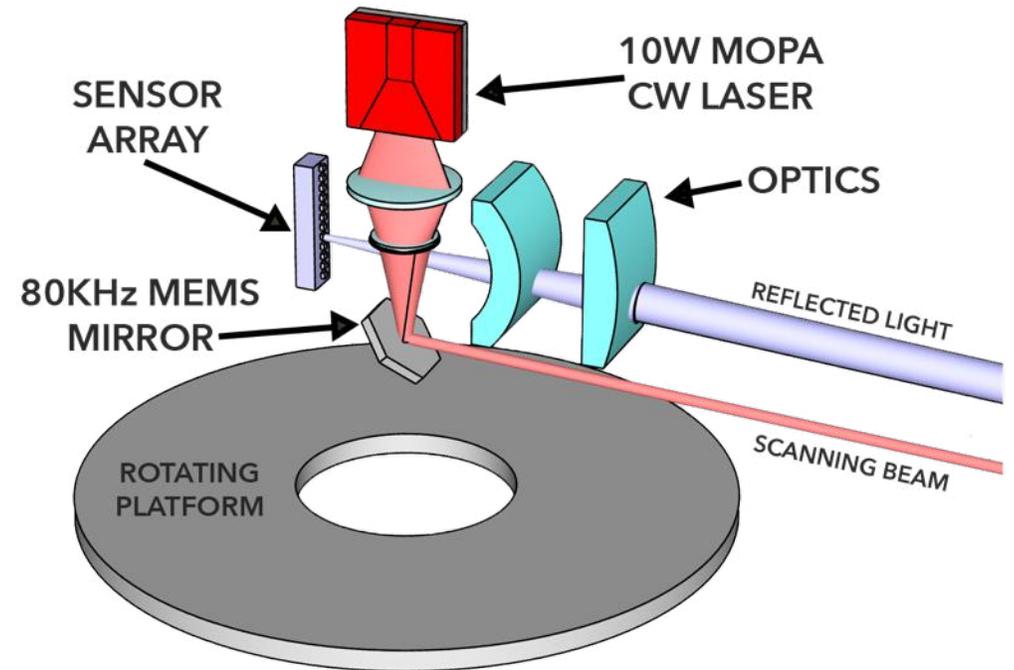
# Red Creamery Approach: CW Laser With “Mechanical Modulation”

- If a CW laser beam is scanned sufficiently fast, it can traverse the FoV of a single small sensing pixel within nanoseconds
- As the laser beam traverses the FoV, the pixel “sees” a bell-shape pulse of corresponding duration
  - The pulse shape is a convolution of the pixel active area and the laser spot imaged by the collection optics
- If there are multiple pixels along the path of the scanned beam, they are illuminated one-by-one
  - Ambiguity limit is avoided, because each pixel is illuminated only once per scan line

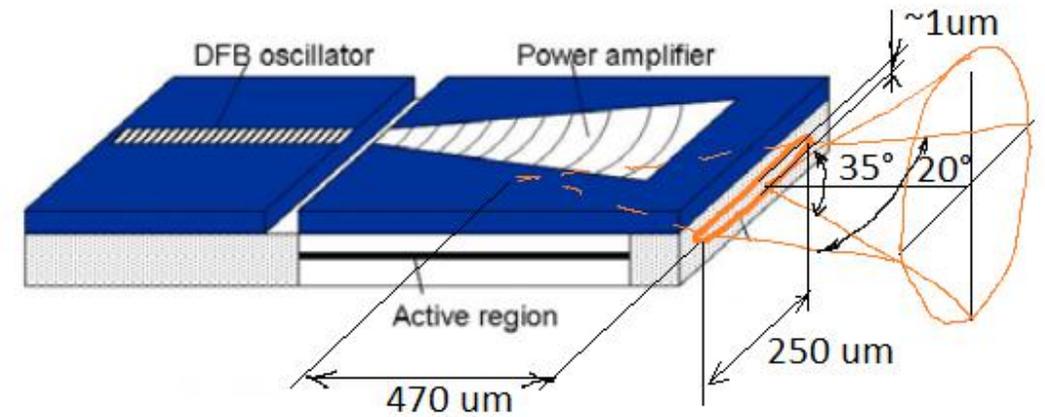


# Red Creamery LIDAR: Implementation

- Master-Oscillator-Power-Amplifier (MOPA) diode laser
  - SM, but with arbitrarily-large active area
  - >10 W @ 1550 nm
  - Available in 900 nm and other wavelengths, but power may be limited by eye safety at ~2...3 W
- Silicon MEMS mirror
  - 80 kHz (each cycle = 2 scan lines: up and down. 160k scan lines per second)
  - 1.5 mm width
  - 40° total optical scan angle (30° active)
- 1D sensing array
  - Long but narrow sliver of a wafer
  - 512-pixel InGaAs LM-APD sensor array
  - >80% fill factor, no micro-lenses needed
  - SPAD sensors possible
- High NA collection optics
- **160k lines/sec\* 512 pixels/line = 82 MSPS**
- Horizontal rotating platform with 360° view can be replaced with a slow-scanning mirror for ~120° front-facing solution

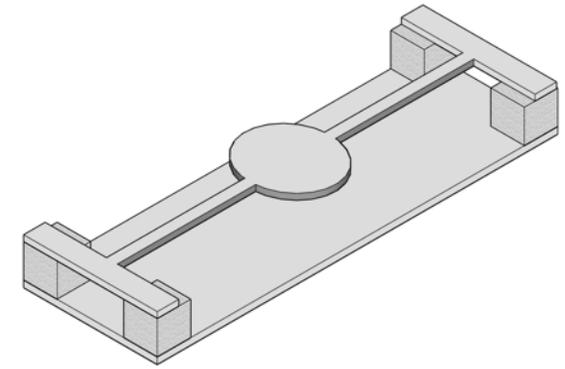


# CW MOPA Laser: Fundamental Advantages And Limitations



- Diode lasers have large cost advantages over solid-state, fiber, and other more complex laser technologies
  - MOPA diode lasers have the same cost structure as other diode lasers
- The bulk of the losses in a laser diode originate in ohmic resistance of the semiconductor material
  - Proportional to the **square** of the current density
  - Therefore, inversely proportional to the duty cycle – therefore, significant efficiency advantage of CW laser diodes over pulsed ones
  - Also, inversely proportional to the active area – therefore, significant efficiency advantage of MOPA laser diodes over conventional single-mode (SM) ones
- MOPA beam is perfectly SM, but astigmatic
  - Collimating optics somewhat more complex
  - Temperature stabilization required – but active cooling of powerful laser diodes is required anyway, so stabilization doesn't add much cost

# MEMS Mirror as a Fast Laser Beam Scanner (LBS)



- Optical resolution of the scanner needs to be comparable to the resolution of the sensor
- Fundamentally, resonant MEMS mirror **is not** the best LBS:
  - Mirror width, scan amplitude and frequency all heavily contribute to mechanical stresses
  - Yet at this time no other scanning technology can match the sampling rate of resonant MEMS scanners
- Present Red Creamery MEMS mirrors satisfy LIDAR sampling rate requirements, with 10x margin: 82 MSPS vs. 7.2 MSPS minimum
  - Still has room for improvement, but the fundamental limits of monocrystal silicon mechanical strength are not far away
- Not really a “moving part”, impervious to shock and vibrations, as internal accelerations are many orders of magnitude higher than external ones

$$N = \frac{\pi D \theta}{4 \lambda}$$

N – number of optically-resolvable points

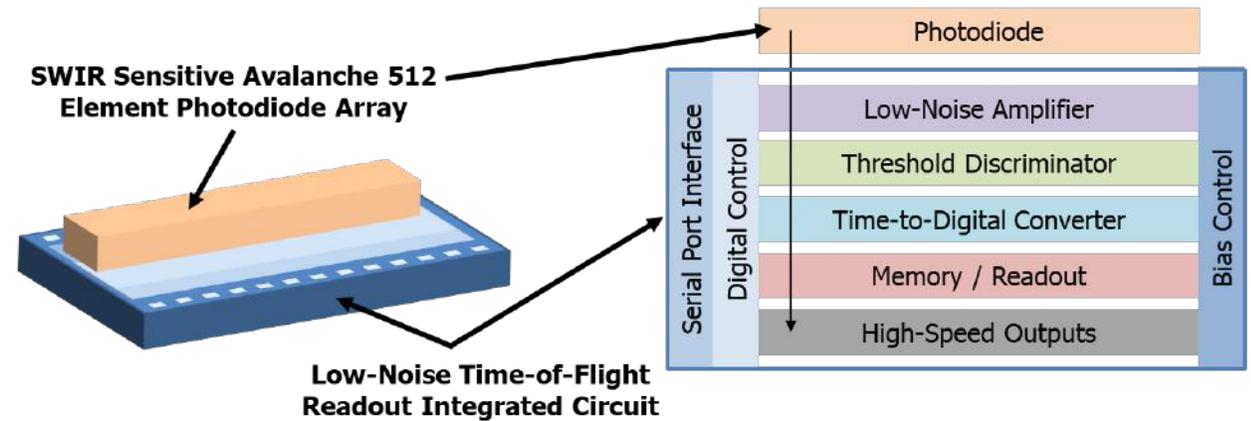
D – mirror width

$\theta$  – mirror scan angle

$\lambda$  – light wavelength

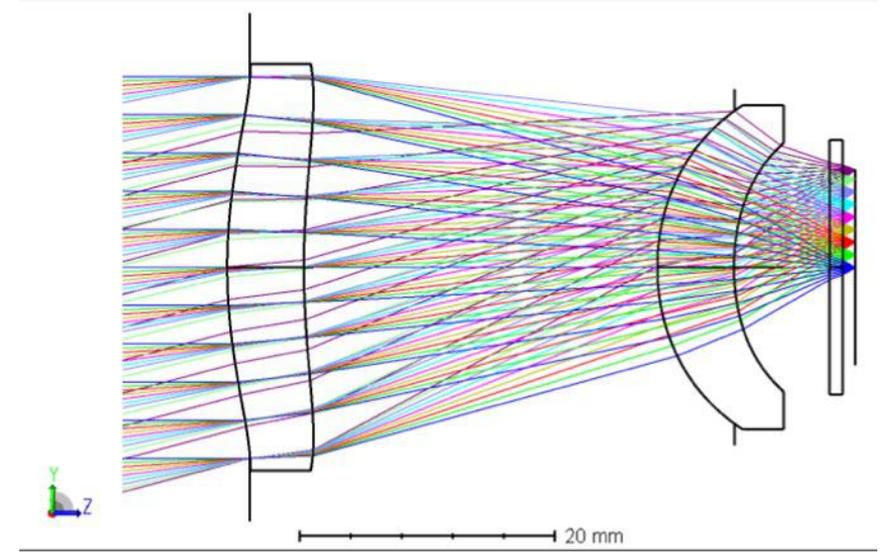
- For Red Creamery mirror @1550 nm, N = 403
- Laser spot is slightly larger than pixels
- From bar code scanning practices, spot can be up to 2.5x larger without much detriment to resolution

# 1D Sensor Array



- Fundamentally, Red Creamery LIDAR is sensor-agnostic
  - Presently, it's 512-pixel InGaAs LM-APD, 30 um pitch, 100 um width
  - Work in progress on silicon SPAD array
- 1D sensor array of any type is a narrow sliver of a wafer – small wafer area, low cost
- “1D” doesn't necessarily mean a single column of pixels, can be several columns, or even several dozens – still, the array stays essentially 1D – long and narrow
  - equivalent of splitting a single pixel into multiple sub-pixels
  - good for SPADs – improves solar immunity
  - good for alignment of sensor array with scan line
- ROIC synchronized with the scanning mirror
  - ToF = ToA – ToD; unlike pulsed illumination, ToD is different for each pixel, it is the moment when the scanned laser beam is colinear with the pixel's FoV
  - Scanning mirror is highly resonant and therefore very stable, its position vs. time is known down to a fraction of a nanosecond

# Collection Optics



- Collection optics for 1D sensor array is not fundamentally different from conventional, narrow-band imaging optics
- Red Creamery InGaAs sensor has high fill factor, obviating the need for micro-lenses. Specifically for that sensor RC developed a high-NA (f/0.9) collection optics with moldable chalcogenide lenses
  - SPAD sensor would need micro-lenses, and lower NA main collection optics – perhaps, f/2...2.5
- Narrowband optical filter of  $\sim 50$  nm BW is used for 1550 nm system
  - 905 nm SPADs would need a narrower filter -  $\sim 30$  nm

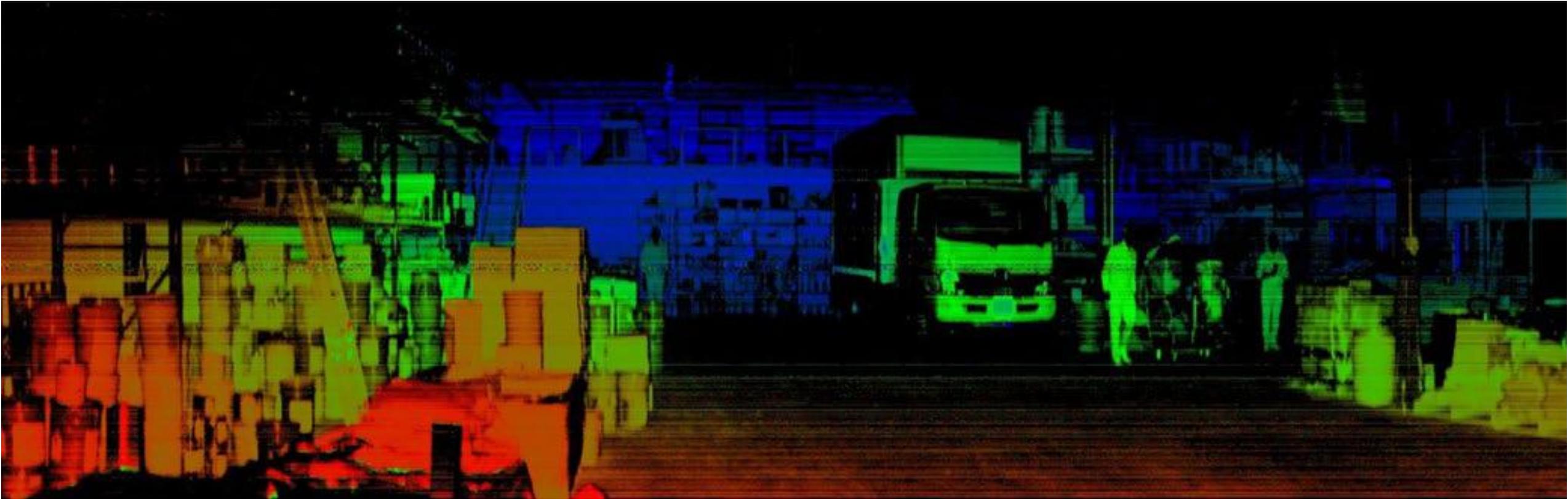
# Red Creamery LIDAR cost structure

- All major components of Red Creamery LIDAR are low-cost, mass-producible parts
  - Our cost estimates are based on quotes from manufacturers, not Moor's Law
- Laser, sensor and mirror are essentially wafer-level parts, cost tied to the wafer area
  - Have already been miniaturized, cost projections not dependent of further miniaturization

	Projected Cost Range @ Quantity 1m Units	
<u>Component</u>	<u>Low Range</u>	<u>High Range</u>
Laser	\$ 25	\$ 25
Mirror	20	30
Molded Optics	40	50
Sensor	30	70
<u>Electronics/Mechanics</u>	<u>125</u>	<u>150</u>
<b>Total Estimate BoM</b>	<b>\$ 240</b>	<b>\$ 325</b>

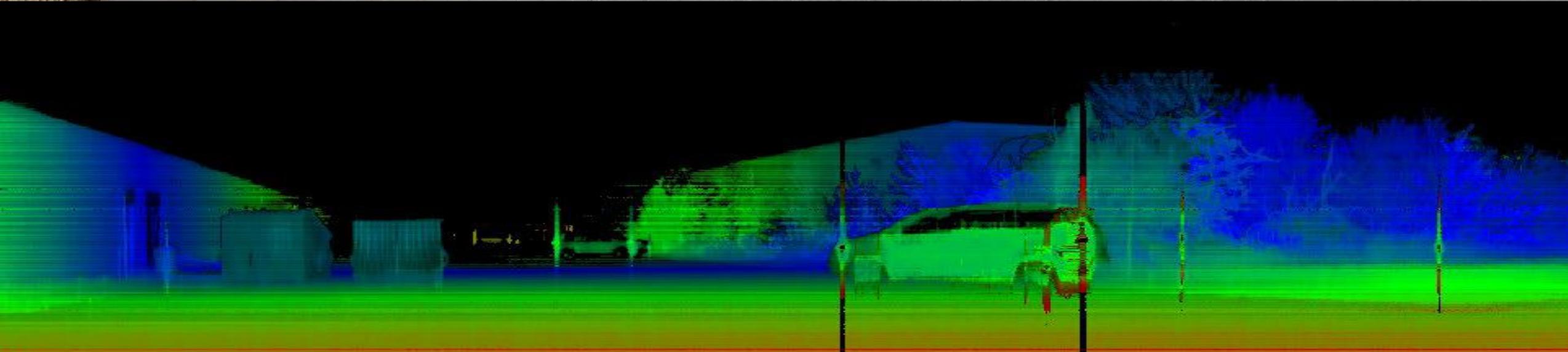


# High-resolution: How It Looks



- This is a 90° slice out of 360° FoV
  - Depth rendered in false color – R-G-B
  - Back wall is ~40 m away
  - Only 200 mW of laser power used

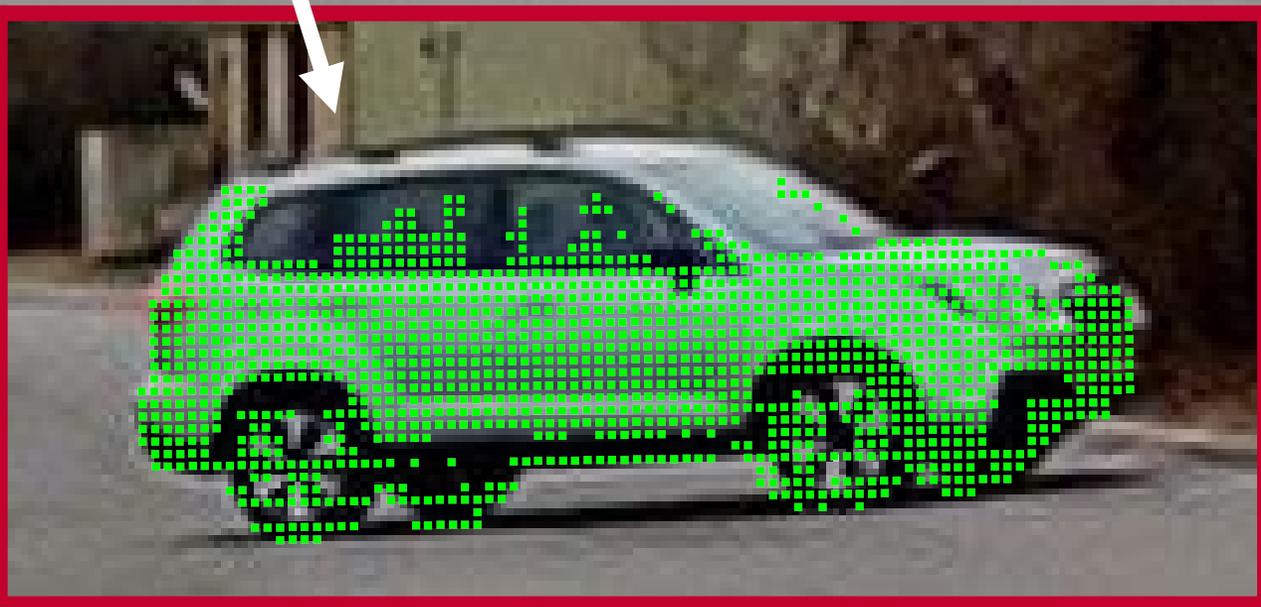
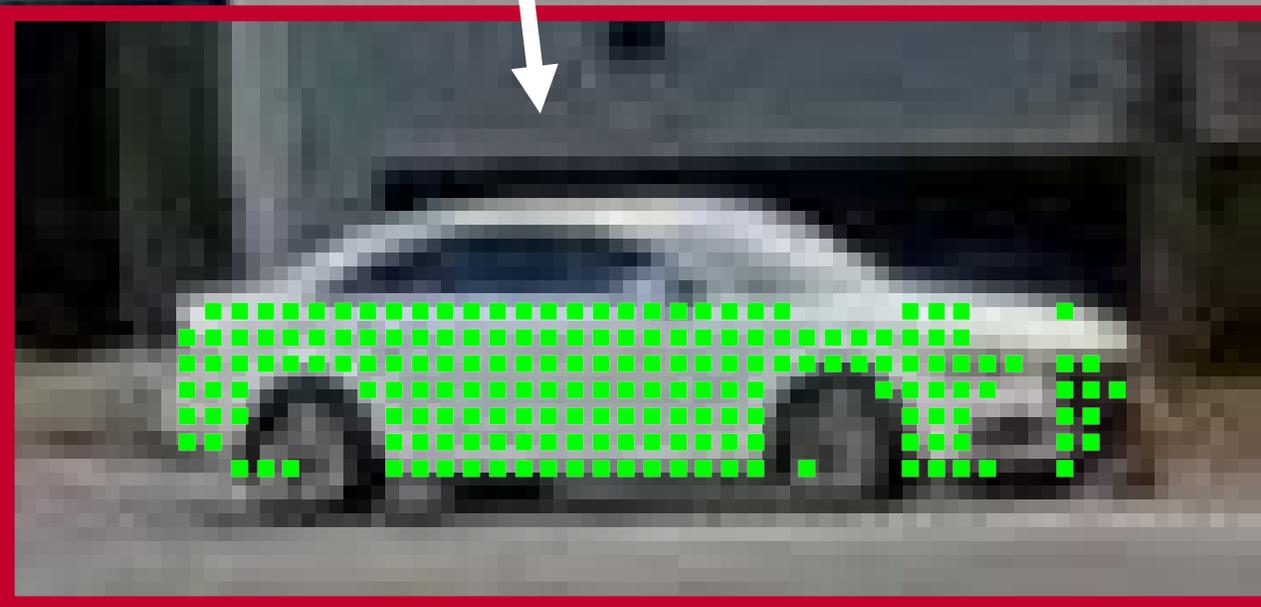
# High-Resolution, Long Range “Folded” False-Color: R – G – B – G – R, up to 200m



# Return Points Close-Up

122 Meters / 400 Feet

61 Meters / 200 Feet



# Red Creamery Status and Plans

- Red Creamery approach has been prototyped and tested, feasibility proven, performance confirmed – including ultra-high-resolution (previous slides)
- Major components of Red Creamery LIDAR have been fabricated and de-risked
- Considerable uncertainty remains about specific configuration most desirable for the industry:
  - 360° degree rotation or front-facing
  - 1550 or 905 nm
  - Final range/laser power requirements
- Looking for
  - industry partners to define specifications
  - manufacturing partners
  - investors

**RED  
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**THANK YOU!**

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