Speaker:

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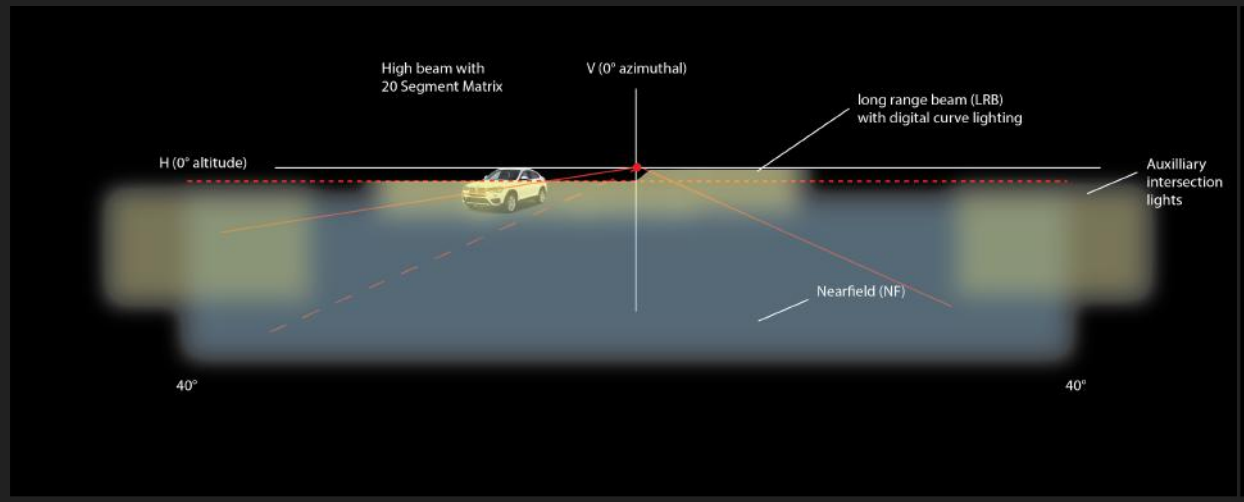
Title @Lucid: Director Electronics and Optical Engineering

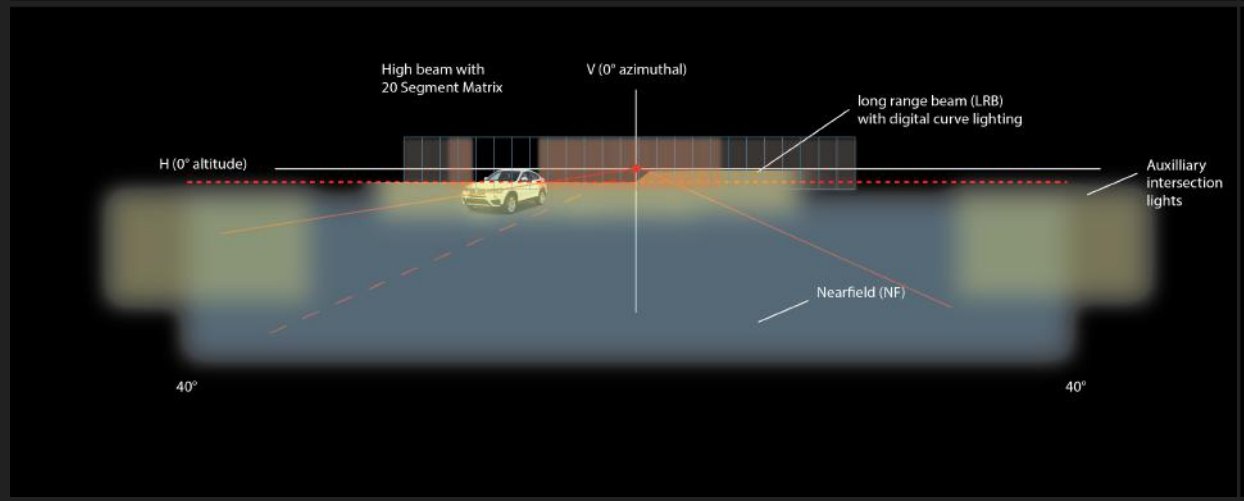
PhD Physics from University of Jena in Germany, 11 years as Research group leader at Fraunhofer IOF. Since 2016 at LUCID, for two years Director Electronics and Optical Engineering

Full Digital Headlamp
Constraints and opportunities

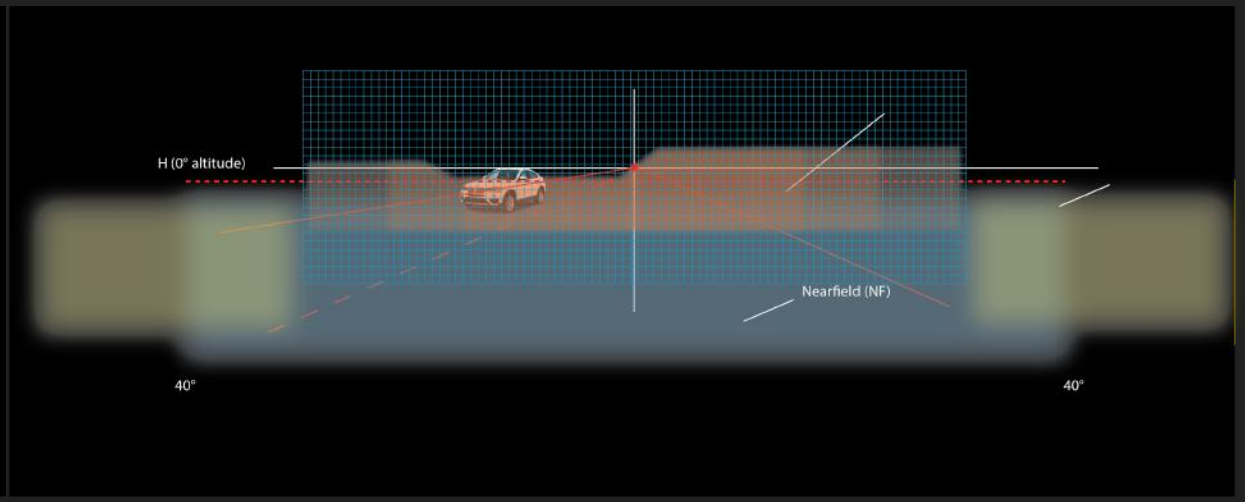
Why Pixelated Headlamps?

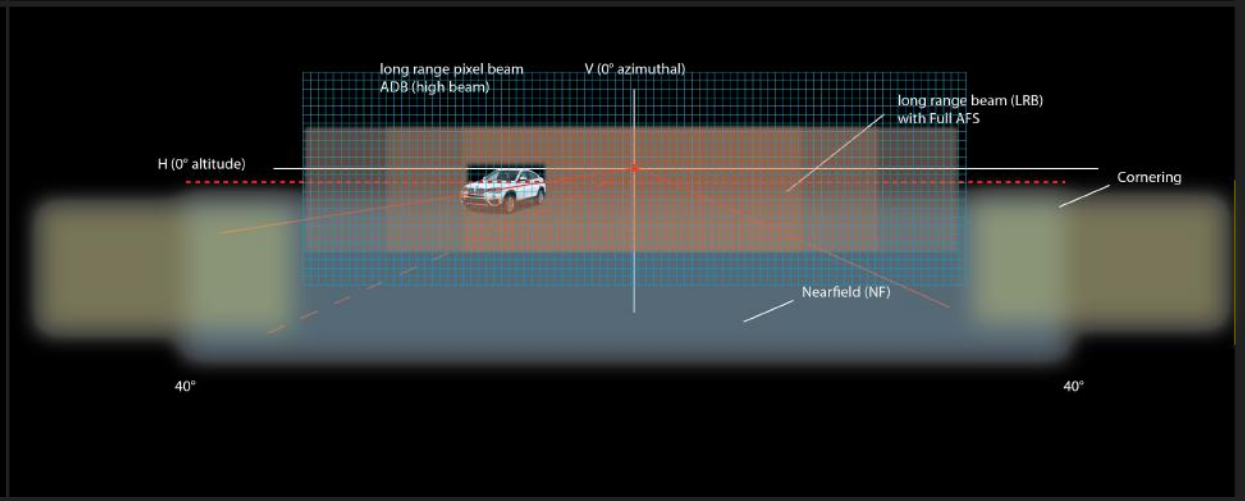
Conventional



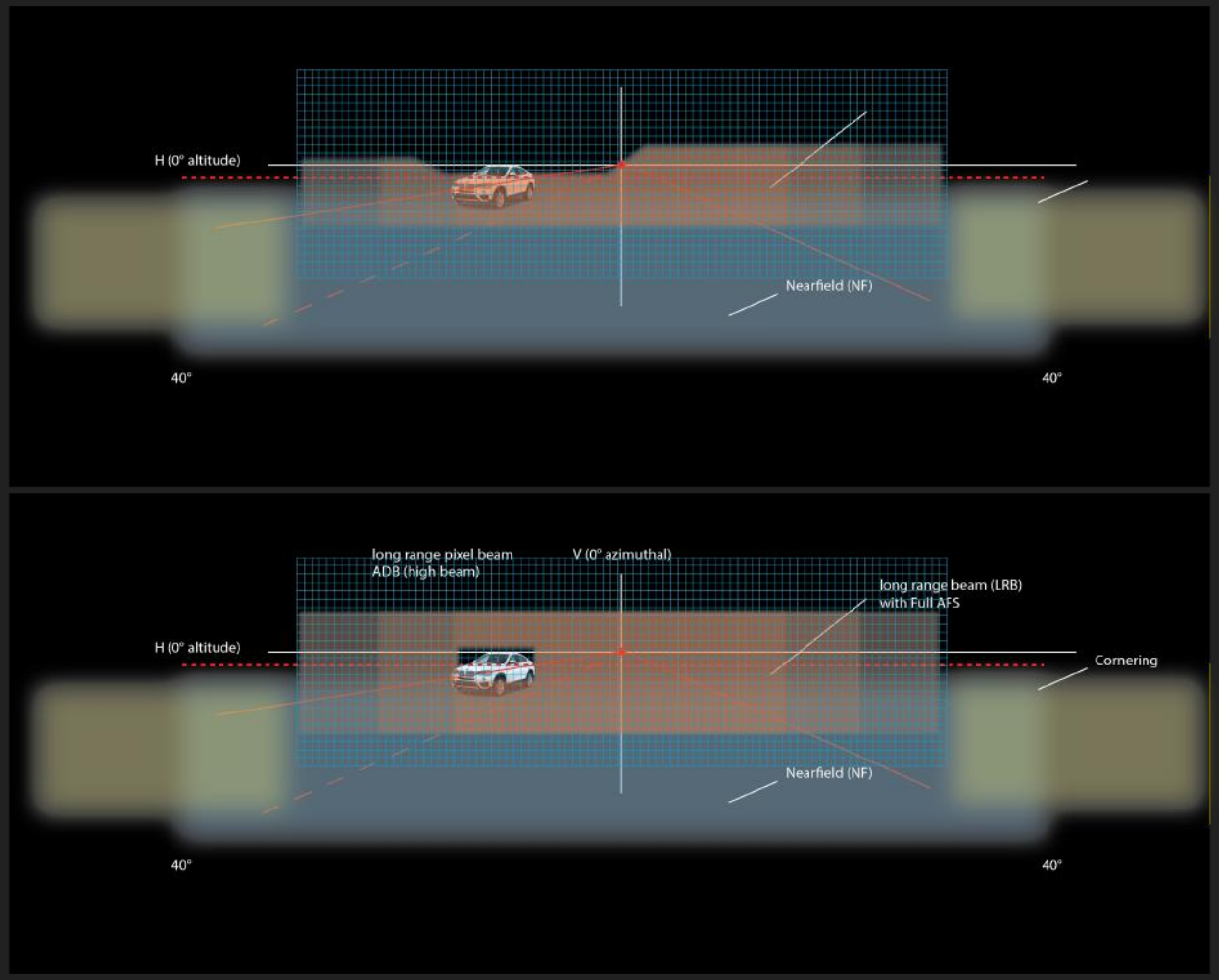


Pixelated





Opportunities of a high-resolution pixel headlight



- Whole world design possible
- High range adaptive low beam and ADB in one module
- More precise ADB modes
- Easy tuning of legal light values and use cases
- No mechanical actuators
  - Aiming/leveling over software
  - Faster leveling/curve lighting
  - Smaller clearance envelope around light modules
  - Cost saving (motor, controller, ECU)
- Reduction in control unit BOM
- Fancy use cases

Basic challenges: Styling, package and technology fight each other

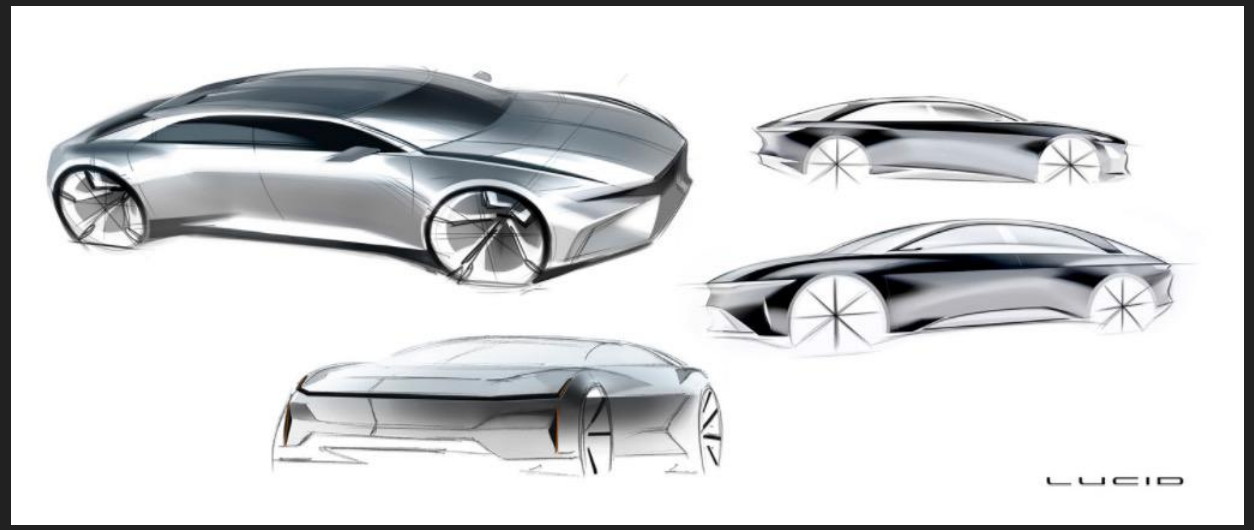
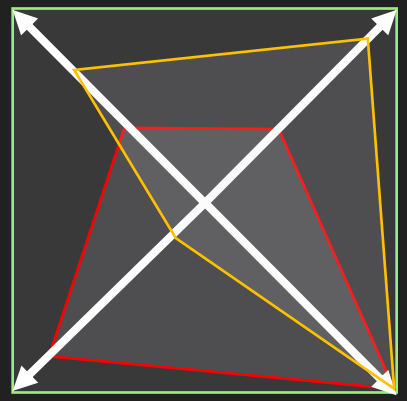


Image from https://als.al.world/technology

HIGH EFFICIENY

HIGH FUNCTIONALITY

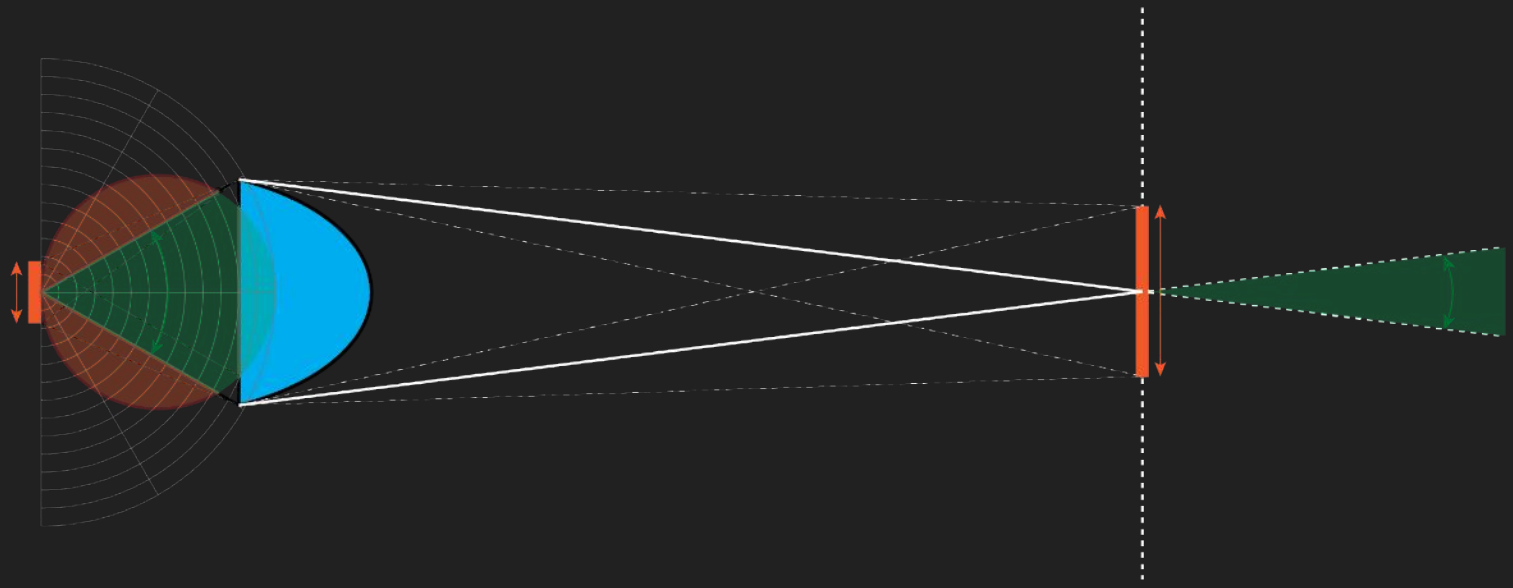


LOW COSTS

COMPACT / SLIM SIZE

Efficiency and flux vs. package size

THE ETENDUE PROBLEM

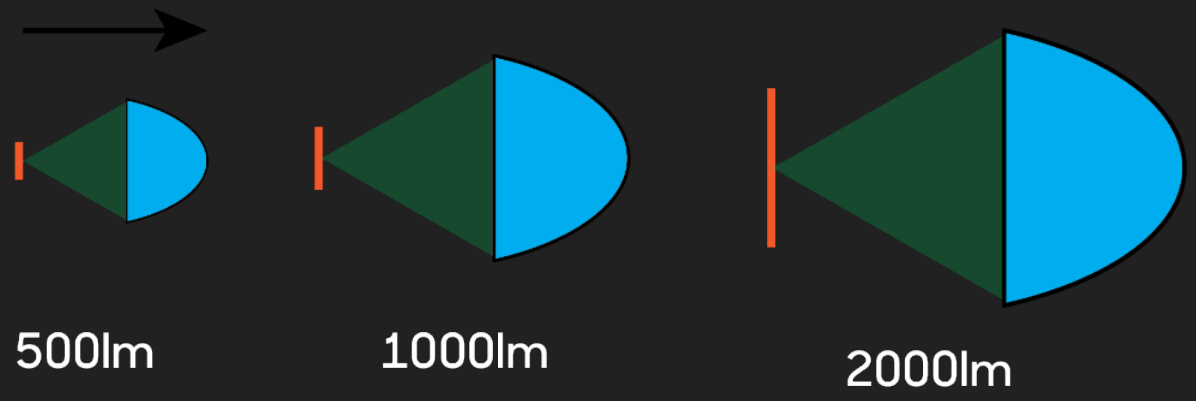


The product of the source size and divergence angle (without losses)
is a conserved quantity called "brightness"

Efficiency and flux vs. package size

THE ETENDUE PROBLEM

To increase the luminance of a Projector with a fixed brightness of the light source, optics need to grow in all dimensions:



How to make it compact?

- Reduce source size, divergence or both
- Use multiple sources (like in array headlight)

High Flux LED → High Luminance LED → LASER

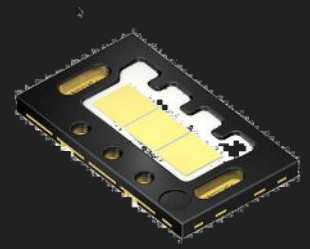


Image from OSRAM

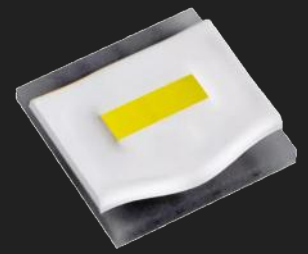


Image from NICHIA

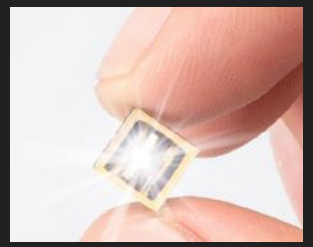
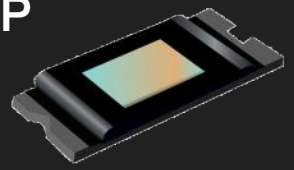
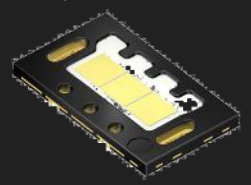
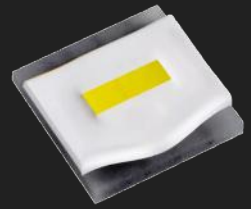
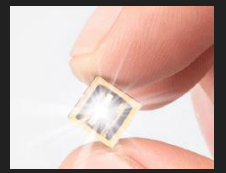
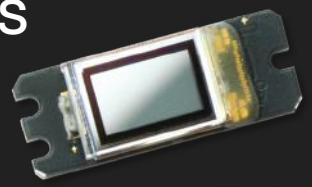
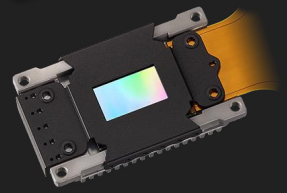
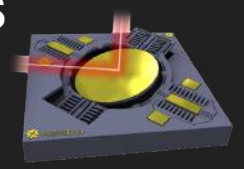


Image from KSLD

Light source and beam shaping element

LIGHT SOURCE

BEAM SHAPER

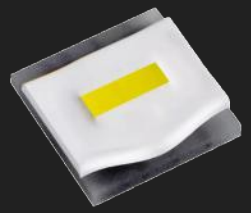
	High Flux LED	High Luminance LED	LASER	Pixelated LED
DLP				
LCoS				
LCD				
MEMS				

Cost Complexity Performance Package

No external beam shaping

LED projector constraints

High Luminance LED + DLP



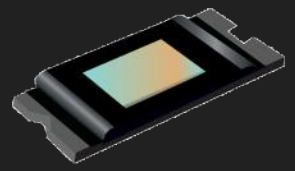
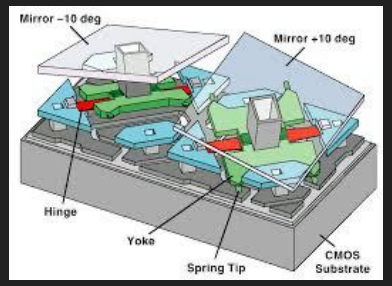
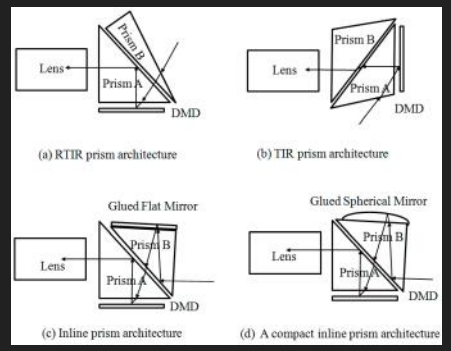
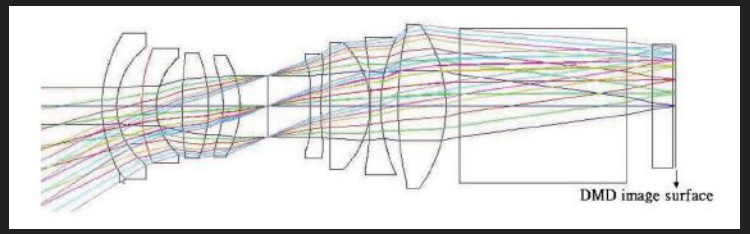


Image from Texas Instruments





Photonics 2023, 10(5), 559;
https://doi.org/10.3390/photonics10050559



Physics Procedia 19 (2011) 301–307

Pros

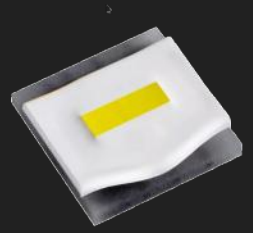
- Automotive DLPs and drivers commercially available
- Good contrast and resolution

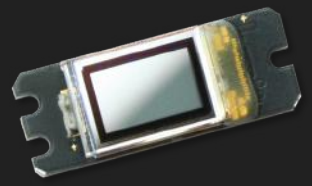
Cons

- Complex optical system
- Single source for DLP and electronics → cost, risk, …
- High intensity DLP headlights require a high surface area of the DLP chip and high luminance to achieve high performance
- Luminance/Flux limit from one LED chip
- → Difficult to achieve high intensity ADB system

LED projector constraints

High Luminance LED + Liquid Crystal





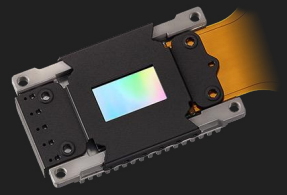
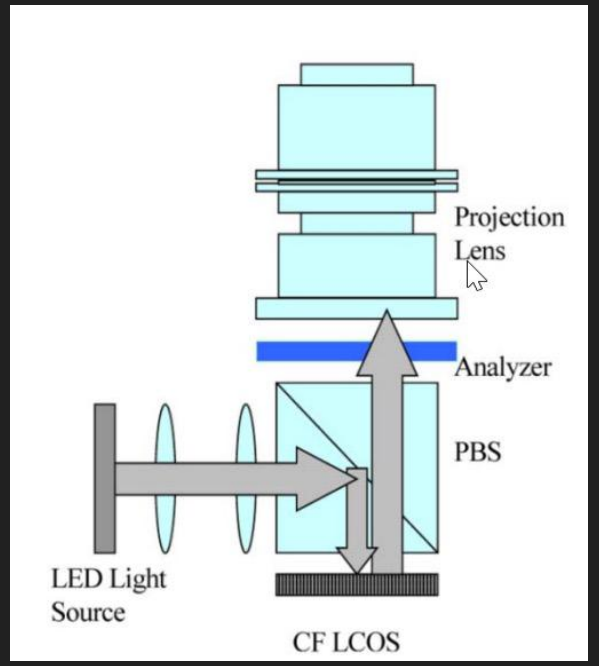


Image from Sony and Omnivision



Yu et. Al.: LED based projection systems

Pros

- No moving parts
- Large LCoS/LCD more cost effective than DLP
- Good contrast and resolution possible
- LCoS with integrated drivers available (low complexity for electronics)

Cons

- Achieving good Polarization contrast for small #F number difficult
- Polarization light recycling needs complex optical system or high loss without
- Temperature operating range and lifetime constraints of LCoS requires sophisticated thermal management
- Limited supply base for automotive LCoS

Pixelated LED

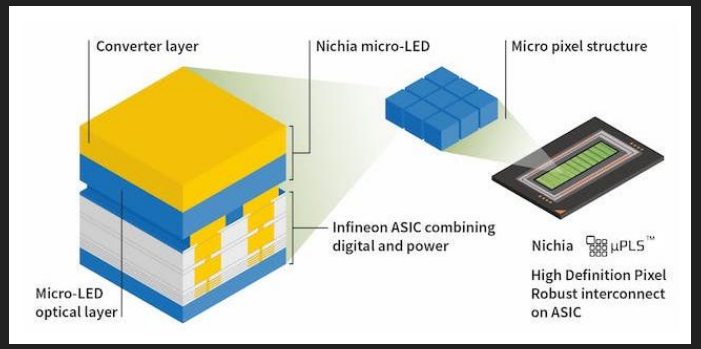


Image from Nichia

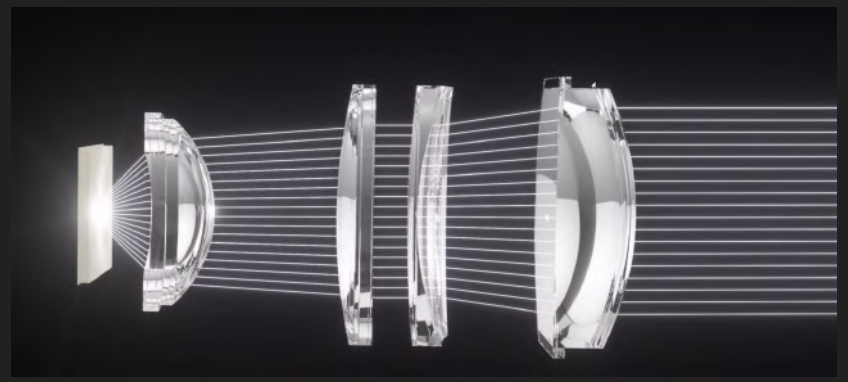


Image from Porsche AG

Pros

- No moving parts
- Fairly simple optical system
- Available toolchain for software and electronics

Cons

- Ultra low #F number needed → either complex design or reduced performance (aberrations, transmission,…)
- Fairly low luminance of light emitting source (<100cd/mm²) → Big aperture or multiple modules needed
- Granularity of phosphor limits resolution
- Contrast and resolution limited by scattering in phosphor and back scattering of optics
- Aberrations problematic to solve without high lens count (low #F)
- Low resolution
- Difficult thermal management

Adaptive laser headlights

Laser beam shaping before phosphor conversion to increase efficiency

MEMS Scanner

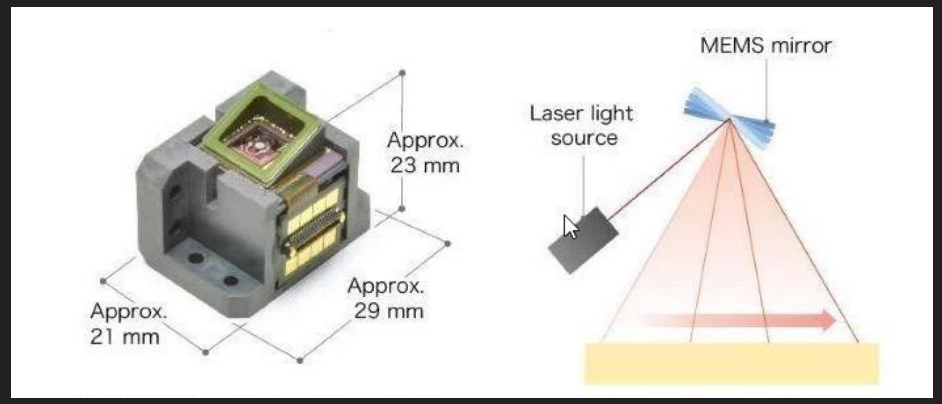
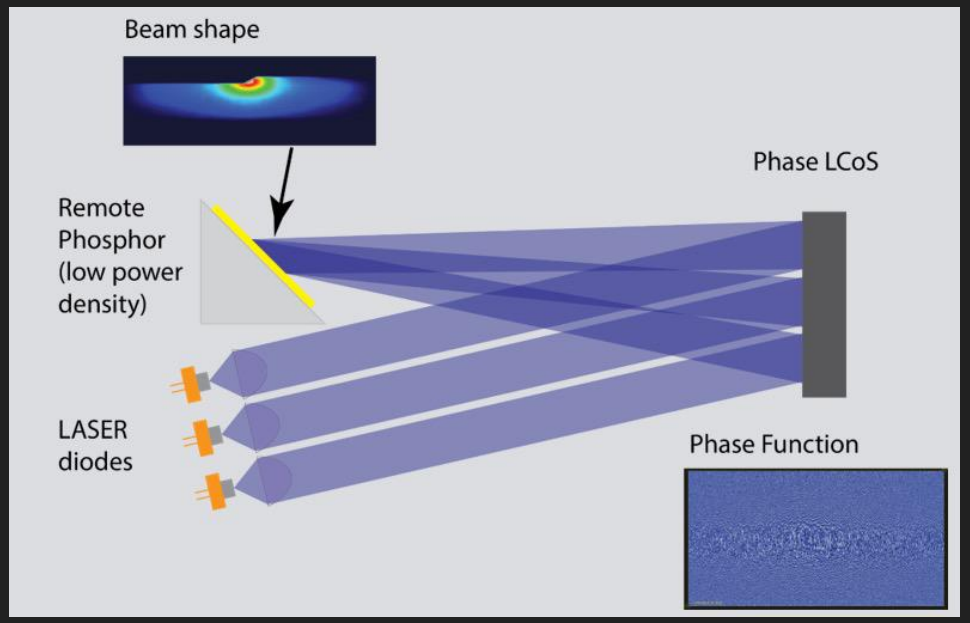


Image from Hamamatsu Photonics Europe

Diffractive beam shaping



Patent Eckstein et al. WO2017178266A2

Pros

- High E/O efficiency from blue phosphor away from heat
- Ultra High Luminance possible
- Small form factor of light output surface
- Possible to add other wavelengths

Cons

- Ultra low #F number needed → either complex design or reduced performance (aberrations, transmission, resolution,…)
- Granularity of phosphor limits resolution, contrast limited by scattering in phosphor
- Complex optical design, high cost (Laser Diode, Phase LCoS or MEMS)
- High computational effort to compute beam pattern

High performance ADB with external beam shaping

How to achieve >100kcd with pixelated headlights?

Pixel LED systems need to add a dedicated module to boost the hot spot (due to limited luminance)

Big light source, long focal length → Big optical system

Image from Porsche AG

High luminance sources:

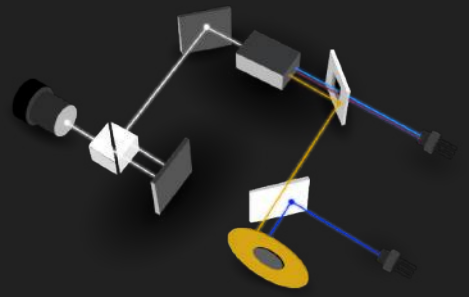


Image from Appotronix

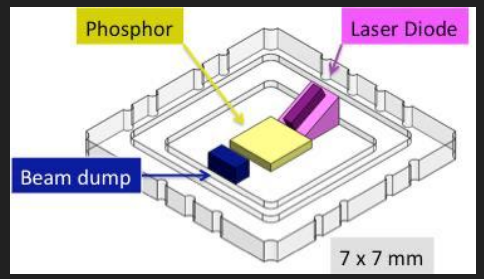


Image from Kyocera SLD Laser

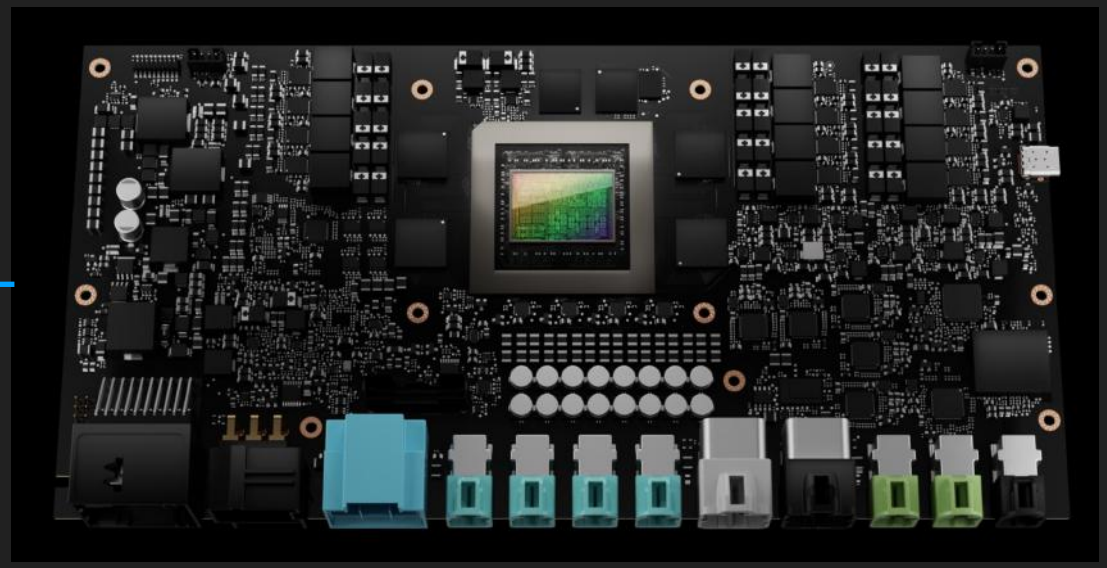
Opportunities: A pixel headlight is a display

Pros

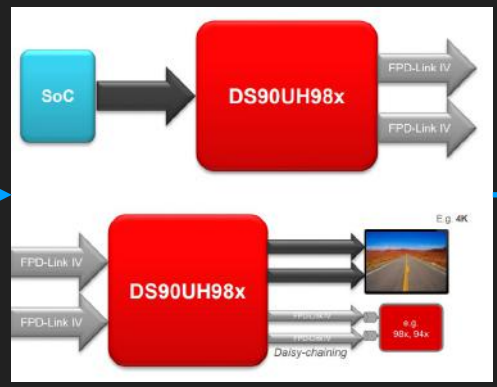
- Usage of high-performance GPU based algorithms are state-of-the-art in infotainment and ADAS
- ADB image data can be computed with low latency and high resolution in ADAS ECU
- No data passing through different ECUs (speed, bandwidth)
- No dedicated SoC and software in headlamp controller needed

Cons

- Cost of wiring (coax) and connectors
- Cost of electrical components
- Challenges for ASIL requirements



Source: NVIDIA



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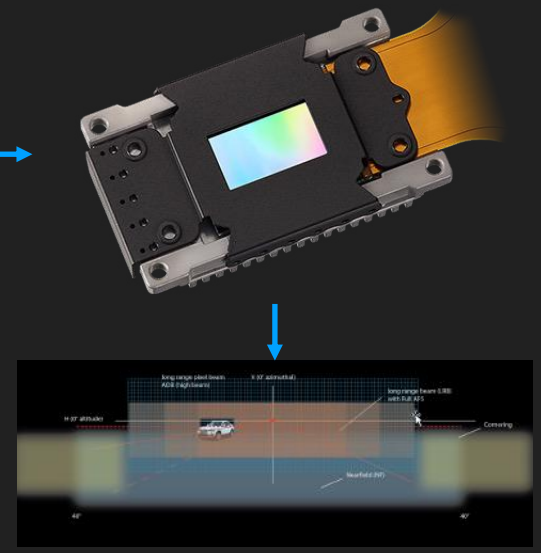

Future headlamps will be digital projectors

- Benefits will:
  - Higher safety and visibility
  - Reduction in package size
  - Reduction of BOM and mechanical elements
  - More use cases and features
  - Easy adjustment to regulations and markets even with OTA/Geofencing

- Challenges remain
  - Light source luminance and flux
  - Optical System (lots of R&D to come ☺)
  - Cost for beam shaping elements, special light sources and electronics


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