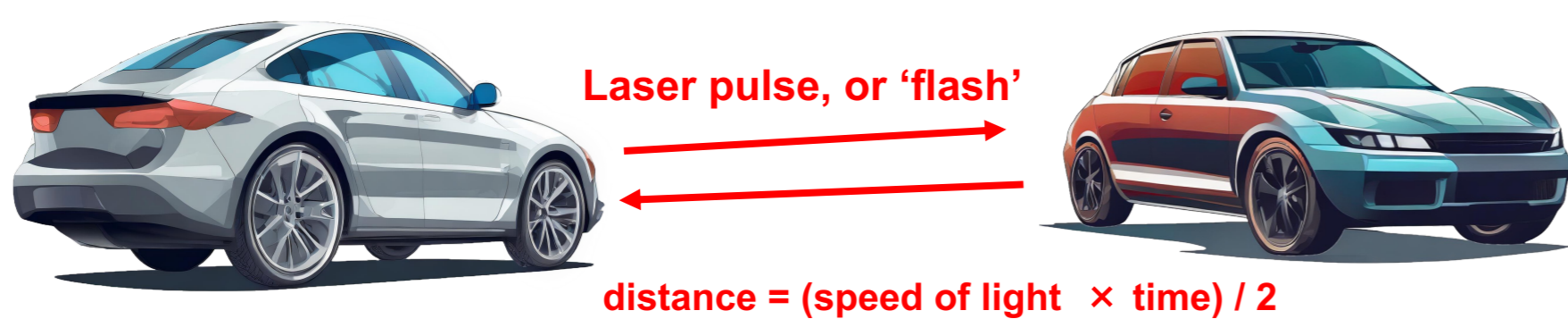
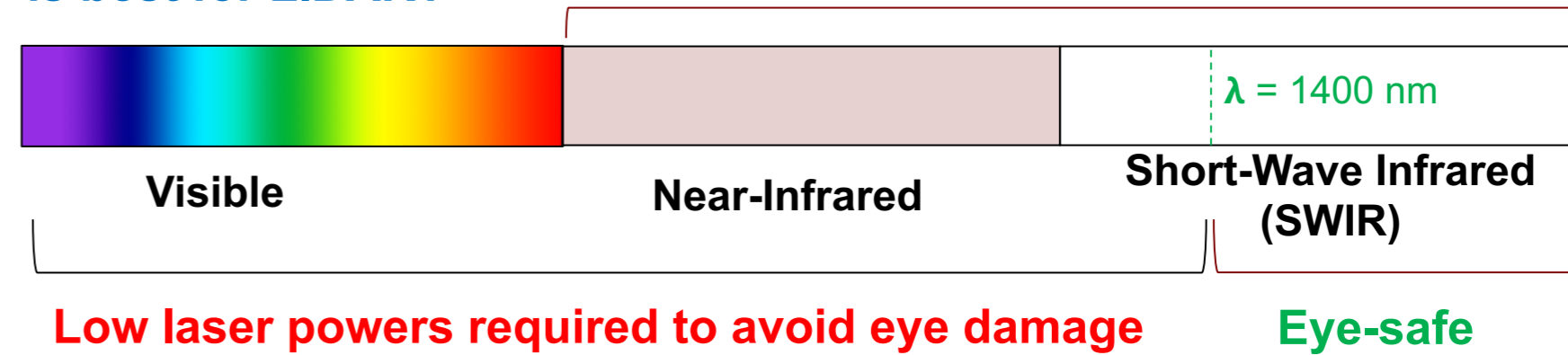


## Light Detection and Ranging (LIDAR)

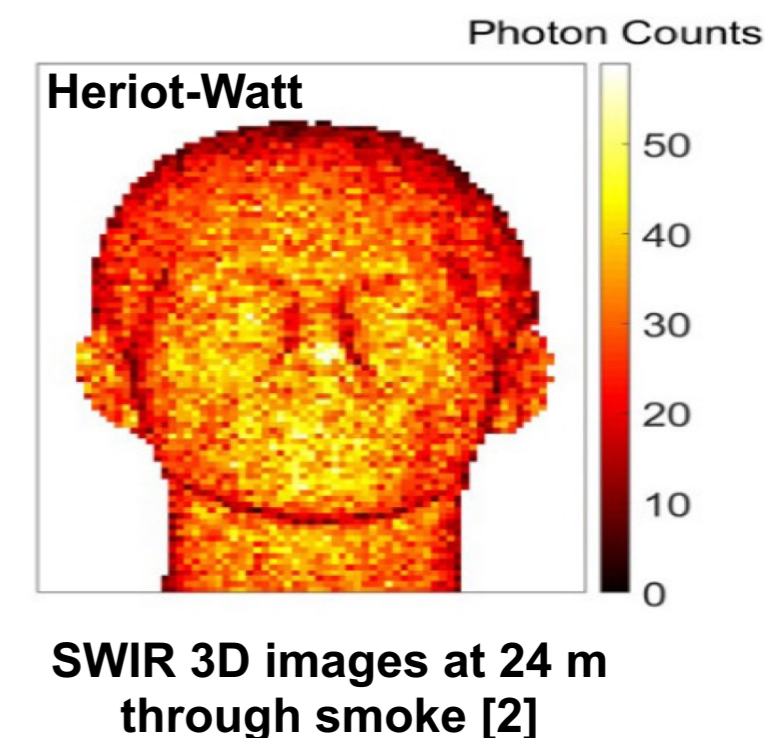


- Accurate timing of a pulse of laser light (to and from object) allows distance to be calculated and 3D maps to be generated.
- 3D vision enables 'connected & autonomous vehicles' (CAVs) e.g. 'driverless cars', or advanced safety for collision avoidance in vehicles.
- CAV technologies alone predicted to be large UK market (£6.4 bn by 2035). [1]

Which colour (wavelength) of light is best for LIDAR?



- Short-wave infrared (SWIR) wavelengths > 1400 nm:
  - Eye-safe
  - Higher permitted laser powers means longer range LIDAR
  - Can image through smoke/fog
  - Resilient in poor weather
  - Enables CAVs to see further down the road and predict danger



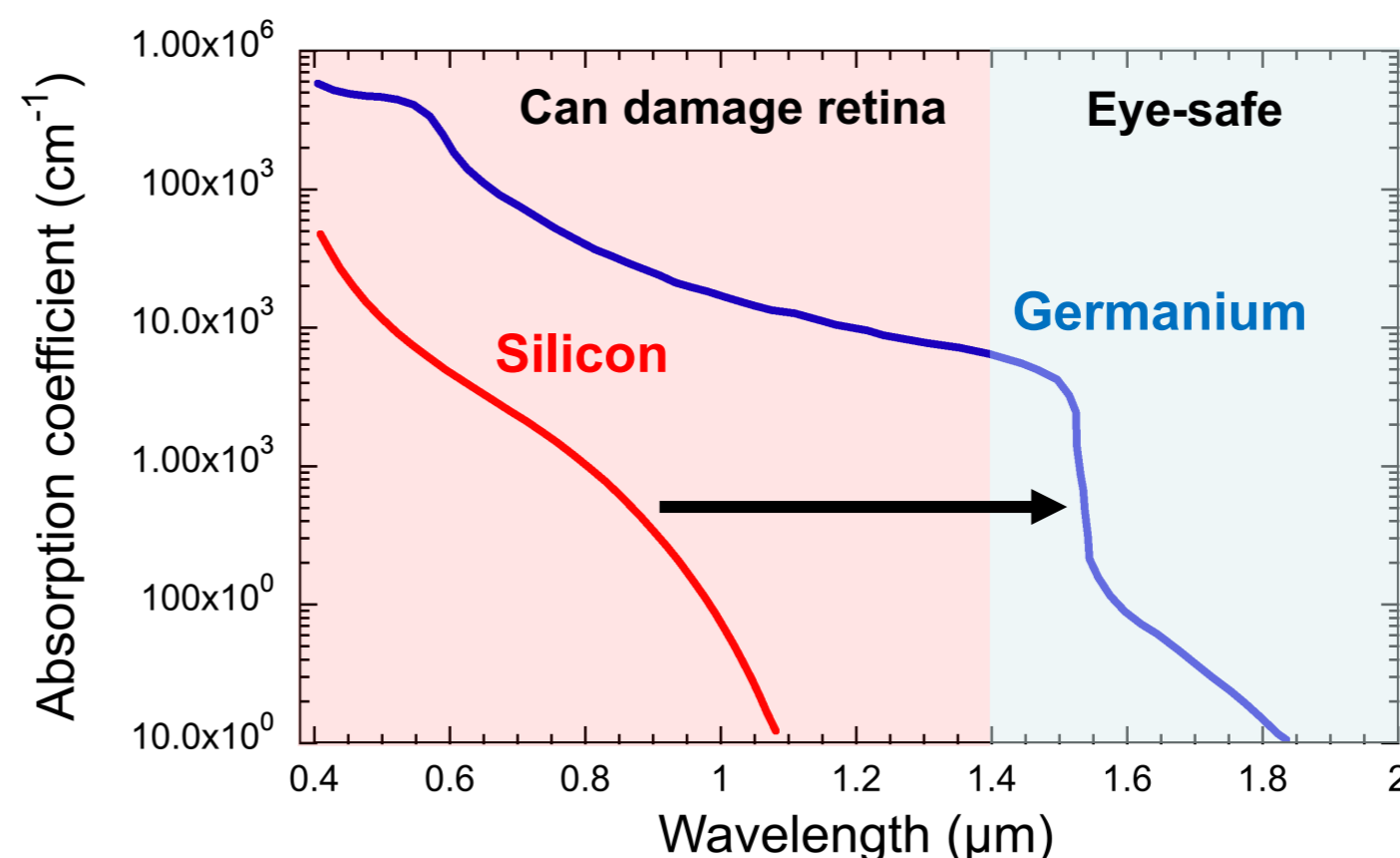
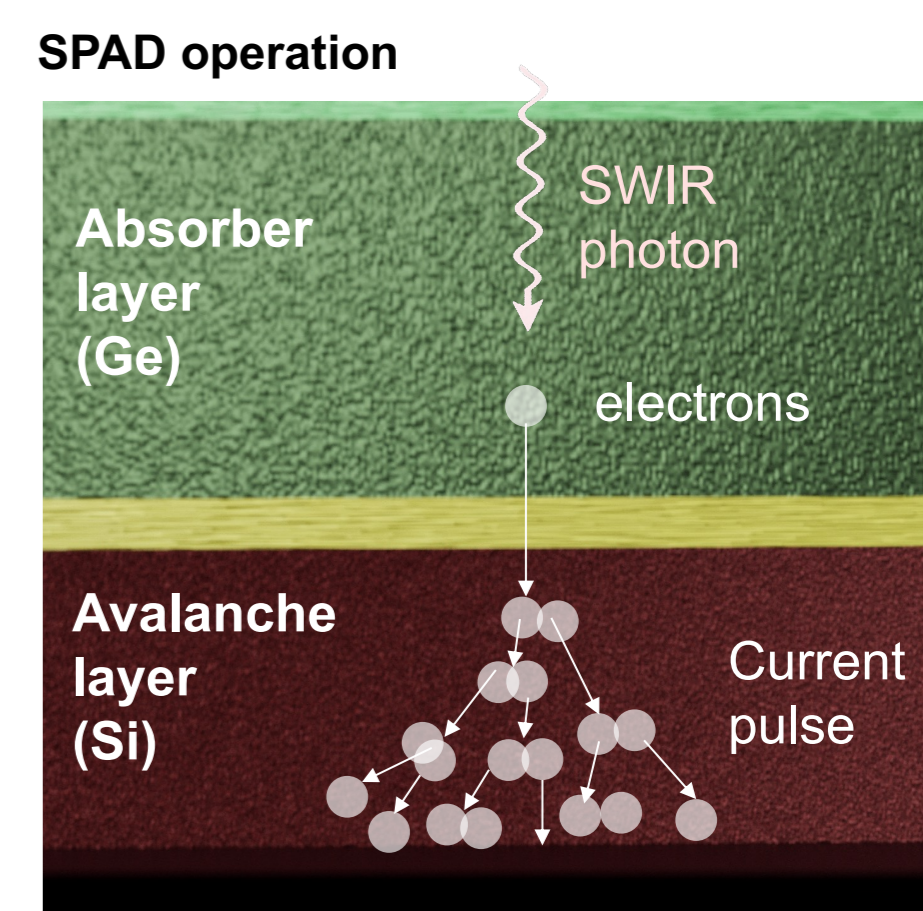
## Detectors for LIDAR

- Single photon avalanche diode (SPAD) detector
- Semiconductor sensor that can accurately time the arrival photons (or quanta) of light
- Excellent for LIDAR

Group IV materials

- **Problem:** Current SWIR SPAD technology is prohibitively expensive
- **Solution:** Use materials compatible with Si foundry processing (used to make computer chips) → Cheaper!
- Extend absorption of Si SPAD technology into the Short-Wave Infrared using Ge absorber layers

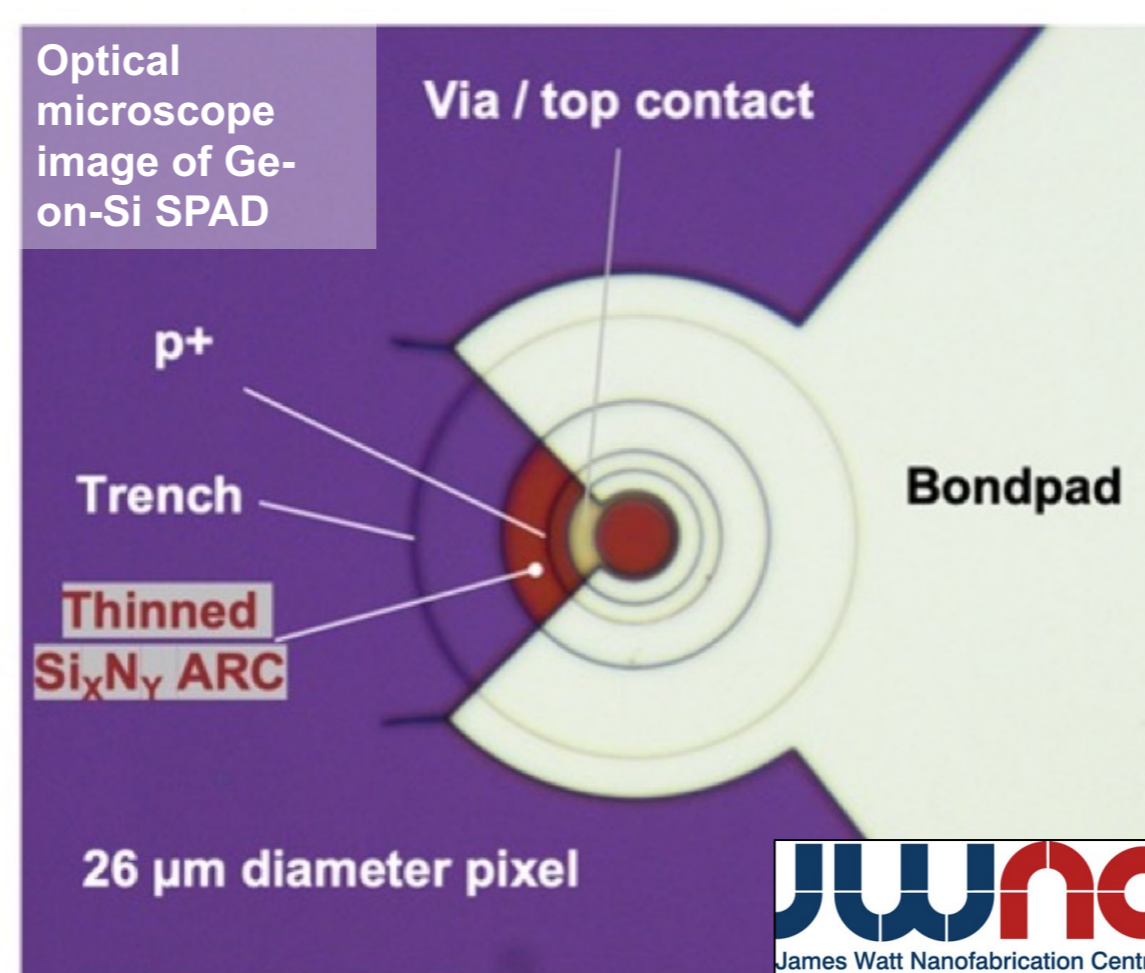
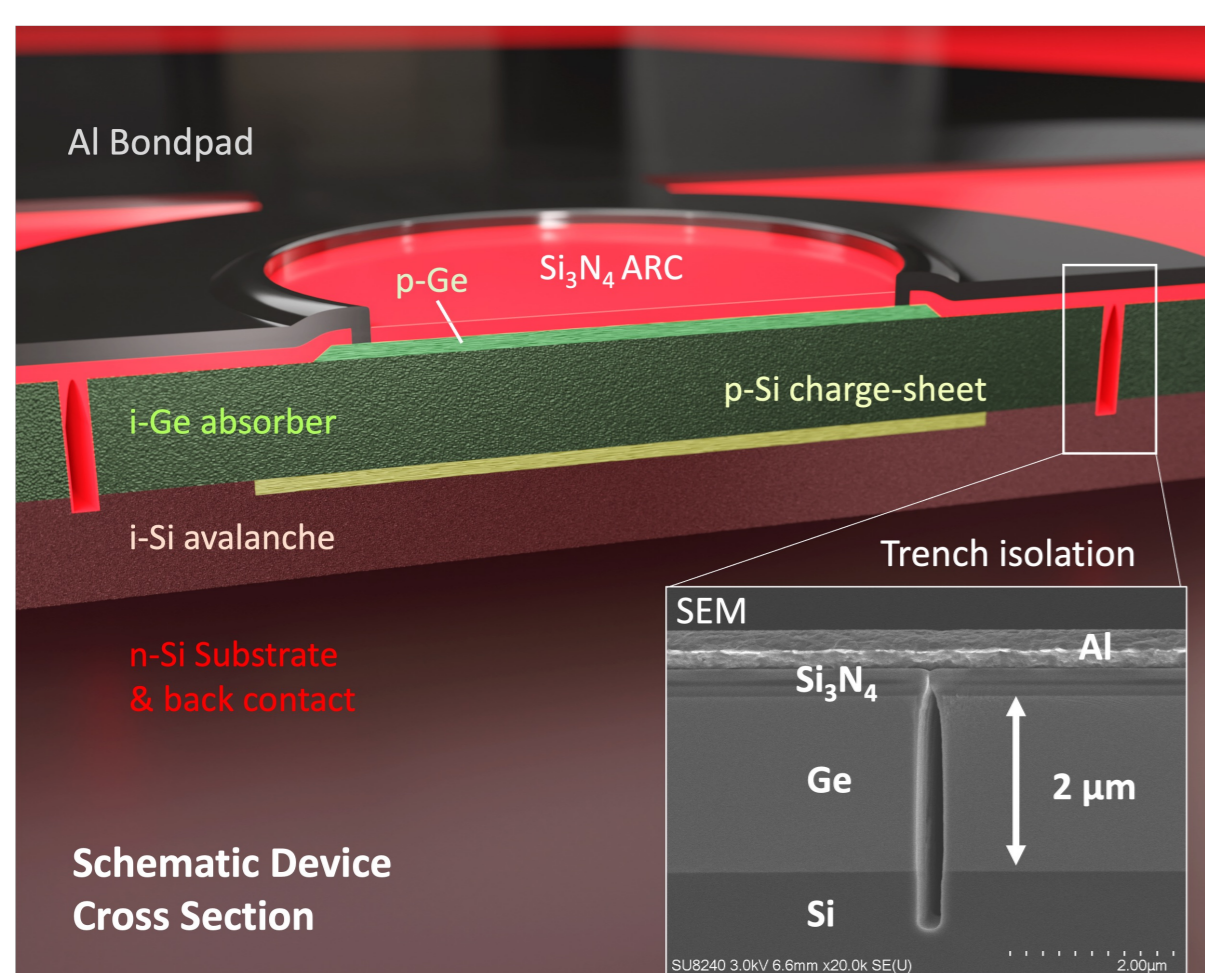
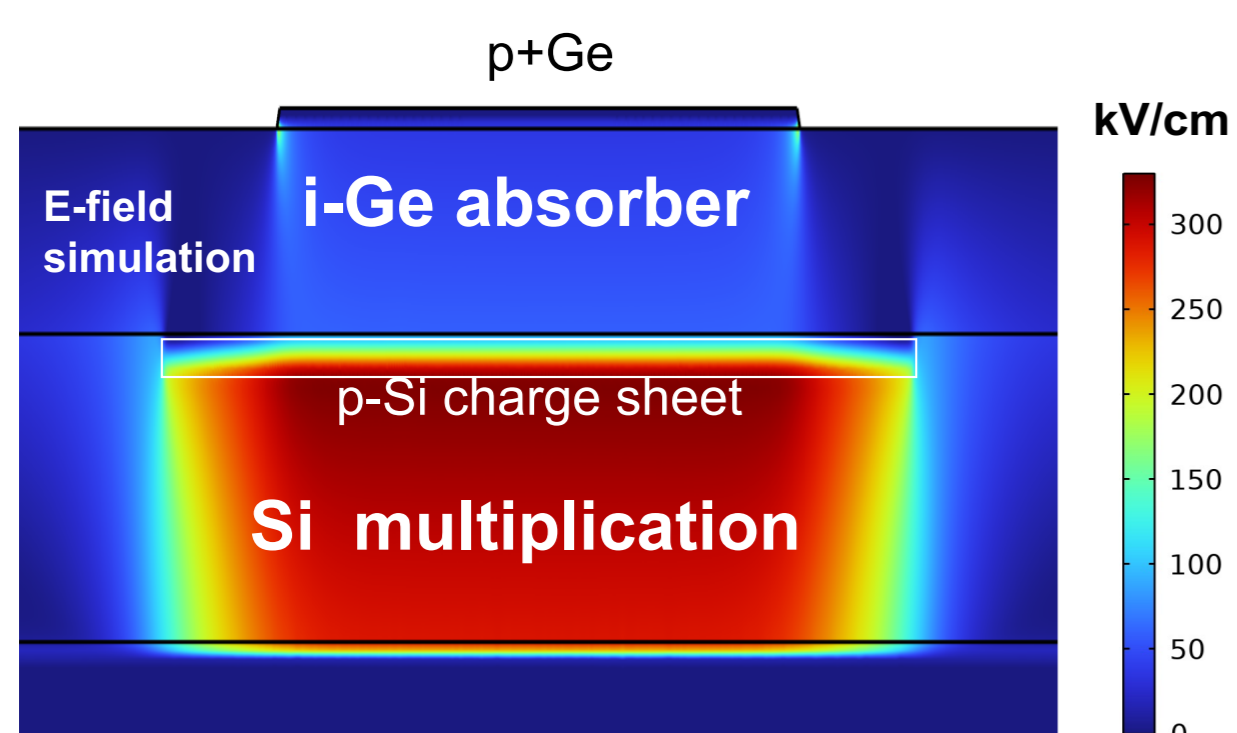
- Absorbed light (photon) gives energy to an electron in absorber layer
- High voltage across avalanche layer gives electron kinetic energy
- Causes avalanche of electrons → current pulse that can be very accurately timed



- Ge can be grown on top of Si, in Si foundries
- Ge absorbs at SWIR wavelengths → allows eye-safe lasers to be used for LIDAR

## Ge-on-Si SPADs: Design & Results

- Developed a patented SPAD design that reduces 'false-counts' [3,4]
- Decouples sensitive region from defective material (isolation trenches)
- Devices 100X more sensitive than previous Ge-on-Si SPADs [5]
- LIDAR demonstrated → 3D map of model car measured (below) [6]



- Sensitivity to single photons, and SWIR operation leads to long range, robust LIDAR systems
- Ge-on-Si SPADs are compatible with Si foundry processing, and can therefore be significantly lower-cost than current technology
- Record performance for Ge-on-Si SPADs has been demonstrated with new design
- LIDAR demonstrated in laboratory conditions using eye-safe lasers
- With optimisation, this technology is suitable for mass-markets such as autonomous vehicle LIDAR

### Funding



### References

- [1] Connected Places Catapult Market Forecast
- [2] R. Tobin et al., *Opt. Exp.* 27, 4590 (2019)
- [3] P. Vines et al., *Nature Comms.* 10, 1086 (2019)
- [4] GB Patent application no. 1814688.6 (10<sup>th</sup> September 2018)
- [5] L. Ferre-Llin et al., *Opt. Letters* 45 (23), 6406-6409 (2020)
- [6] K. Kuzmenko et al., *Opt. Exp.* 28, 1330 (2020)