

Extended range SWIR imaging with C-RED 2 ER

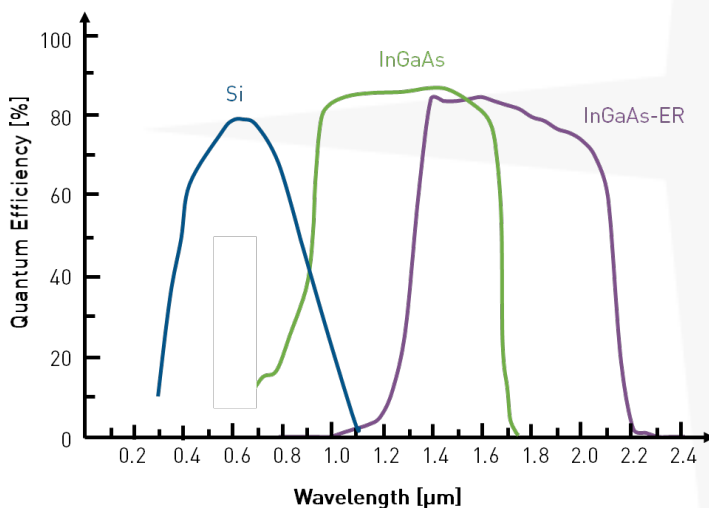
C-RED 2 ER is a highly sensitive extended short wave infrared (1300 nm – 2200 nm) camera. It is based on a VGA (640x512 pixels) ER-InGaAs detector array and offers framerates up to 600 Hz. This camera is a real breakthrough, as it is the only one with such technology on the market. It opens new imaging and sensing opportunities for life science, defense, laser measurements, and industrial applications.

This note is an introduction into the world of C-RED 2 ER.

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1. What is extended range?

Extended wavelength InGaAs



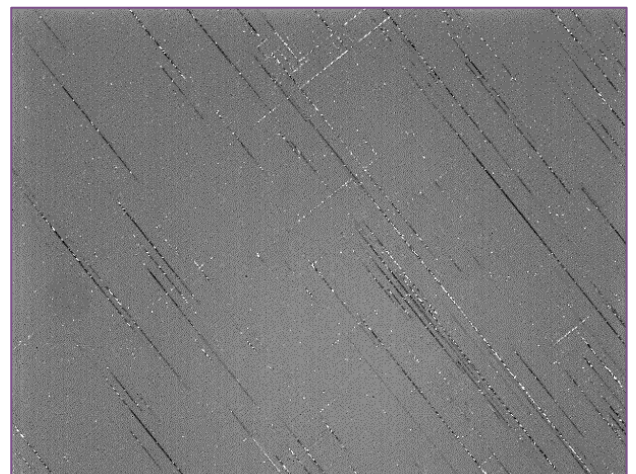
Comparison of the quantum efficiency curves for cameras based on Silicon, InGaAs and InGaAs-ER (typical values).

InGaAs material absorbs light in the short wave infra-red spectrum and can be used as an optical detector in this range. Standard InGaAs-based detectors have a long wavelength cutoff of 1700 nm. They are fabricated by growing a crystalline layer of InGaAs on an indium phosphate (InP) substrate. In this case, the substrate has the same lattice constant as the alloy resulting in lattice-matching.

The sensitivity of InGaAs can be extended to higher wavelengths (up to 2.5 µm). Introducing more indium into the ternary compound decreases its bandgap and hence enables the detection of longer wavelengths. $\text{In}_x\text{Ga}_{1-x}\text{As}$ with a longer cutoff is called "extended wavelength InGaAs."

Consequences on image quality

However, changing the composition of a ternary compound (InGaAs) will also change the lattice constant of the material. Adding a little more InAs increases the lattice constant of the thin film, which causes a mismatch with the substrate, reducing the quality of the thin film. Lattice mismatching means more crystal structure defects, leading to raw images of poor quality. Until now, this has prevented extended SWIR imaging from becoming more widespread.



*Raw image acquired in dark condition.
Acquisition parameters: medium gain, 600 fps, integration time 1.66 ms.*

2. C-RED 2 ER camera

C-RED 2 ER is part of the C-RED range of cameras.

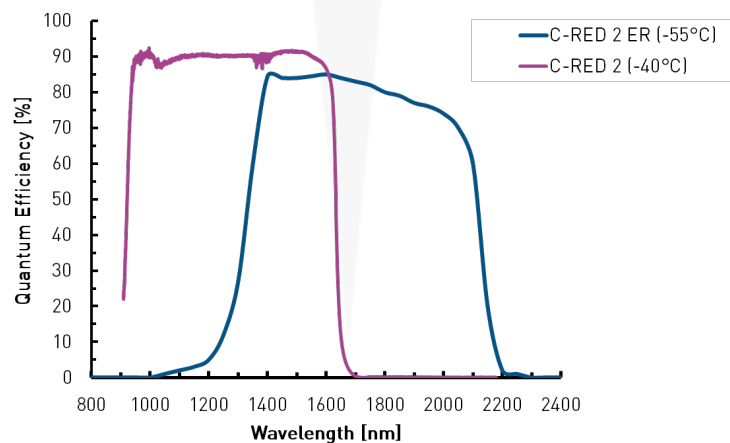


C-RED 2 ER camera

Why choose C-RED 2 ER?

- **Extended SWIR range.** C-RED 2 ER is sensitive in the spectral range of 1200 to 2150 nm, which constitutes a shift compared to standard InGaAs based detectors. This enables C-RED 2 ER to target new applications!
- **Specific factory-built correction map.** The defects on the sensor, specific to extended range detectors, are corrected on-the-fly, offering very high image quality. The correction file is built by First Light Imaging.
- **On-the-fly corrections.** In addition to the factory-built correction map, bad pixel correction and a two-point Non-Uniformity Correction (bias and gain) can be applied in real-time.
- **Easy integration.** The camera can be easily integrated in a system thanks to the mechanical interfaces on each side, and has a C-mount optical interface. C-RED 2 ER is supported by our software First Light Vision. Additionally, thanks to a versatile SDK, the camera can be interfaced with MatLab, LabView *etc.*

C-RED 2 ER is complementary to C-RED 2 in terms of sensitivity as it covers the high end of the SWIR spectrum.



C-RED 2 and C-RED 2 ER cameras quantum efficiency curves

How can you control C-RED 2 ER?

- ❖ C-RED 2 ER is integrated in First Light Vision, the **Graphical User Interface (GUI)** developed for all C-RED and C-BLUE cameras. It is compatible with both USB and CL interfaces and is cross-platform (x86 / ARM, Windows/ Linux). It is user friendly, allowing easy controlling, and offers multiple functionalities for higher end usage.
- ❖ To help programmers develop their own interface for C-RED 2 ER, the **Software Development Kit (SDK)** provides source codes for short demos in C/C++, Labview, Python and MatLab. C-RED 2 ER can also be controlled using Micro Manager.

3. Imaging with C-RED 2 ER

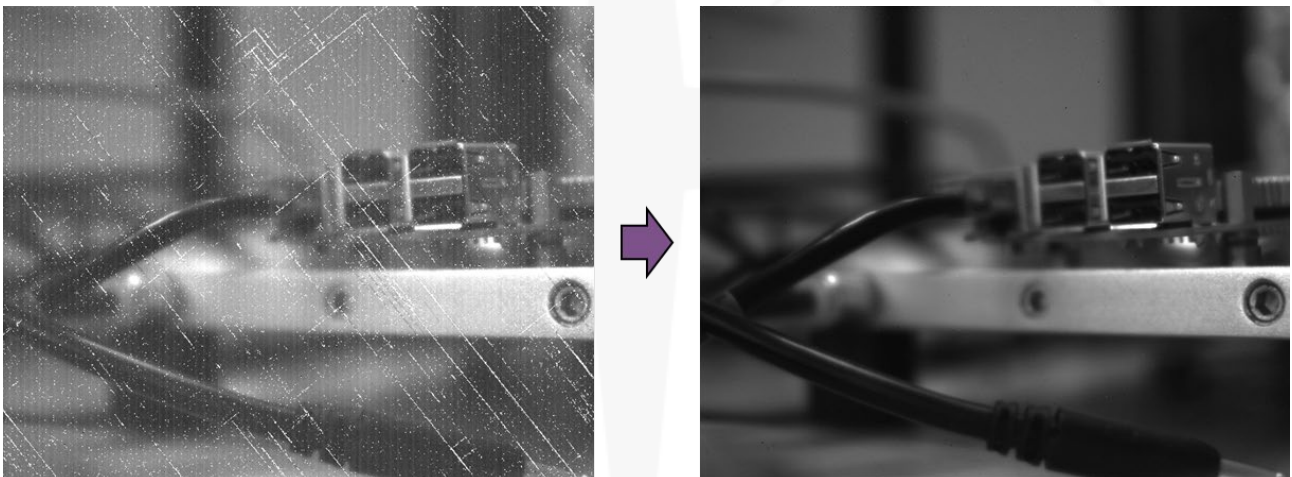
To get the best imaging experience, First Light Imaging recommends using the C-RED 2 ER camera at -55°C with the built-in correction maps to correct for the lattice mismatch artefacts which corrupt the raw images.

Cooling down C-RED 2 ER

Sensor temperature for C-RED 2 ER can be set anywhere from ambient temperature to -55°C . Temperatures up to -15°C can be stabilized using air cooling only, while lower temperatures require using a liquid chiller. Cooling down the sensor optimizes the dark current and hence the performances of the camera. You can refer to the note "[C-RED 2 : long exposure time optimizations](#)" for more information.

On-the-fly image optimization

First Light Imaging has developed a specific on-the-fly correction process to compensate the lattice mismatch artefacts of the extended range detector. The process corrects the image in real-time and can be applied to all gains and a large range of integration times. Importantly, the user has access to the image at all the steps of the process, including the initial raw image.



*Electronic board illuminated with ambient light. Before and after applying the full correction process.
Acquisition parameters: medium gain, 300 fps, 3.33 ms integration time.*

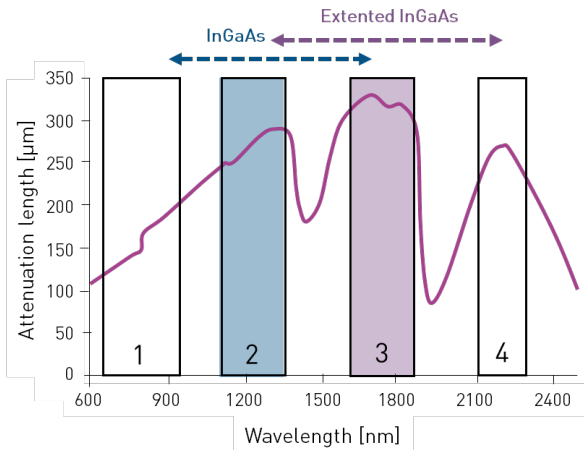
- ❖ With the corrections applied, C-RED 2 ER has a very high experimental operability ($> 98\%$ at 600 FPS).
- ❖ The corrections are applied with no degradation of the image spatial resolution.
- ❖ All the corrections are based on physical models. The corrected image yields full physical meaning and can be used for quantitative measurements.
- ❖ The entire correction process is applied on-the-fly without any loss of speed or restriction on framerate.

C-RED 2 ER enables high performance scientific imaging in the extended SWIR range (up to 2150 nm). The raw image is available. Alternatively, lattice mismatch artefacts can be corrected on-the-fly.

4. Why going “extended range”?

Extended range InGaAs opens new perspectives in applications that require the detection of light with wavelengths further than the 1700 nm limit of standard InGaAs. Here is a short overview of some of the applications of C-RED 2 ER.

Life science and medical



Transmittance in brain tissue of 200 µm thicknesses. Four optical windows are identified. The third window can be exclusively detected by extended range cameras.

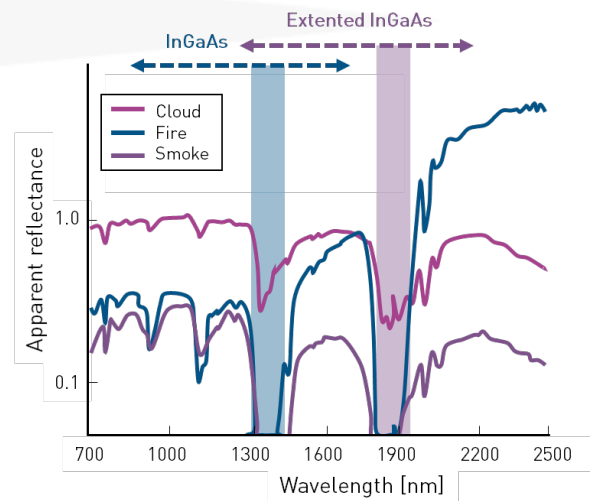
The first optical window (650 – 950 nm) has been widely used for clinical and preclinical fluorescence imaging. More recently, cameras sensitive to the NIR-II range have enabled to target the second optical window (1100 – 1350 nm). It is now used for *in vivo* small animal imaging and more recently for clinical applications. You can refer to the application note [“in vivo NIR-II Small animal imaging with C-RED 2”](#) for further information.

Two more optical windows exist: the third (1600 – 1870 nm) and the fourth (centered at 2200 nm). The third window optimizes the scattering and absorption of tissues, hence the penetration of light in tissues¹. It is ideal for deep brain imaging. Other applications such as Optical Coherence Tomography (OCT) will also benefit from the longer penetration depth of light.

Defense, surveillance & security

Day and night vision in foggy weather conditions is a major concern for surveillance applications. Visible imaging has low performances in these conditions. Two major windows exist in the SWIR range for imaging through clouds and smoke: 1350 – 1400 nm and 1850 – 1900 nm.

In military applications, extended range sensors are extremely interesting as they are capable of imaging light that cannot be seen by current night vision technologies. This permits to see “invisible” lasers that are currently being used on the battlefield.



Reflectance spectra. Two windows are identified to “see through” various weather conditions.

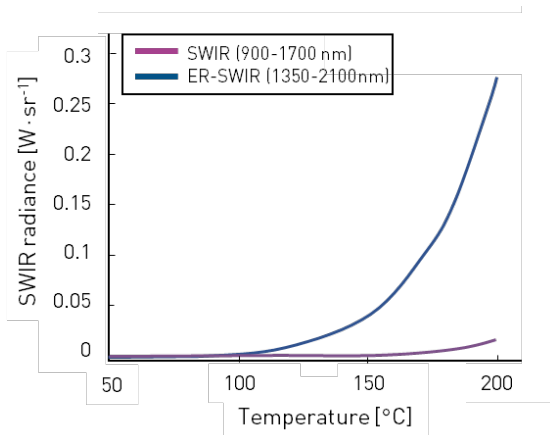
Free-Space Optics (FSO)

Optical transmission in free space is influenced by disturbances such as fog, dust, and atmospheric turbulence. The use of the SWIR band (0.9 µm – 1.7 µm) has been shown to be extremely pertinent because of their ability to penetrate through obstacles such as fog or some types of plastics. The use of longer wavelengths combined to band path filters will likely optimize the penetration. Eye-safe lasers exist in both SWIR and ER-SWIR bands enabling the use of these wavelengths for free space communications. On this topic you can refer to the application note [“Free Space Optical communications with C-RED 3”](#). C-RED 2 ER can be used as the wavefront sensor in an adaptive optics loop, for example.

Optimized optical transmission is a major asset for:

- ❖ Ground-based astronomical observation
- ❖ Free space optical communications

Thermography



As a general rule, the error on a temperature measurement is higher for higher temperatures at longer wavelength. Hence, the SWIR and ER-SWIR ranges are better than MWIR or LWIR at temperatures within the range 300°C to 1600°C. ER-SWIR, contrary to SWIR enables measurements at temperatures below 300°C thanks to the higher radiance.

Thermography has many applications, examples include:

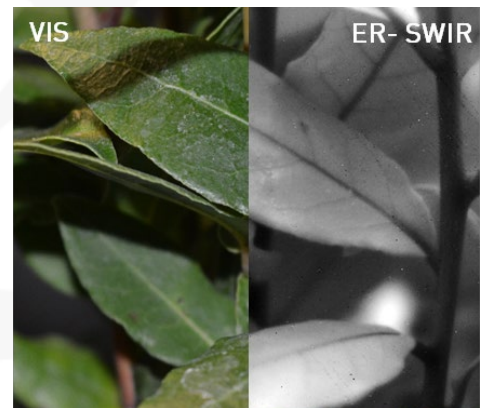
- ❖ Non-contact measurements on hot glass
- ❖ Molten metal monitoring in additive manufacturing applications.

Theoretical radiance of a black body at low temperature integrated over the SWIR and ER-SWIR spectral ranges.

Agriculture and food inspection

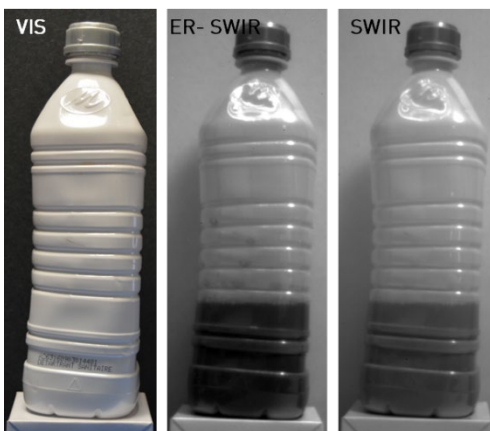
Water has four absorption bands within the infrared region, at wavelengths 1200 nm, 1450 nm, 1940 nm and 2950 nm. Measuring the absorption of thin food slices or foliage at these wavelengths enables to quantitatively determine their water content². On thicker objects, such as fruits and vegetables, the absorption properties allow to detect moisture or defects that are imperceptible in the visible range (by the naked eye). This is particularly useful for food sorting applications and observation of crop fields.

Visible versus ER-SWIR images of bay leaves.



Laser and LiDAR applications

SWIR and longer wavelength are interesting because they are invisible to the human eye. Hence, lasers in these ranges find numerous applications. One is LiDAR, which enables distance measurement by measuring the reflection of laser light. LiDAR systems often use lasers that emit light with a wavelength of 2.05 μm, which is beyond the detection limit of standard InGaAs. C-RED 2 ER can also be used for laser beam characterization and optical power measurements.



And many more...

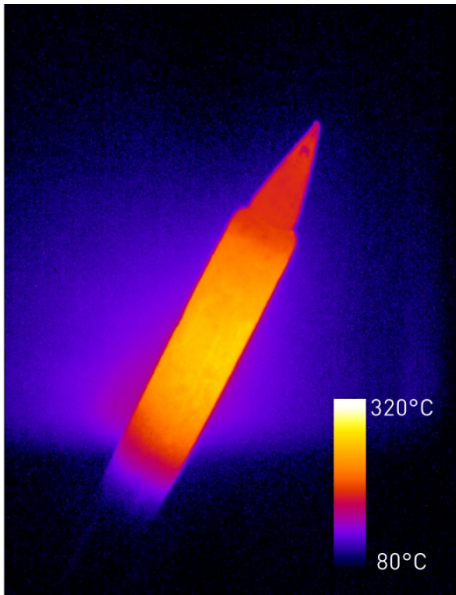
- ❖ Gas sensing
- ❖ Raman spectroscopy
- ❖ Hyperspectral imaging
- ❖ ...

Visible versus SWIR and ER-SWIR images of a plastic bottle filled with water. The bottle is opaque in the visible range, while ER-SWIR increases the contrast compared to SWIR.

Take-home message

Imaging in the SWIR extended range is an entirely new field of research. C-RED 2 ER is a key asset to push the doors of outstanding applications wide open!

5. Conclusion



Thermal imaging with C-RED 2 ER of a soldering iron tip heated at 250°C.

C-RED 2 ER is a state-of-the-art camera, the only one using a 640 x 512 extended range InGaAs detector. It is designed for demanding applications. At First Light Imaging, we believe that C-RED 2 ER is opening an entirely new field of research in multiple domains, ranging from astronomy to agriculture.

C-RED 2 ER enables high quality sensing at extremely fast framerates (up to 600 FPS) and short integration times. To answer your needs the camera can output a completely raw image or a corrected one. The ER-specific correction process that is implemented is based on the physics of detectors and optimizes your acquisition in real-time without losing either resolution or physical meaning of the image. Thanks to these different acquisition modes, C-RED 2 ER is very flexible and perfectly suited for numerous applications.

6. Bibliography

- (1) Shi, L.; Sordillo, L. A.; Rodríguez-Contreras, A.; Alfano, R. Transmission in Near-Infrared Optical Windows for Deep Brain Imaging. *J. Biophotonics* **2016**, *9*(1-2), 38-43. <https://doi.org/10.1002/jbio.201500192>.
- (2) Mesic, M.; Corluka, V.; Valter, Z. Analysis of Some Parameters Influencing Moisture Quantity Measurements in Wheat with NIR Technique. In *2005 18th International Conference on Applied Electromagnetics and Communications*; IEEE: Dubrovnik, Croatia, 2005; pp 1-4. <https://doi.org/10.1109/ICECOM.2005.204959>.

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