COOLING SWIR SENSORS

AN OVERVIEW

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Dark current is a critical parameter when one is looking to acquire a scientific imaging camera, especially in the short-wave infrared (SWIR) region. Very careful attention must be paid to the cooling method used to optimize this parameter.

Multiple cooling technologies are available, each having certain benefits and drawbacks. In its new ZephIR line of SWIR cameras, Photon etc. uses a four stage thermoelectric (TE4) air-cooled system to enhance the sensitivity of its imaging sensors.

BECAUSE OF THEIR LONG LIFETIME AND RELIABILITY, TE COOLED CAMERAS ARE THE IDEAL TOOLS FOR INDUSTRIAL CONTINUOUS PROCESS CONTROL OR ANY OTHER APPLICATIONS IMPLYING NON-STOP CYCLES OF OPERATION.

The ZephIR 1.7 is an InGaAs camera sensitive in the 800 nm to 1700 nm range. The ZepIR 2.5 and 2.9 are HgCdTe cameras sensitive in the 0.85 µm to 2.5 µm and 0.85 µm to 2.9 µm ranges respectively. With their integrated TE4 air-cooled systems, these cameras reach an operating temperature of -80 °C and possess dark currents of 300 e^-/p/s s (ZephIR 1.7), 30 Me$^-$p/s (ZephIR 2.5) and 340 Me$^-$/p/s (ZephIR 2.9).

In this white paper, a short introduction to thermoelectric (TE) cooling is presented, as well as a comparison with other available cooling methods.

OVERVIEW OF COOLING METHODS

THERMOELECTRIC COOLING

Thermoelectric (TE) stages are solid-state devices composed of two differents faces. Those stages uses Peltier effect to generate a temperature difference between the two faces. Semiconductors with different electron densities, n-type and p-type (see FIG. 1), are placed in series and connected with a conducting material on each side. The passage of an electrical current through the junction induces a heat flow from one face to the other, creating a cold and a hot side. The cold face absorbs heat which is carried to the other side where the heat sink is located. TE stages are usually connected side by side and sandwiched in two insulators. Water or air cooling is typically used to dissipate the heat accumulated in this process.

The temperature that can be reached by TE coolers is related to the number of stages being used. Hence, for more effective cooling, it is possible to stack several stages. This is the case of Photon etc's SWIR sensors, where four thermoelectric stages are cascaded together to lower the temperature. With four stages, a ΔT* of 120 °C can be reached. This results in a detector operating temperature of -80 °C (193 K) with proper heat extraction, at 25 °C ambient temperature.

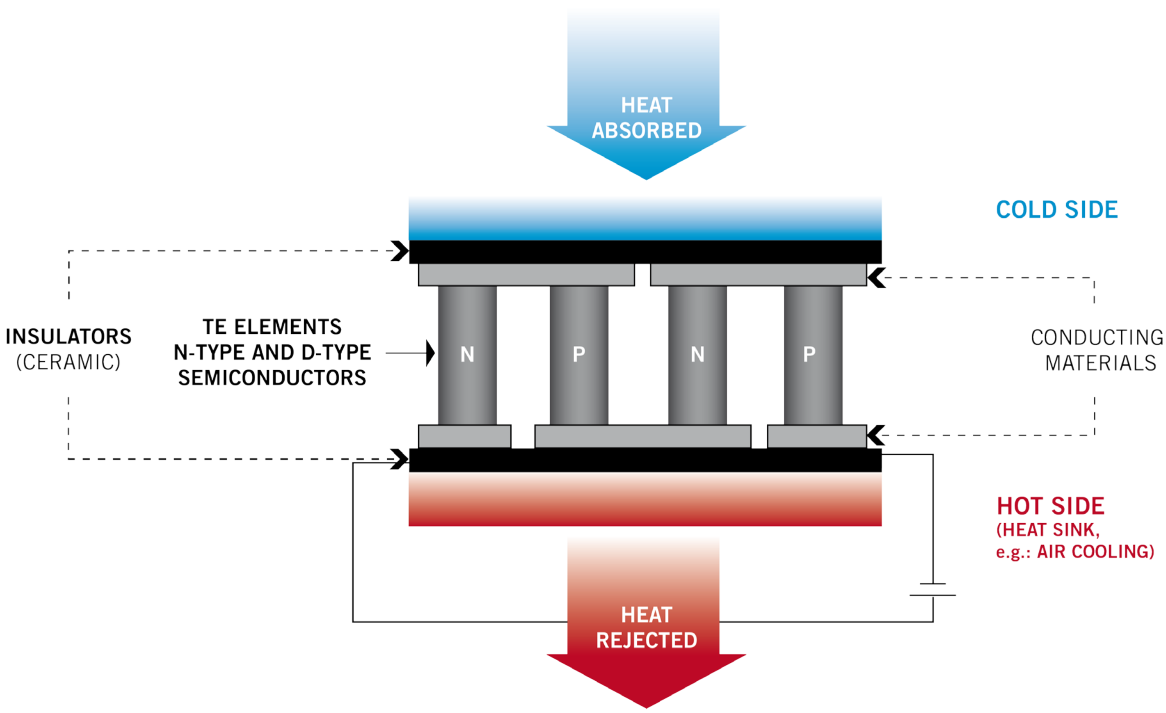


FIG. 1. Schematic of a thermoelectric device where the Peltier effect is used to generate heat flow between two materials.

* ΔT is the difference of temperature between the hot and the cold side of the Peltier stage.

STIRLING COOLING

Stirling coolers based devices operate on a closed Stirling cycle where a nearly ideal gas (usually helium) is being repeatedly compressed and expanded. A schematic of an ideal Stirling cycle and a stirling cooler is shown in figure 2. In order to obtain the change in pressure and temperature of the gas, two pistons are required: a displacer which put alternatively the gas in contact with a cold and hot reservoir and a working piston which is moved by the expansion and compression of the gas. A regenerator is also required and act as an internal heat exchanger.

Following the Ideal Gas Law, heat from the surrounding is being absorbed by the expanded gas during the expansion which makes it colder. When the gas is being compressed, heat is ejected from the gas to the atmosphere.

Four steps are needed in an ideal cycle, see figure 2 (A):

1. Isothermal compression: heat ejected.
2. Isochoric process: the system is kept a constant volume. Heat is rejected to the regenerator.
3. Isothermal expansion: heat is absorbed by the gas.
4. Isochoric process: the system is kept a constant volume. Heat is absorbed from the regenerator.

Stirling cooled detectors can reach -210 °C (63 K).

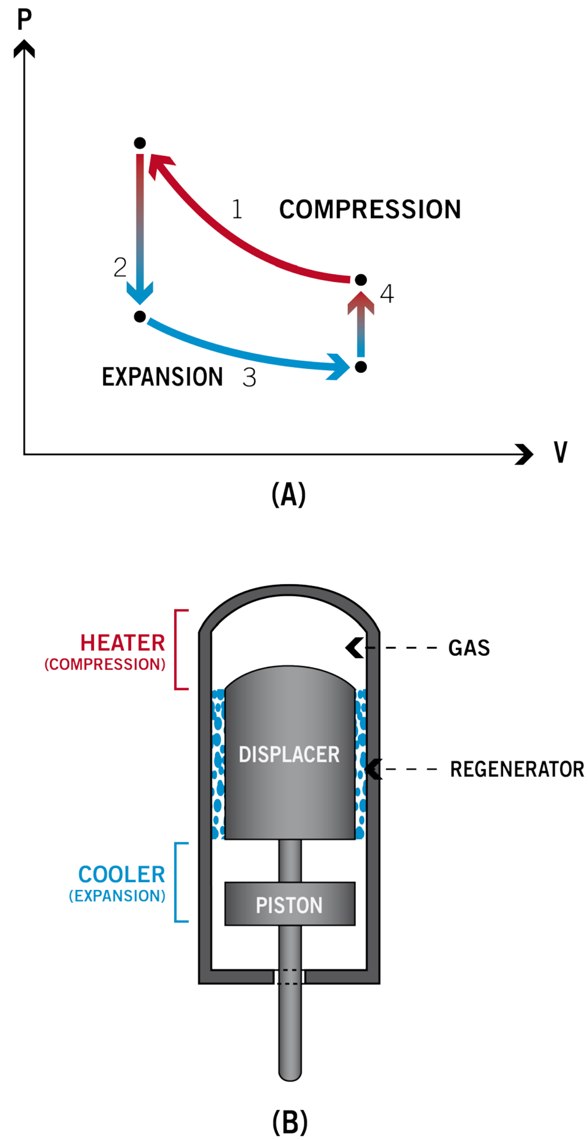


FIG. 2 (A) Pressure-Volume diagram or the Stirling cycle (B) schematic of a stirling cooler.

LIQUID NITROGEN COOLING

Detectors can also be cooled with liquid nitrogen to reach -196 °C (77 K). In liquid nitrogen cooled system, the detector is placed in a cryostat that holds a dewar where the liquid nitrogen is stored. Different type of detector chamber are available. The detector can be connected to a copper cold finger inserted in the dewar. The finger carry the heat from the detector to the liquid nitrogen tank.

WHY A TE4 AIR-COOLED SYSTEM?

MAIN ADVANTAGES OF TE COOLED AIR SYSTEM

- › Compact
- › No moving parts
- › Highly reliable
- › Long lifetime
- › No maintenance
- › Low dark current
- › Low readout noise

Each cooling method possess his advantages and downsides, the application will dictate the appropriate approach. Liquid nitrogen is used, for example, with MCT sensors working in the long wavelength infrared (LWIR - 8-15 µm) range to reduce thermal noise. It is also used for application requiring high cooling capacity and stability. Liquid nitrogen cooled sensor also possess long lifetime and relatively low initial cost. The main disadvantage is the regular need of liquid nitrogen supply, the limited autonomy and the time required to stabilize the temperature.

Stirling cooling also provides really low temperature and offers a good solution for applications requiring long acquisition time with low dark current or low power consumption. Stirling cooling is efficient and compact however, it induces vibration, it has a limited lifetime and high initial cost to which rework cost need to be added later on.

In industries where long life time and easy maintenance are essential, thermoelectric cooling seems to be the best suited option. It is also vibration-less and user friendly when compared to Stirling and LN2 cooling respectively, two advantages that are also often mandatory in advanced scientific imaging. This is why Photon etc. decided to go in this direction for its ZephIR line of cameras. An overview of the main advantages of TE cooling is presented here.

LONG LIFETIME

Unlike Stirling coolers, TE stages do not possess moving parts, which is a significant advantage for the overall durability and maintenance needs of the camera. No moving parts also means no vibration, which is perfectly suited for high magnification SWIR microscopy. Because of their long lifetime and reliability, TE cooled cameras are ideal for industrial process control or any other applications implying long cycles of operation.

COMPACT

Their small size is ideal to manufacture compact sensors that can be easily installed in either academic laboratories or industrial environments.

USER-FRIENDLY

An air-cooled system does not require a continuous flow of cold water in the camera. This greatly facilitates its integration in various environments.

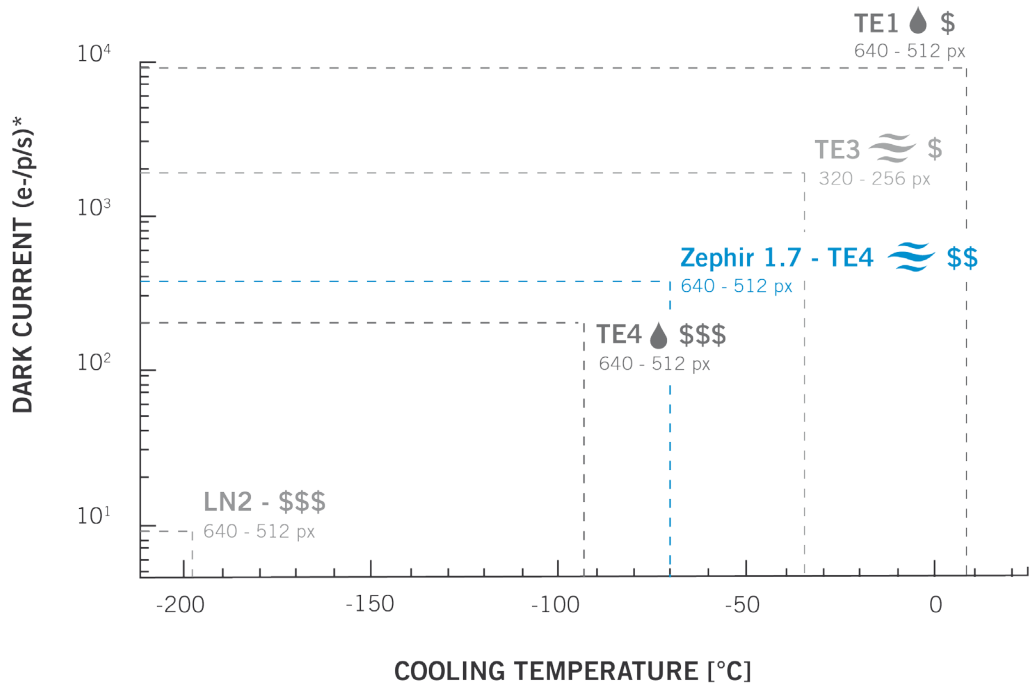
LOW DARK CURRENT

The small bandgap of InGaAs (~0.75 eV at room temperature) and even smaller bandgap of HgCdTe (~0.15-0.43 eV) imply that electrons will be more likely to reach the conduction band and contribute to the dark current. For this reason, sensors based on InGaAs or HgCdTe possess a high intrinsic dark current at room temperature. For example, the dark current of InGaAs-based sensors approximately triples with every 10 °C increase. Cooling these sensors is crucial to attaining a good dynamic range and higher sensitivity.

Photon etc. has thus integrated a four stage Peltier module into their cameras reaching -80 °C, a temperature which significantly lowers the dark current of the camera.
The ZephIR 1.7 dark current is typically 300 e^-/pix/sec.

TE4 AIR-COOLED VS THE COMPETITION

Figure 3 presents a comparison between Photon etc's ZephIR 1.7 InGaAs camera equipped with a TE4 air-cooled system and other sensors available on the market. The figure presents the dark current per pixel of different SWIR sensors as a function of their respective cooling temperatures. The order of magnitude of the price is also indicated as well as the heat dissipating methods (water or air cooled). When compared to its competitors, the ZephIR 1.7 offers the best price-performance ratio, in addition to being easier to install and operate because of its air-cooled system.



LEGEND

**$$$** 100 000 - 120 000 US$
**$$** 50 000 - 60 000 US$
**$** 30 000 - 45 000 US$

AIR COOLED
WATER COOLED

TEX **X** PELTIER STAGE(S)
LN2 LIQUID NITROGEN COOLED

CONCLUSION

The suitable cooling method strongly depends on the application. TE4 air-cooled system are best suited for industrial application as well as demanding scientific imaging. This cooling system is more reliable, simpler and less expensive than other available cooling technologies. The TE4 cooled ZephIR InGaAs and HgCdTe are ideal cameras for state-of-the-art scientific research and a wide variety of industrial applications. They are perfectly suited for hyperspectral microscopy, fast broadband imaging, line-scanning systems, industrial sorting and quality control, thus broadening Photon etc's scientific solutions to the SWIR spectral window.

MEET THE AUTHORS

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is the Director of Electronic & Software Engineering at Photon etc. He oversees the activities of the electronics and software development team for the full range of Photon etc.'s products. He holds a bachelor degree in electrical engineering from the ÉTS (École de technologie supérieure). Since 2009, his efforts have been in part devoted to develop a product line of infrared imaging. This system, unique and renowned for its performance, helped Photon etc. carve out an important place in the industrial sector of optical control. Its role as a technology leader brings to the company the necessary expertise for its technological renewal.

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is an Application Scientist at Photon etc. She is in charge of product development, marketing and sales. She holds a BS in physics and a master's degree in condensed matter physics from Université de Montréal. Her deep understanding of material sciences has led to numerous publications in collaboration with researchers worldwide. Laura's expertise has opened new application territories for Photon etc's hyperspectral imaging systems.

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