Cooling SWIR Sensors

Photon etc

A spectrum of solutions

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

Multiple cooling technologies are available, each having certain benefits and drawbacks. The ZephIR and Alizé product line of Photon etc.'s SWIR cameras uses a four stage thermoelectric air-cooled system to enhance the sensitivity of its imaging sensors. With their integrated four stage thermoelectric air-cooled system, all ZephIR cameras reach an operating temperature of -80 °C. Their -60 °C Alizé counterpart represents a compromise; a lower cost at the expense of a higher dark current.

Our ZephIR 1.7 cameras (1.7s and 1.7x) use InGaAs detectors deep-cooled to -80 °C and display extremely low dark current. ZephIR 1.7s and 1.7x are sensitive in the 900 nm to 1700 nm and 500 nm to 1700 nm range respectively. The ZephIR 2.5 and 2.9 are HgCdTe cameras sensitive in the 850 nm to 2500 nm and 850 nm µm to 2900 nm ranges respectively.

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

Because of their long lifetime and reliability, thermoelectric cooled cameras are the ideal tools for industrial application.

Overview of Cooling Methods

Thermoelectric Cooling

TEC stages are solid-state devices composed of two different faces. Those stages use the Peltier effect to generate a temperature difference between the two faces. Semiconductors with different electron densities, n-type and p-type (see Figure 1), are placed in a 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 hot side. The cold face absorbs heat which is carried to the other side where the heat sink is located. TEC 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 TEC 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 35 °C ambient temperature.

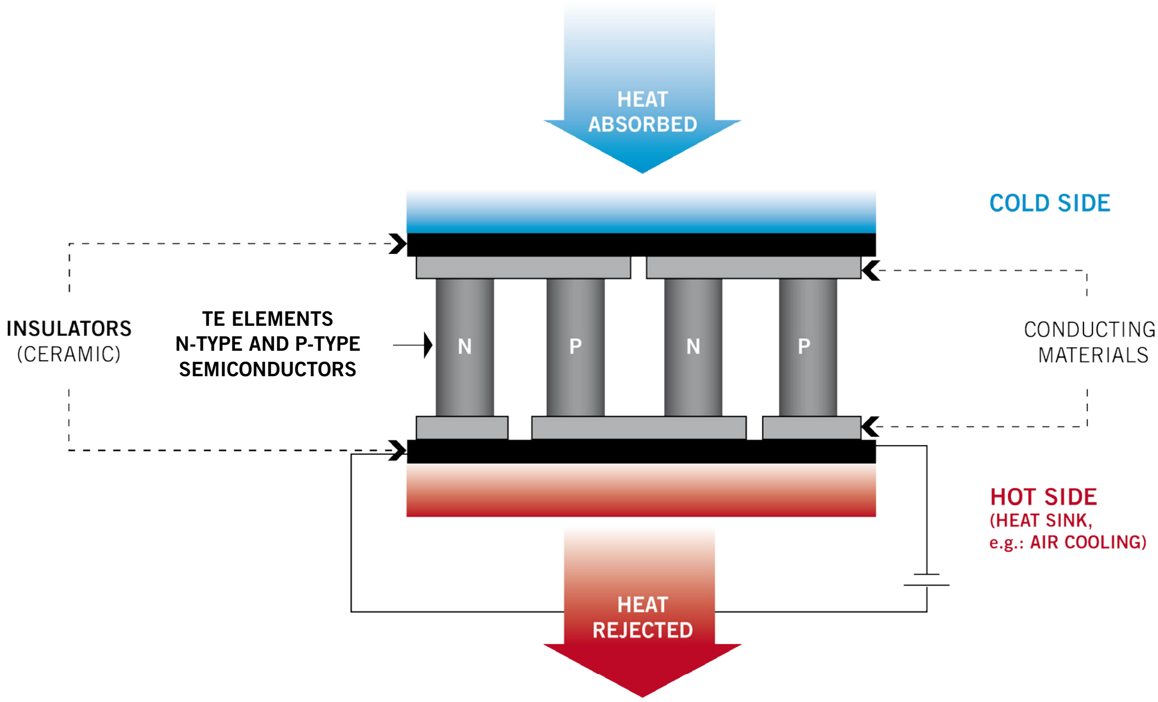

Figure 1. Schematic of a TEC device where the Peltier effect is used to generate heat flow between two materials.

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 (A) and (B). In order to obtain the change in pressure and temperature of the gas, two pistons are required: a displacer which puts 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 acts 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. Stirling cooled detectors can reach -210 °C (63 K).

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

1. **Isothermal compression:** heat ejected.
2. **Isochoric process:** the system is kept at 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 at a constant volume. Heat is absorbed from the regenerator.

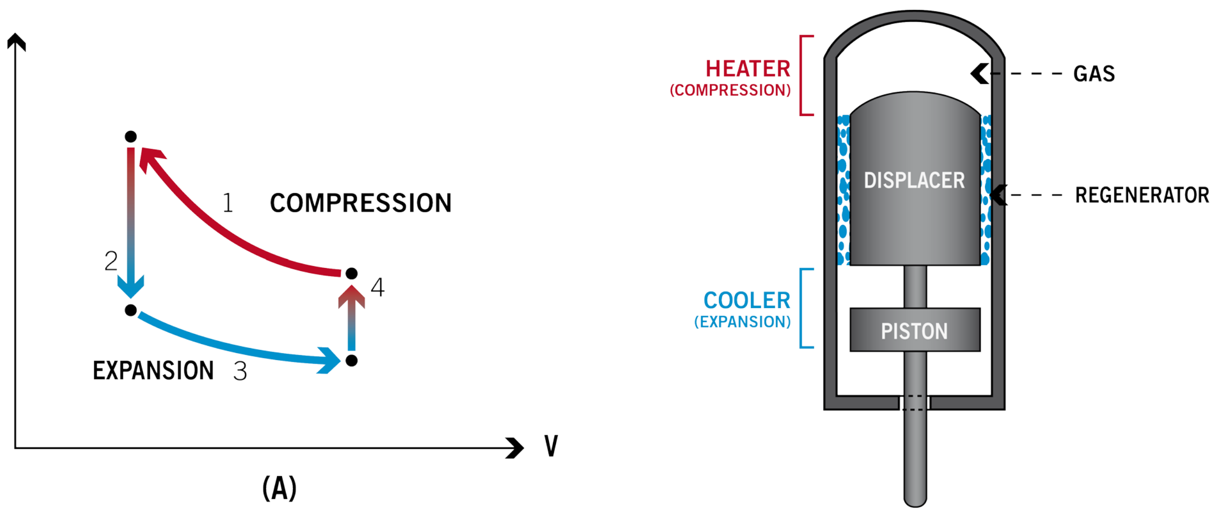

Figure 2. (A) Pressure-Volume diagram or the Stirling cycle (B) schematic of a Stirling cooler.

Liquid Nitrogen Cooling

Detectors can be cooled using liquid nitrogen to reach temperatures as low as -196 °C (77 K). In a liquid nitrogen-cooled system, the detector is typically housed in a cryostat, which contains a dewar for storing the liquid nitrogen. The dewar, a vacuum-insulated container, helps maintain the low temperature by minimizing heat transfer. Various types of detector chambers are available for specific applications. To facilitate cooling, the detector may be connected to a copper cold finger, which is inserted into the dewar. The cold finger acts as a conduit, transferring heat from the detector to the liquid nitrogen tank, ensuring efficient and stable cooling.

Comparative Analysis of Cooling Methods

Each cooling method possesses specific pros and cons, the application will dictate the appropriate approach. Liquid nitrogen is used, for example, with HgCdTe sensors (or mercury cadmium telluride - MCT) working in the long wavelength infrared (LWIR - 8-15 µm) range to reduce thermal noise. It is also used for applications requiring a high cooling capacity and stability. Liquid nitrogen cooled sensors also possess a long lifetime and relatively low initial cost. The main disadvantages are the regular need of liquid nitrogen supply, the limited autonomy and the time required to stabilize the temperature.

Stirling cooling also provides really low temperatures 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, has a limited lifetime and a high initial cost to which rework costs need to be adjusted for.

In industries where a long life time and easy maintenance are essential, TEC seems to be the best suited option. It is also vibrationless and user-friendly when compared to Stirling and liquid nitrogen cooled 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 TEC is presented here.

Why TEC is better for the industrial world?

Long lifetime

Unlike Stirling coolers, TEC do not possess moving parts, which is a significant advantage for the overall durability and maintenance needs of the camera. Because of their long lifetime and reliability, TEC 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 industrial environments or academic laboratories.

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.

Main advantages of a TEC Air System

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

Conclusion

The suitable cooling method strongly depends on the application. TEC systems 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 TEC 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 (IMA), and line-scanning systems (L-EOS) for industrial sorting and quality control.

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