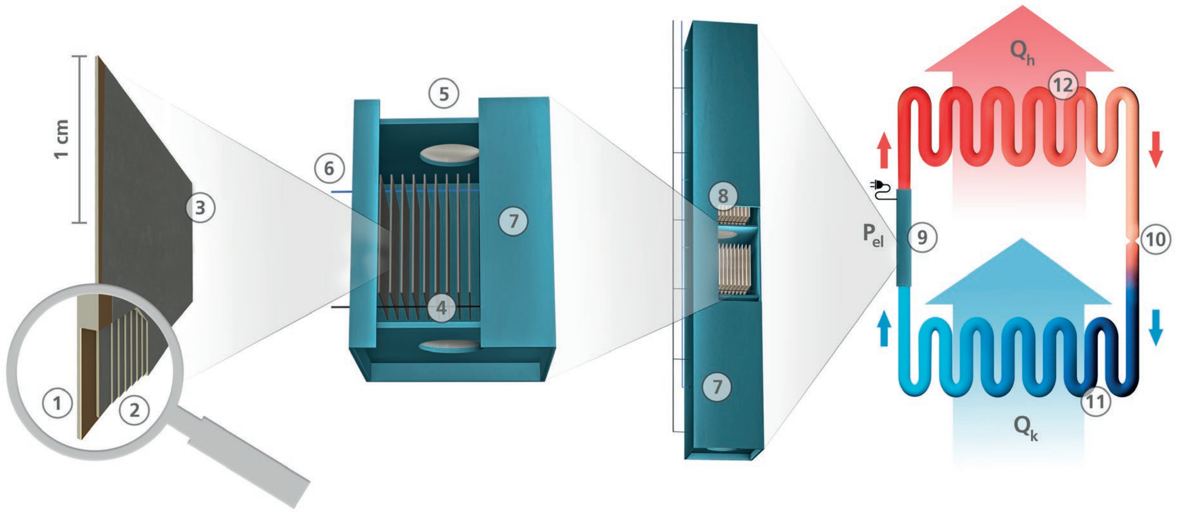
Focus Electrocaloric heat pumps

Making heat pumps more efficient using a material-based technology featuring caloric systems instead of compressors

Electrocaloric components: Ceramic multilayer components were integrated into a heat pipe to enable especially efficient heat dissipation.



Design of an electrocaloric (EC) heat pump: The EC components consist of the EC materials (1) including electrodes (2) and coating (3). Several of these components (4) as well as the check valves (5) and the electrical supply line (6) are integrated into a gas-tight housing (7) and assembled to form an EC segment. Several such EC segments (8) are connected in series to make up the EC system (9) and, together with a throttle (10), the evaporator (11) and the condenser (12), they constitute an EC heat pump.

Ever since Carl von Linde registered his patent for a refrigeration machine in 1873, compression has been the name of the game in refrigeration technology. Refrigerators, air conditioners and heat pumps for heating buildings still operate on the principle of compression to this very day. However, for several years now, various research groups have been investigating caloric cooling systems as an alternative to compressors. And significant progress has been made in this area in recent years, including at Fraunhofer IPM. In general, compressors only achieve 40 to 50 percent of the Carnot limit, in other words, the absolute limit of efficiency. In caloric heat pumps, the theoretically achievable coefficient of performance is much higher. Another disadvantage of compressors is that they mostly still use flammable or environmentally harmful refrigerants.

No expensive materials or wear and tear

Fraunhofer IPM has been researching caloric systems for more than seven years. The researchers have already achieved resounding success in the development of magnetocaloric and elastocaloric heat pumps and have published their findings in renowned specialist journals. In the meantime, research in the area of electrocaloric heat pumps is now also gaining momentum. In the Fraunhofer lighthouse project ElKaWe, for which we are the project coordinator, we have been developing the technology in cooperation with five other Fraunhofer institutes since 2019. Electrocalorics (EC) is the least researched of all the caloric technologies even though it has a number of specific advantages over the alternative caloric approaches. For example, electrocaloric systems do not require expensive materials or complex mechanics so are beneficial in terms of costs, size and long-term stability.

As in all caloric systems, the heat in EC systems is pumped using caloric materials, in this case ceramics and polymers. These materials heat up when an electric field is applied and cool down as soon as the field is removed. The heat generated when the electric field is applied is dissipated via a heat sink, causing the material to cool down to its initial temperature. As soon as the field is removed, the material can absorb thermal energy from a heat source. This effect is highly reversible and can be used to establish an electrocaloric cycle, making it suitable to serve as the basis for highly energy-efficient cooling systems and heat pumps.

High cycle frequency to ensure rapid heat transfer for high power densities

Despite their technological advantages, electrocaloric systems will only be able to enjoy market success if they can also compete in terms of costs. To achieve this, the systems will require high power densities. In other words, they must be able to pump as much heat as possible with as little EC material as possible. The cycle frequency determines how much heat systems of this kind can pump. And, in turn, this frequency depends on how quickly the heat can be dissipated from the caloric material. A patented heat transfer concept developed at Fraunhofer IPM works in accordance with the heat pipe principle by evaporating and condensing a liquid. This allows heat to be transferred up to one hundred times more quickly than with conventional heat dissipation concepts based, for instance, on the active pumping of liquids. The concept has already been tested on electrocaloric systems developed at the Institute, where it has reached cycle frequencies of up to 10 Hz.

Choice of material and system design are pivotal

For EC heat pumps to be widely used in the future, two aspects need to be optimized in particular: the quality of the EC material and the system design, which must be perfectly tailored to the material. As part of the ElKaWe project, the research partners are working on developing EC functional materials with a high figure of merit together with the related manufacturing processes. The research project is also focusing on developing the electronics, coating the components and reliability testing. Fraunhofer IPM is responsible for designing, building and characterizing the system, all the while focusing on the need for optimized heat transfer. To date, the team has achieved a power density of 1.8 W per gram of electrocaloric material used in its laboratory setup, which is more than an order of magnitude greater than that of known comparable systems.

ElKaWe project website

> "Efficient heating and cooling without moving parts is only possible with electrocalorics!"
>
> *Dr. Kilian Bartholomé, Group Manager*

from: Fraunhofer IPM: Measuring, Monitoring, Optimizing. Annual report 2022/2023, Freiburg i.B., 2023. pp 64-65