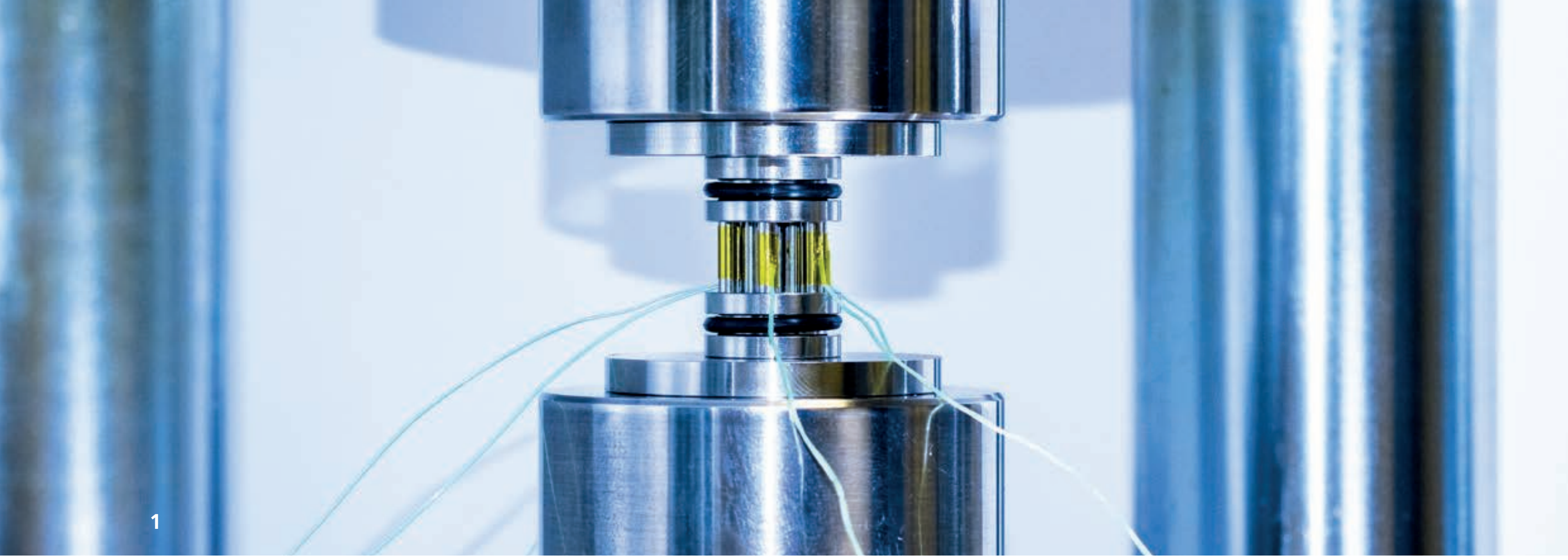


1 *Heat generated by pressure: Elastocaloric materials heat up when deformed. This reversible effect can be exploited in the construction of heat pumps.*

GROUP **CALORICS AND THERMOELECTRICS**

Efficient elastocaloric heat pumps

Heat pumps operate almost exclusively with compressors, regardless of whether they are used for heating or cooling. They pollute the environment with refrigerants and achieve only comparatively low levels of efficiency. Fraunhofer IPM is therefore developing efficient elastocaloric heat pumps that exploit an innovative new heat transfer concept as an alternative to compressor technology.

Air-conditioning devices in homes and cars, fridges and geothermal heating systems all work with heat pumps. Most of the refrigerants employed in them are dangerous or harmful, as a result of which the EU is gradually phasing in restrictions on their usage from 2020 on. New technologies for the heat pump market, which is worth millions, are therefore urgently needed. For some years now, solid-state caloric systems based on magnetocaloric, electrocaloric or elastocaloric materials have been seen as promising alternatives and have been the subject of intensive research, including at Fraunhofer IPM.

Elastocaloric (EC) materials can adopt two different crystal structures. When pressure is exerted on them, a crystalline phase change takes place in which the material warms from the initial temperature T_0 to $T_0+\Delta T$. The heat generated is carried off via a heat sink and the temperature of the material returns to the temperature T_0. If the mechanical stress is removed, the material cools to a temperature below the initial level ($T_0-\Delta T$). When the material is placed in contact with an area that needs to be cooled, it absorbs heat until the initial temperature is reached. Repeatedly exerting stress on the material then removing it, and combining this with an appropriate means of heat dissipation, allows a cycle to form. This creates an efficient heat pump – for cooling or heating without harmful refrigerants. Shape-memory alloys such as the commercially available nickel-titanium alloy Nitinol are among the materials with a significant elastocaloric effect, big enough to enable a large temperature difference.

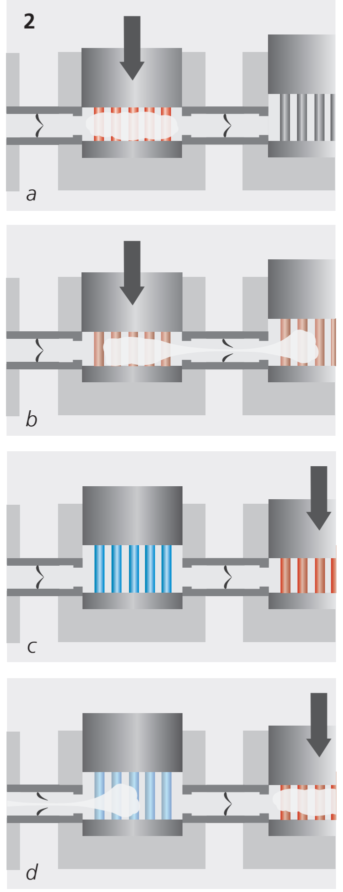
Latent heat transfer increases efficiency

Using an experimental set-up, researchers at Fraunhofer IPM achieved a temperature difference of 15 K when applying a pressure of 750 MPa to Nitinol rods. Other research teams have also achieved comparable temperature differences. It is the transfer of heat between the EC material and the heat exchanger, however, that is the decisive factor in the overall efficiency of electrocaloric heat pumps. Conventional concepts use active fluid pumping to achieve this. The disadvantage of this approach is that pumping restricts heat transfer and limits the cycle frequency of the system to just a few Hertz. By employing the concept of latent heat transfer, Fraunhofer IPM is for the first time adopting a passive approach that is already utilized in heat pipes and thermosiphons. Here, heat is transferred (latently) by evaporating and condensing a fluid such as water or ethanol. The fluid is contained in a hermetically sealed tube that is free from all extraneous gas, and is present in both liquid and gaseous form. The heat transfer coefficient during evaporation reaches values of up to 100 kW / (m^2K), and is therefore many orders of magnitude higher than that achieved with classic systems. Several elastocaloric units are connected in series and designed as thermal diodes, so that heat is transported segment-by-segment in a single direction such that one side of each segment is cooled and the other heated. Initial estimates show that heat can be transmitted from one segment to the next in milliseconds, allowing the system to operate with a frequency of over 10 Hz. This patented combination of latent heat transfer and thermal diodes in an elastocaloric heat pump promises to offer high levels of pumping capacity and a high degree of efficiency.

THE ELASTOCALORIC EFFECT was observed as long ago as the early 19th century when rapidly stretching and releasing Indian rubber. Some 50 years later, the physicist J.P. Joule reported on small reversible temperature changes in metal and wood caused by applying force. It wasn't until the 1980s, however, that studies were performed on latent heat development and the corresponding temperature changes seen in NiTi and Cu-based materials.

First prototypes developed

To date, IPM researchers have achieved a temperature lift of 10 K by setting up a system based on commercially available EC materials. The next goal is to build an EC heat pump as a demonstration unit that achieves a pump capacity of 100 W and a temperature difference of 35 K at a coefficient of performance of over 5. A series of challenges must be overcome in order to do this, however. Firstly, the material needs to display cycling stability. Furthermore, the desired coefficient of performance can only be achieved through maximum possible recovery after elastic deformation. The intention is therefore to develop a suitable concept for energy recuperation using eccentric actuators. Extensive simulations and design optimizations are also required here.



2 *How an EC segment works: Phase 1 – compression: (a) The EC material is compressed and heats up; the liquid present evaporates. (b) This causes the vapor pressure in the segment to rise, the valve to the right opens, the gaseous fluid escapes and latent heat is transferred to the next segment. Phase 2 – release: (c) The external force is removed and the EC material cools. (d) The vapor pressure falls and a vacuum develops in relation to the previous segment. Gaseous fluid flows in and heat from the previous segment is absorbed.*

Dr Kilian Bartholomé, P +49 761 8857 - 238, kilian.bartholome@ipm.fraunhofer.de