Energy Filtering Non-Equilibrium Devices

EFINED aims for revolutionary energy filtering nano-devices for information and communications technology (ICT), sensing, and imaging. It is at the intersection of phononics, photonics, nanoscale electro-thermal devices and molecular engineering.

EFINED is being carried out by a consortium of 5 partners representing a European-wide community of experts on state-of-the-art molecular synthesis, micro and nano devices, bolometers, scanning probe microscopy technologies and theoretical modelling.

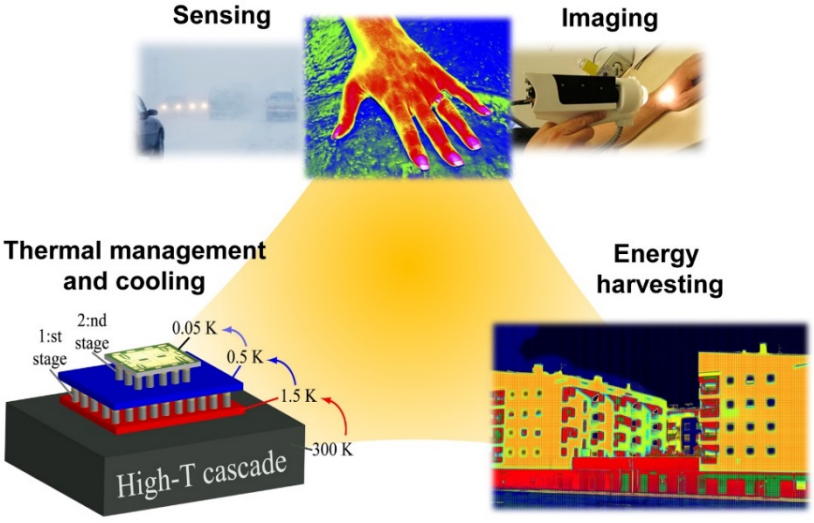
Background

Nanoscale energy and heat management is becoming more and more important. Partly, this is due to the new challenges resulting from continuous performance improvements of micro- and nano-electronic devices by device down-scaling, which has led to extremely high heat dissipation levels in individual transistors. This is reflected to high energy consumption in the global scale by the growing demand of distributed smart systems.

On the other hand, some devices require maximal energy focusing and local temperature rise, such as phase change devices and thermal detectors. Thermal energy harvesters and electronic refrigerators especially benefit from the branch of nanoscale energy management that targets to the minimization of phonon heat flux, which again provides a path to maximize efficiency and/or local cooling.

Approach of project EFINED

By building new energy filtering nano-devices down to molecular scales the project aims to generate new knowledge and understanding of the electronic, phononic and near-field energy/heat fluxes at the fundamental limits of nano-scale energy management, and to demonstrate novel proof-of-concept non-equilibrium phonon engineered electro-thermal devices in real applications.



Application fields of project EFINED.

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5 organisations, from 5 European countries
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Prof. Mika Prunnila, VTT Technical Research Centre of Finland Ltd
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In 2020, Dr. Varpula started as a WP leader of project RaPtor funded by Business Finland.

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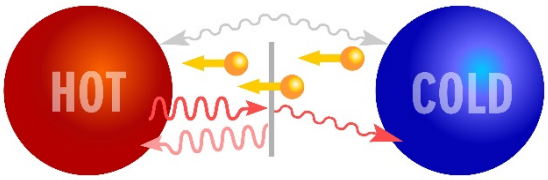
The efficient nano-scale thermal management necessitate developing new theoretical and experimental tools for understanding and mastering the individual non-equilibrium energy/particle channels and interchannel couplings. Control of the physical mechanisms behind non-equilibrium electronic energy filtering effects will be firstly addressed by non-linear transport in molecular junctions by developing new research tools that combine state-of-the-art molecular synthesis, bolometers, scanning probe microscopy technologies and theoretical modelling.

In parallel with the molecular bottom-up approach, we will work with scalable thermionic nano-junctions, which not only have great technological potential of their own but also serve as a model system for the molecular devices. By employing non-linear out of equilibrium electro-thermal effects in molecular and scaled-down junction systems, we pursue the realization of proof-of-concept ICT devices utilizing these technologies within the time span of the project.

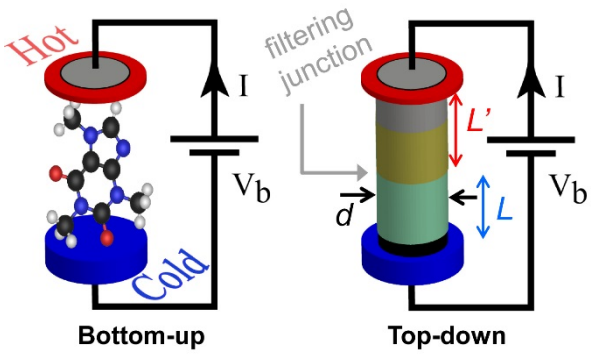
EFINED targets breakthroughs in

- developing the theoretical, modelling and experimental tools to control the electron, photon and phonon energy/heat flux channels in a solid-state device
- realizing nano-scaled devices that minimize phonon and photon heat flux and maximize electron cooling and electron flux responsivity under non-equilibrium

This project will combine synergies in theory, experiment and technology-development covering different fields from chemistry to electronics. The project partners, who are leaders in their respective fields, form a consortium that is uniquely positioned to achieve the ambitious objectives.



Particle and energy fluxes in junction between hot and cold during electronic cooling.



Schematic illustration of the two EFINED approaches in the case of biased detection / electron cooling. In the bottom-up approach the main engineering tool is synthesis whereas in the top-down approach the selected materials and dimensions d, L and L' provide similar handle.

PROJECT STRUCTURE

EFINED is divided into four distinct work packages. Each of the work packages (WPs) is led by a partner with the necessary expertise and ability in the relevant field. The main aims of each work package are summarised in work plan. The activities and flow of information between WPs is shown in the figure on right.

Work plan

WP1: Theory and modelling (lead: CNRS)

The first work package (WP) focuses on theory/modelling of electron, phonon and near-field/photon heat transfer and electro-thermal engineering. Theoretical tools linked to top-down and bottom-up approaches involving transport in micro and nanostructures down to molecular channels, are adapted in the linear and non-linear regimes.

WP contributors: CNRS, VTT, UOL, UDUR, IBM.

WP2: Components (lead: IBM)

Electro-thermal micro- and nano-components and elements are developed in this WP and they are characterized electrically and thermally. Experimental iterations are performed with strong theoretical/modelling support from WP1. The bulk of the development work for the applications of WP3 is performed in this WP.

WP contributors: IBM, VTT, UOL, UDUR.

WP3: Applications and instrumentation (lead: VTT)

Specifications for instrumentation and applications are given in this WP. Advanced scientific instruments for the electrothermal and near-field studies of WP2 are constructed. Proof-of-concept EFINED device is designed, fabricated and demonstrated using the elements of WP2.

WP contributors: VTT, UOL, CNRS, IBM.

WP4 - Management, dissemination and exploitation (lead: VTT)

This WP includes project management, dissemination, and exploitation activities. The goal is to maximize impact of the research and propose and initialize exploitation plans.

WP contributors: VTT, UOL, UDUR, IBM, CNRS.