Summary for Publication

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GreEnergy
Power from optical antennas

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www.greenergy.eu

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Summary of the context and overall objectives for the project

Electrification of society is often stated as the most important strategy to decrease CO2 emissions and to counteract the ongoing climate change. But this implies that we can then generate the electricity from non-fossil energy sources. The sun is the cleanest, most powerful and nearly unlimited energy source available, but conversion of abundant solar radiation to electricity still provides a small percentage of total world's energy needs. All possible strategies, and new technologies, for direct transformation of solar power to electrical power, are of utmost interest and importance.

The overall objective of the GreEnergy project is to harness solar energy with potentially higher efficiency and lower cost than the current photovoltaic (PV) solar cells technology. The concept is based on (nano-) antennas, that could theoretically absorb the electromagnetic waves of sunlight with a potentially high efficiency, as compared to e.g., photovoltaic cells. Such a nanoantenna concept could also have a large impact for small self-powered systems, where high power conversion efficiency can be critical for the function of miniaturized devices.

Earlier attempts to take on the challenge of harvesting solar energy by means of nanoantennas have not resulted in high enough efficiency to be further implemented, nor have they coped with the challenge of converting the idea into a system level approach, that can be practically used.

The GreEnergy solar harvesting and energy storage concept, i.e., to (i) capture the electromagnetic field of light with a nano-antenna array, (ii) convert it to DC current via nano-diodes (nano-rectifiers), and (iii) use it to charge a micro-supercapacitor for energy storage, represent several steps beyond today´s state-of-the-art, both in terms of theory and modelling of nano-antennas and nano-diodes, and within nano-fabrication. The components to be manufactured requires well-defined, high precision structures, with features down to a few nanometres.

Work performed and main results achieved

Following the system approach methodology of the GreEnergy project, we have first through simulations examined different system architectures including nano-antennas, nano-antenna arrays, and nano-diode structures. We have then manufactured rectifiers (antenna combined with rectifier) and storage components, and integrated these on the same chip.

The major results achieved are:

- Design of an optical antenna structure model with a world record reception efficiency of 71% over a broad spectrum of sunlight;
- Low-frequency design of a 4-terminal graphene ballistic diode with nearly 50% efficiency through accurate charge transport modelling;
- Development and optimisation of the process flow for the manufacture of the diode and the optical antenna for the THz range to prove the principle;
- Design, fabrication and verification of various structural components of the energy storage unit (supercapacitor or microsupercapacitor) such as electrode materials, electrolytes, separators, current collectors in assembled devices;
- Simulation and analysis of various options for interface circuits;
- Fabrication and characterisation of graphene-based ballistic diodes exhibiting rectification in DC and at low THz frequencies;
- Fabrication of nanoantenna structures for improved energy transfer from metal to graphene;
- Development and demonstration of a complete multi-physics toolkit for the simulation of arbitrarily shaped antenna structures and geometric diodes;
- Development of special microsupercapacitors with processing parameters/procedures that are compatible with those of the rectifiers and enable future integration at system level;
- Development of a testbench for the design and optimisation of complete energy and harvesting systems based on the characteristics of each individual component of the system.

Dissemination and communication of the project objectives and results have been made continuously through the GreEnergy website and LinkedIn channel, and through presentations at international conferences and workshops. 19 scientific journal articles and four doctoral theses were published, and two GreEnergy doctoral schools were organised, one on theory/simulation and one on nanomanufacturing. In September 2024 we presented the work at a dedicated session at the ESSERC conference in Bruges, Belgium. For additional information, please visit the project's website at https://www.greenergy-project.eu.

Progress beyond the state of the art, results, and potential impacts

The Multi Physics Tool kit, combining I) ab-initio simulations at atomistic level, II) Monte Carlo simulations at meso-scale level, III) full-wave simulations at continuum level in the same environment is a breakthrough. Moreover, the nanoantenna array design for broadband capturing of sunlight with 70% efficiency and ballistic diodes (around 50% efficiency), based on simulations are beyond the state of the art.

We have achieved lab scale technology validation at the system level, at least in the low THz regime for rectennas, and in the visible regime for nanoantenna structures. The GreEnergy nanoantenna-diode-storage concept could also be of future interest for local harvesting in self-powered units, e.g., for Internet of Things applications.

Still the challenges related to bringing this technology to useful systems, especially of the optical regime, are enormous. Single components and nanomanufacturing must be further developed, development of materials and materials with dedicated properties is necessary, insertion losses must be reduced, and in particular, the nanoantennas must be perfectly impedance-matched to the rectifiers, to avoid losses. The GreEnergy project has made several important steps forward in this area, even though much research and development remain in the coming decades.

Efficiency and cost are critical parameters in all energy harvesting and storage systems. If successful, the GreEnergy concept could contribute to the clean energy market penetration and strengthen the EU, and facilitate worldwide leadership on new form of energy harvesting. Fostering the use of green energy while reducing fossil fuel consumption is important for the economy, the health and wellbeing of human kind and reduces the threat of global warming.