Naplife: Nanotechnology with a perspective on nuclear fusion

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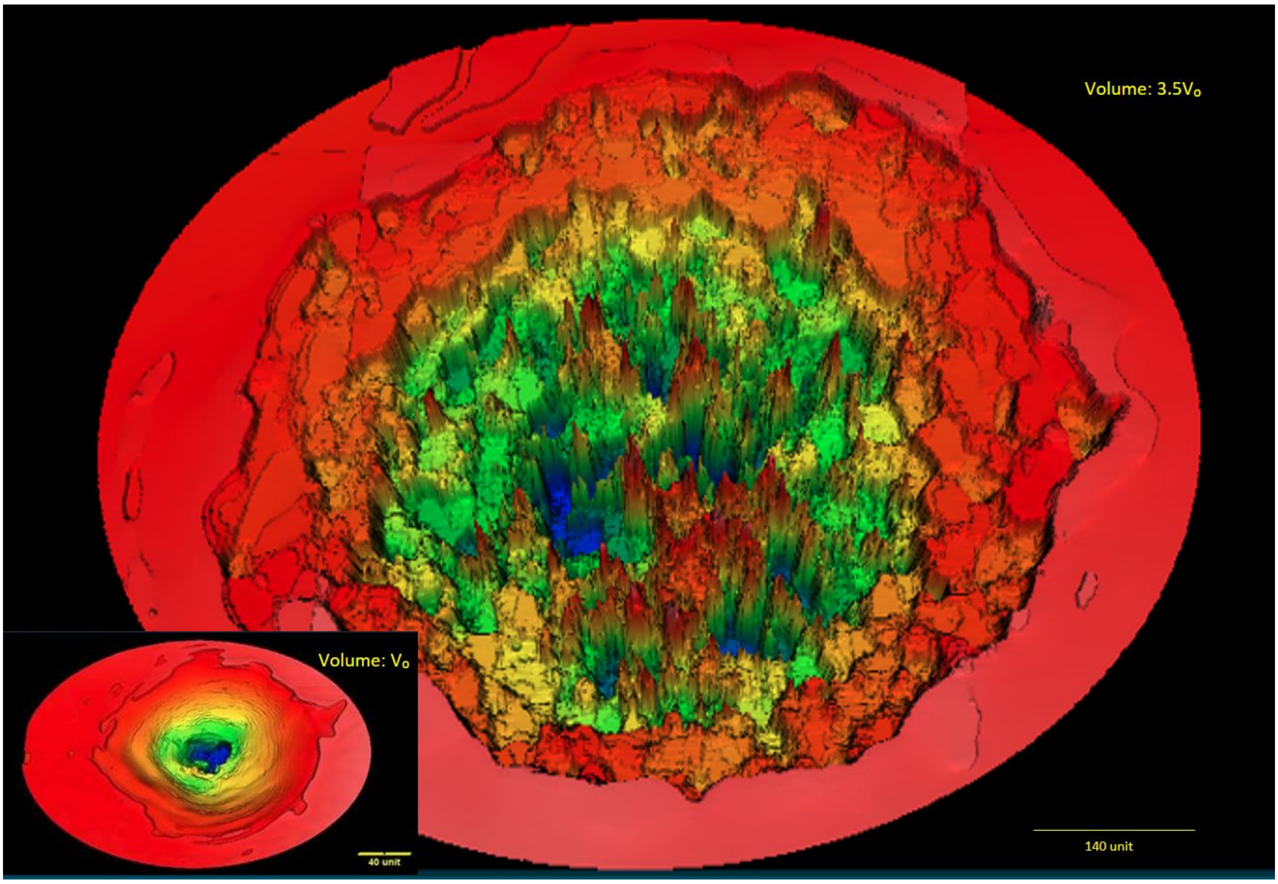

Figure: Craters made in virgin and in nano-doped targets.

Biró. Tamás Sándor a research professor at the Wigner RCP in Budapest, Hungary, discusses using nuclear fusion as a primary energy source in his project 'NAPLIFE'

Human civilization needs energy. Starting with the use and production of fire (chemical energy fed by biomaterial, mainly wood), using animal muscle power, the kinetic energy of water (irrigation, mills) and wind (sailing, turbines), and continuing with the industrial era when the use of steam and less than 100 years later that of electricity arose.

Energy and Civilization

To date, electricity is the predominant form of energy consumption, distributed on complex networks and produced from various sources. Direct burning of fossil fuel (gas and oil) heats houses and drives trucks and cars, as a main tool for the transportation of persons and goods, but here the perspective of the electric drive is apparent. However, electricity must be produced first from primary energy sources.

All energy production is in fact a transformation from one form of energy to another. This transformation itself consumes energy, therefore, the effectivity depends both on the density of attainable energy in the fuel (MJ/kg) and on the dissipative losses during transformation.

Nuclear power stations use fission energy transformed to heat, exchanged to steam heat, driving turbines, and finally, rotating generators to produce electricity, which goes into the network. All other means of electricity production connect to the primary energy extraction process either by mechanical motion (wind turbines) or heat production (coal burning).

The most direct producer of electricity is represented by solar cells, here the problems arise from the huge area needed and from the special composite materials needed to produce the photovoltaic elements. Comparing demands and production for energy, in particular electricity, the world shall need nuclear power for long-term solutions, since it is being the best considering these factors.

Future Technologies for global energy production

New technologies are needed to improve the present efficiency in global energy production. Although all the presently applied production forms can be improved in the future, including the safety of nuclear power stations and the reduction of environmental damages caused by wind turbines and solar cell fall-outs, new sources of energy are and shall be needed. One promise is to use nuclear fusion as a primary energy source.

The fusion of atomic nuclei of light elements up to producing iron provides even more energy per fuel mass than nuclear fission. Since the first construction and experimental explosion of the H-bomb, nuclear fusion research aims at the taming of this process, to bring it under controllable conditions and use it for the release of energy in much smaller amounts, proper for civilian use. Nuclear fusion does not have a critical mass; theoretically, it can be downscaled to a usable amount of energy production. It needs, however, extreme energy density conditions; thereby the fusion fuels found in nature must be heated and compressed or otherwise accelerated to ignite the process.

Exactly the way, how it is proposed to work, classifies the main branches of modern fusion research. The most conventional one is magnetic confinement fusion, the tokamak and stellator type containers for the hot plasma. A prominent representative of this approach is the ITER, under construction in Cadarash, France. Next to it is laser inertial fusion, where the target fuel is compressed and heated by laser energy. The National Ignition Facility (NIF) announced already an energy gain ratio of 1.5, although the energy which reached the fuel target was estimated, not directly measured. Beyond these two most known approaches a number of side research is emerging. Laser driven ion acceleration, originally planned for constructing table-top particle accelerators, is one of them.

Nanoplasmonic Laser Inertial Fusion Experiment research

In our Nanoplasmonic Laser Inertial Fusion Experiment (NAPLIFE) we aim at yet another additive conducive phenomenon: plasmons alongside metal nanoparticles have the potential to confine the energy of an incoming laser pulse. According to theoretical simulations, given shape and material nanoparticles act as antennae collecting radio waves. In plasmonically enhanced fusion they act as receiver and the laser pulse energy is efficiently collected. In this way, theoretically, field enhancement factors around and over 100 may be achieved and translated to an energy density increase of 10.000.

Nanotech improvements for energy absorption

The material, size and shape of nanoantennas must be calculated and experimented with in order to find the best recipe. Only the size is given by the resonant antenna condition, fitted to the frequency of the laser pulse. We also need these energy-concentrating antennas distributed in 3D space, rather than on 2D surfaces: therefore we have chosen a particular polymer, hardened by UV light after mixing the nanoparticles by, as the carrying medium, borrowed from dentistry.

At the time being, cylindrical shapes from gold are in use in our lab, but we have plans to test various antenna types. Additives, like boron, are important as reaction partners for laser-accelerated protons on the spot. Although to construct arrangements operable at scales demanded for industrial use, we shall need quite a few more years, such first steps are better done now.

Preliminary results: crater study and deuteron detection

Our first observations on these experimental arrangements of ultrashort laser pulses, vacuum chambers, and various detectors with nanogold antenna-seeded polymer targets are indirect. Certainly, at such low energies massive nuclear reactions are not expected; claims on quantum effects are weak and do not bring enough probability for a good flux of nuclear fusion reactions. On the other hand, the laser–matter interaction is strong. We reach high power density due to the short pulses (40-120 fs), and even higher densities can be reached by the 30 J pulse at the Extreme Light Infrastructure (ELI) Szeged, Hungary, commissioned soon. Molecular vibrations and atomic electron transitions are studied, all being sensitive to the ratio of deuteron (heavy hydrogen) to natural hydrogen. Mass spectrometry analyses are in progress. Damage craters are studied by microscopic techniques after irradiation. Nuclear gel measurements are planned to be installed this year.

Our first, preliminary results on crater sizes indicate a better energy absorption with plasmonic nanoparticles than without, by an estimated factor of three. This can be and must be further improved. Furthermore, deuteron- related indirect spectroscopy indicates an increase in the deuteron content of about five per cent from the natural target. To produce a background, we also investigate targets with already deuterated polymer-carriers, too.

Based on these initial experiences, there is still a lot to do

More direct analysis of possible nuclear remnants of typical nuclear fusion processes includes the determination of both the energy and the type of the produced particles and radiation. A throughout nanotechnological study requires more variations in compositions and in techniques fabricating the targets of a small thickness, fitted to the time of a 40-femtosecond laser pulse passing through. This short-pulse-driven time-scale in tailored targets keeps the physics out of thermal equilibrium and suppresses possible hydrodynamical instabilities related to extreme compression shock waves at the NIF technique.

We are optimistic right now since several research groups around the world are seeking new technical ways to approach laboratory-size fusion, and also to make the energy investment need lower for the ignition of the nuclear processes. Such research deserves special attention from governments and they are just starting to attract private investments. Industrial use is a question of tomorrow, but tomorrow is sooner here than we expect it today.

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