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NANOTECHNOLOGIES IN ENERGETICS. TENDENCIES AND HOPES

Our human civilization has never been so strongly energy dependent as in the present times. The forecast is that around 2050 the global population reaches the 10 billion value and 10 Terawatt additional energy resources will be needed. And for global prosperity this energy should be cheap. However, the recent energy crisis indicates a process in the fading of access to cheap energy, loaded with uncertainties and risks. But even without these tendencies, it is impossible to produce the needed energy with the presently used technologies. The resent energy mix used by mankind is shown in Fig. 1, but it is continuously changing.

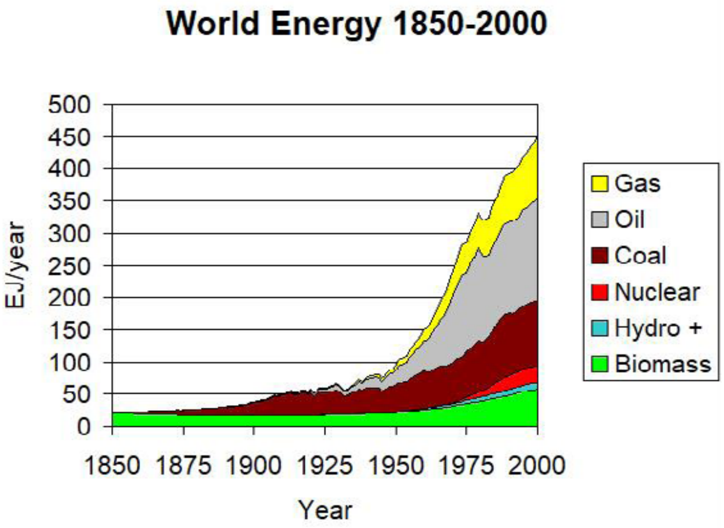
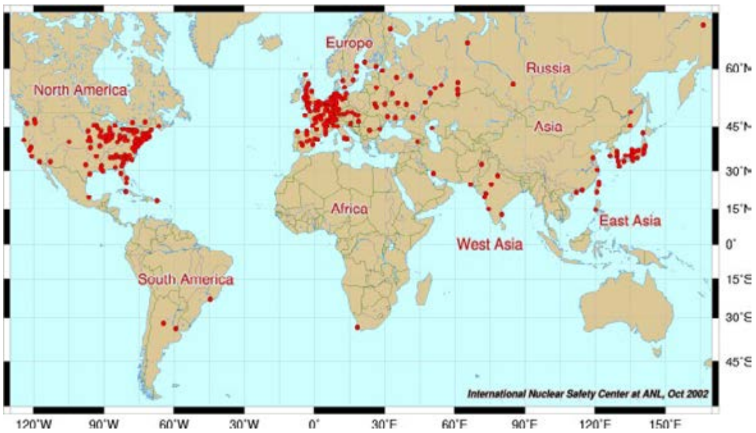


Fig. 1: Annual dependence of the share of globally explored energy resources.



The fossil resources are the main ones, but there is a renaissance of the nuclear power, based on the nuclear fission process. However, there is a strong geographic disbalance. Most of the nuclear power stations are working in Europe, Eastern region of the US and Japan, as seen in Fig. 2.

Fig. 2: Recently operating nuclear power stations in the World.

Our greatest principal energy resource is sunshine. The solar energy reaching our planet at present time is about ten thousand times higher, than the total energy consumption of mankind at present time. However, this resource is time dependent and also creates storage problems. Both the conversion of solar energy to usable and stored resources can cover only a small proportion of our needs. Therefore, in a foreseeable future we have to rely on an optimalized energy mix, but we also have to work on the increase in the share of more environment friendly resources, and also a look for potential new ones. Our dream has already been for several decades to successfully explore technologies, based on nuclear fusion of light atoms. This could be a perfect solution, because of the existing abundant potential fuel reserves and the stronger environment friendliness of the fusion process.

One example of a potential fusion energy facility is ITER (France), where a low-pressure deuterium-tritium gas is contained in a huge torus by strong magnetic field and heated to temperatures in 100 million degree range, where the atoms collide with high velocity and fuse. The recent expectation is that this multi-billion Euro facility will be operational around 2035.

Another example is the National Ignition Facility in the US. It is working in the so-called inertial confinement regime, where 192 lasers with a few times 10 nanosecond pulses try to compress the D-T fusion material to high density in a complicated geometry and reach the needed high temperature. The present status is a one shot per day regime, the lasers are driven with 400 megajoule energy, about 1.5 megajoule reaches the complicated 150 thousand USD target, and 1.3 megajoule fusion energy is obtained.

Our idea is to combine the fusion process with a certain nanotechnological technology. Our experience was, that the combination of two (or more) technologies may always lead to technological break-throughs. Shortly on the basis of a potential process of this character:

In Fig. 3 it is shown that with the development of "microscopy" we could observe smaller and smaller objects down to the atomic levels (left hand side of the figure). And we could also create objects on the same length scale, as seen on the right hand side off the figure.

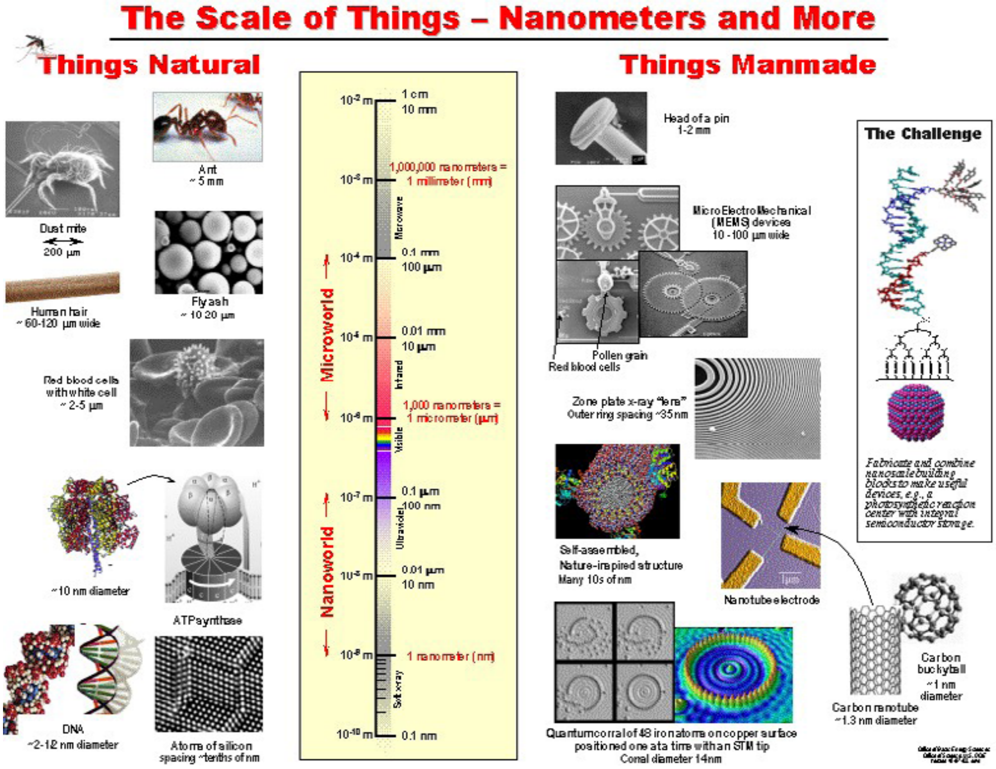


Fig. 3: Down to the nanoworld in nature and in structures, created by human efforts.

This development opens up a broad field of applications. Therefore, it is expected that the nanotechnologies are going to impact upon virtually all technological sectors as "enabling" or "key" technologies, including certain energy technologies too. However, classical optical technologies are excluded from the nanoworld because of the so-called diffraction limit, allowing resolutions of any optical device only around half of the used wavelengths, being around half a micron in the visible range, far above the ~100 nm upper dimensional boarder of nanotechnologies.

We can bypass this hurdle e.g. by using a "new type of light", namely the so-called surface plasmon polaritons or simply surface plasmons (SPP; the marriage of conduction electrons on the surface of many materials, first of all metals with the electromagnetic field bound to these electrons). These plasmons can also be bound to nanosized particles, called localized plasmons (LSPP). There is another advantage of plasmons; they concentrate electromagnetic energy into small volumes, increasing the energy density even by a factor from thousand to million. In Fig. 4, a typical illustration is shown. Small nanoparticles with proper size are put into water. If the container is irradiated by sunshine, the small nanoparticles collect the radiation energy, the surroundings water is heated to boiling temperatures and so the solar energy is captured in the form of steam.

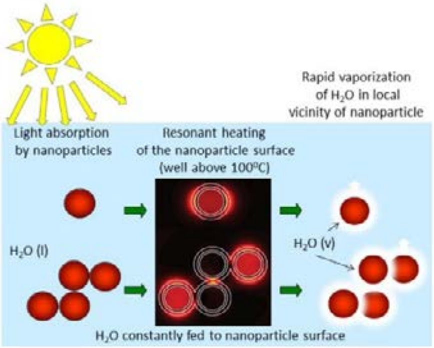


Fig. 4: Plasmonic nanoparticles in water for solar heat production.

One of the typical attempts to use lasers to ignite fusion processes is the National Ignition Facility in the US, where the analogy of the energy production process of the Sun is explored, replacing the gravitational compression of materials in the centre of the Sun by laser-driven compression, evaporating the surface of a spherical fusion material and exploring the reactive force caused by the evaporated material. The question is: can localized surface plasmons excited on nanoparticles be used to improve the nuclear fusion conditions?

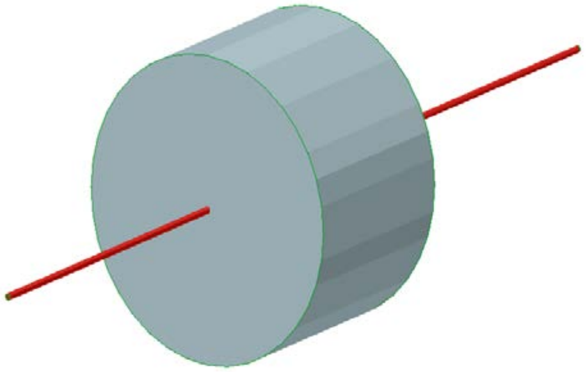


Fig. 5: Flat target, irradiated from two opposite directions.

The lifetime of LSPP-s is e.g. in gold nanoparticles in the order of a few times ten femtoseconds, a million times shorter than the pulse lengths of the NIF lasers. Therefore, the instability problems they are struggling with are not showing up and femtosecond lasers are optimal for plasmon excitation, having their lifetime also in this femtosecond range. Another advantage of these extremely short pulses is that we do not need spherical targets irradiated from as many direction as possible (in the NIF case 192 laser beams), but it is enough to use 2 from the opposite sides of a flat target (Fig. 5).

It is foreseen that for these studies the ELI-Szeged 2 Petawatt Ti:Sa femtosecond laser will be used, which is still under construction. Some preparatory experiments have already been carried out with a Ti:Sa femtosecond laser of the Wigner Research Center of Physics, delivering thousand times smaller energy pulses than the planned ELI ones. To our surprise we have found some energy production already in these cases, being even higher than that of the energy of the plasmon exciting laser.

A polymer has been used (UDMA, used in dentistry) with and without gold nanoparticles implanted into the solid target. Femtosecond pulses with energies up to 30 millijoule have been shot on the target and a typical result is shown in Fig. 6. The laser shots produce craters in the polymer. The left one is without and the right one with gold nanoparticles with resonantly excited localized plasmons.

The difference is striking; the volume of the right crater has been found to be up to 3.5 times higher than the left one, although the energy of the laser shot has been the same and the sub-structure of the 2 craters is also strikingly different.

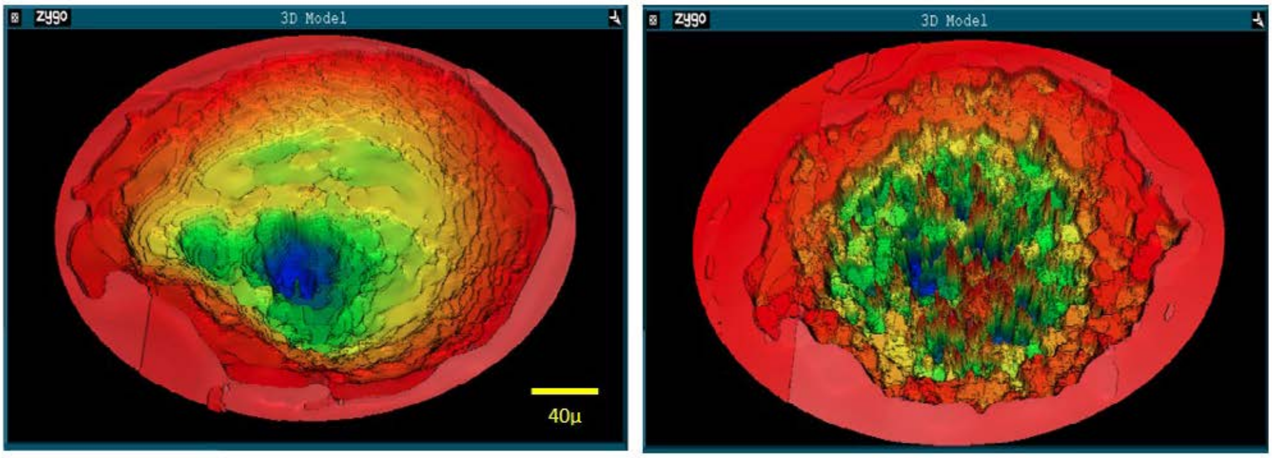
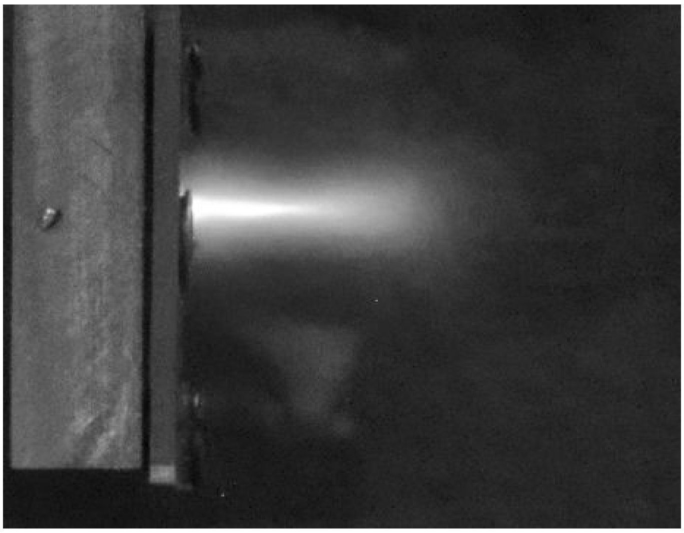


Fig. 6: Craters produced by femtosecond laser shots on undoped (left) and plasmonic gold nanoparticles doped (right) targets. The larger size and the sub-structure of the doped crater indicates also some potential nuclear processes.

What could be the explanation of this observed difference? One attempt to find the explanation has been the study of the crater surface with so-called Raman Spectroscopy. The polymer molecules of the target contain C-H bonds which oscillate at a certain frequency. If the hydrogen atom is replaced with deuterium this frequency changes significantly. In the crater of the clean sample this C-D oscillation frequency has not been found, but in the doped one it exists, indicating the stepping in of a nuclear process, where 2 hydrogen nuclei fused into a deuterium one, producing also some energy, leading to the formation of a larger crater in the doped case. Although at the used relatively small laser pulse energies this nuclear process in principle could not happen, but its experimental observation seems to indicate the significance of the plasmon amplification effect and some other special properties of the plasmons which are connected with the collective motion of electrons in these excited plasmons.



The significance of this energy producing effect is so important, that one indirect proof should not be satisfactory. Therefore, some other attempts have been decided and their results, based on some experiments of this other approach have been carried out. Some results of these experiments are also presented here. This other method, LIBS (Laser Induced Breakdown Spectroscopy) has been explored here, also shooting the laser pulses on both type of samples and the plasma plume (Fig. 7*)* has been spectrally analyzed.

Fig. 7: The plasma plume emitted after the laser shot from the polymer sample.

The H^a and D^a spectral Balmer lines have been measured and the result is shown for a special case in *Fig. 8*. It is clear that the Deuterium spectral line is observed only in the case of the nanoparticle doped sample, being a more direct proof of the hydrogen to deuterium transmutation.

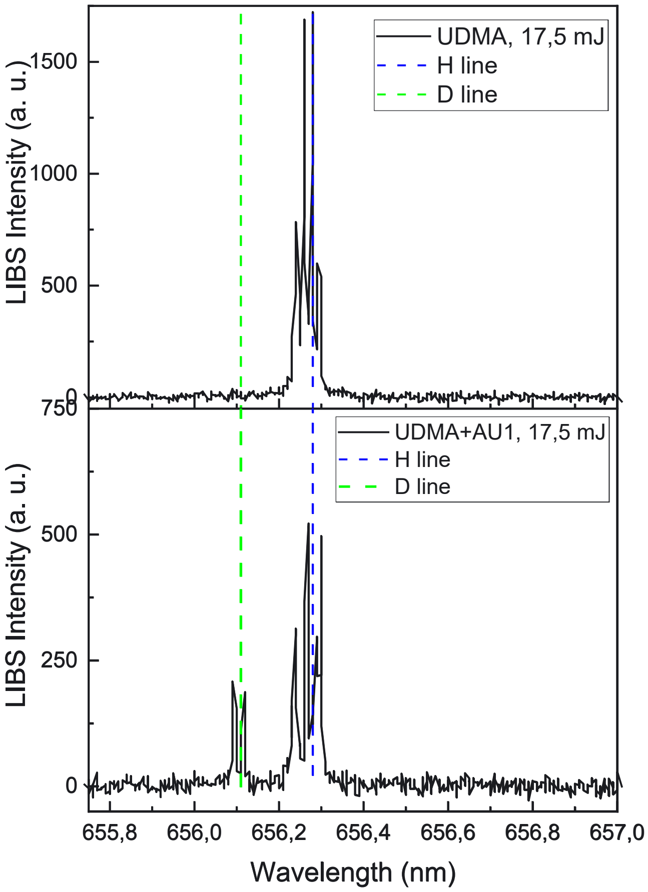


Fig. 8: LIBS Balmer alfa line spectra of hydrogen and deuterium of the undoped and doped polymers.

To sum up the experimental results it is clear that the combination of nuclear processes with plasmonic nanotechnology results leads to strikingly significant effects, which may be further developed in order to potentially achieve economically and also feasible energy production. However, there are still numerous open questions, both of plasmonic and nuclear character, which have to be cleared with the presently used and higher laser pulse energies. The optimal target material should also be found, as well as the optimal plasmonic materials and geometry of the nanoparticles. It has also mentioned that many technical details and even principal ones have not been mentioned, only the main points of our ideas and the background philosophy of the experimental studies.

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