# Metallic nanoparticles in thin foils for laser ion acceleration

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## *Abstract*

Metallic nanoparticles have been obtained by $10^{10}$ W/cm$^2$ Nd:YAg laser ablation in liquid at different irradiation conditions. The nanoparticles were based on Au, Ag, Ti and Cu with means size ranging between 10 nm and 100 nm at different concentrations. Nanoparticles were analyzed with optical absorption spectroscopy in the wavelength range 300-1000 nm. The resulting solutions have been deposited or embedded on different thin polymeric substrates (mylar, nuclepore, polyethylene). The laser irradiation of the prepared thin targets produces a backward plasma emission characterized by ion acceleration. Plasma was monitored in vacuum through ion collectors employed in time of flight configuration. The measurements reveal a significant ion acceleration enhancement of proton and carbon ions in the case of metal nanoparticles with respect to the case without, due to the increment of the laser energy deposition in the prepared targets for Surface Plasmon Resonant (SPR) absorption effect.

## *Introduction*

One of the most important phenomena in nanoscale materials is the coherent electronic excitation in metals, known as surface plasmon resonance (SPR) effect. It represents a collective oscillation of conduction band electrons on the nanoparticles (NP) surface that typically occurs at optical frequencies or in the near IR region [1]. These electrons generate an electric field opposite to that of interaction laser, increasing the absorption. Considerable importance has the effect of absorption in the case of interaction of high-intensity lasers with solid matter for the ion acceleration process. Lasers, using short and high pulses energy, irradiates thin solid targets and produces non-equilibrium plasmas in vacuum. This Physical processing is opening the frontiers to study new regimes of light-matter interactions, accelerating ions up to energy values of the order of tens MeV per charge state [2]. The purpose of this study is to determine the effect of metal nanoparticles on the surface and inside the targets when they are irradiated by lasers at about $10^{10}$ W/cm$^2$ intensity, and that to measure the energy of the produced ion accelerations. The final goal is that to demonstrate that the ion acceleration occurs also at relatively low laser intensity and that

such investigation is need to prepare thin targets to be irradiated at higher laser intensities, of the order of $10^{16}$ W/cm$^2$, to be irradiated in TNSA regime at which kinetic energies above 1 MeV per nucleon can be obtained [3].

## *Experimental section*

NP were obtained with Nd:YAg Laser operating in the infrared region irradiating metallic sheets placed in water. The laser beam is produced and subsequently deflected at 90° by a prism in a beaker with 15 ml of liquid. After the deflection it is focused with a lens on the sample surface where ablation occurs. In Fig.1 we can see the production of nanoparticles in water (a), the experimental setup for the ablation in liquid using a prism (b) and the experimental setup for the particle TOF measurements (c).

Every NP type was prepared used 6000 laser shots irradiating for 10 minutes at 10 Hz the metal sheet placed in the liquid.

A Nd:YAg laser operating at 3 ns pulse duration, 1064 nm wavelength, 200 mJ pulse energy, 0.6 mm$^2$ laser spot, $10^{10}$ W/cm$^2$ intensity, operating at 10 Hz repetition rate was employed in this experiment to produce the NP in water using 10 Hz repetition rate and to perform a plasma in high vacuum condition which has been investigated in single laser shot. Pure targets of Ti, Cu, Ag and Au were employed as thin targets. The plasma diagnostics was based on ion collectors (IC) operating in time-of-flight (TOF) configuration. IC was placed at 118 cm from the target, along the normal direction to the target surface and it is connected to a fast storage oscilloscope, 20 GS/s. The incidence angle of the laser was 45° and the laser spot was 1 mm$^2$. Measurements were performed in vacuum at 2x10$^{-6}$ mbar pressure.

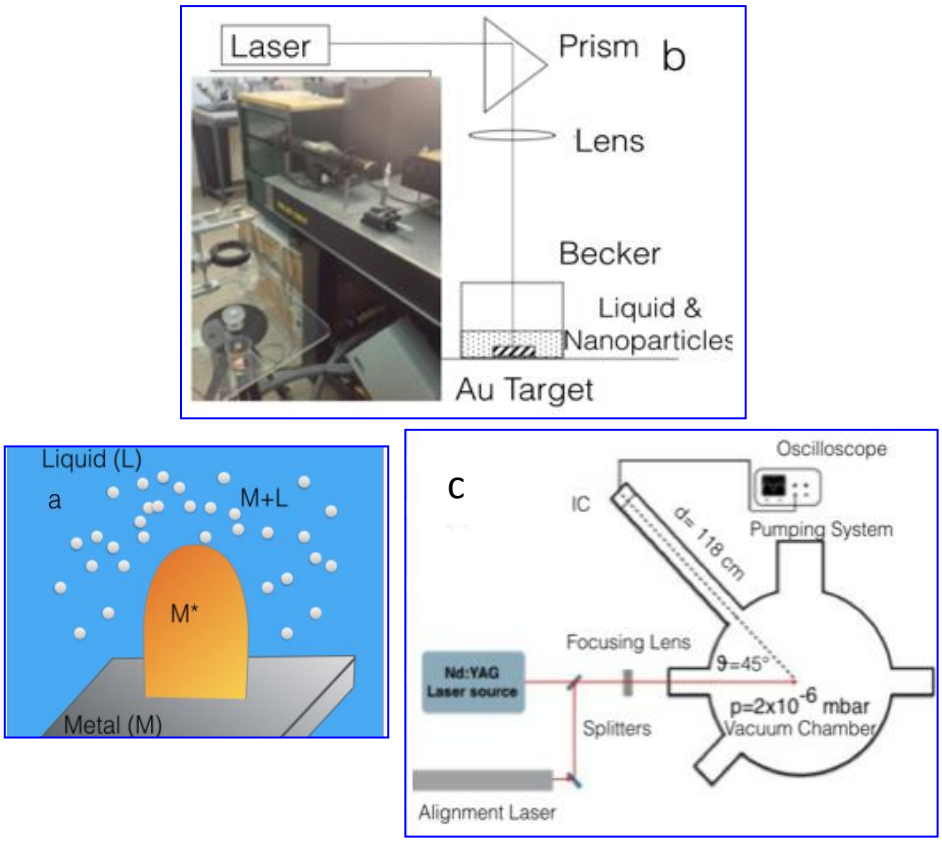


*Fig. 1: Production of metal nanoparticles by laser ablation in a liquid (a),experimental apparatus for laser ablation (b) and set-up for the measurements of particles time of flight (c).*

For these measurements were investigated three kinds of target:

1) Pure Al substrates on which surface the different NP were deposited as a solution drop;
2) Polymeric filter substrates based on polycarbonate (nuclepore filters), 100 micron in thickness, on which the liquid containing the nanoparticles was deposited and dried;
3) Polymeric substrates, 10 micron in thickness, based on polyethylene (PE) in which the NP were uniformed embedded in all the volume.

## *Results*

NP were prepared ablating 1 mg metal in 10 $cm^3$ water. The obtained solution was characterized with visible absorption spectroscopy and with transmission electron microscopy. Fig. 2 shows a typical spectrum of optical spectroscopy of a solution containing Au NP in terms of absorbance vs. wavelength (a) and a TEM image of the Au NP produced in solution. The Np have spherical shape and mean NP size of 50 nm.
Fig. 3 shows a comparison between the IC-TOF spectra obtained irradiating, in the same experimental conditions, the pure Al and the Al on which surface was deposited a drop of solution containing the NP of Ti (a), Cu (b), Ag (c) and Au (d).
Results indicate that the ion acceleration increases significantly irradiating a target obtained depositing on the Al surface a film containing NP with higher atomic number Z.
The Al ions, normally plasma accelerated up to 1.36 keV, increase their kinetic energy up to 1.95 keV when Au NP are employed and protons, accelerated in pure Al up to 90 eV, reach about 201 eV when Au NP are employed. Additionally, the kinetic energy of the employed NP ranges between 1.76 keV for Ti up to 3.57 keV for Au, as reported in the result summary plot of Fig. 5a. This result can be explained on the base of the high laser absorption in the surface containing the NP with higher atomic number.
Further investigations performed depositing the NP solution as a film on the nuclepore substrate, irradiated in the same conditions of the Al substrates and using an Al substrate as a backing for the nuclepore support, give the TOF spectra reported in Fig.4. From these spectra it is possible to evaluate the maximum ion kinetic, in this case protons plasma acceleration goes from 72 eV irradiating pure nuclepore up to 201 eV irradiating nuclepore containing the Au NP.

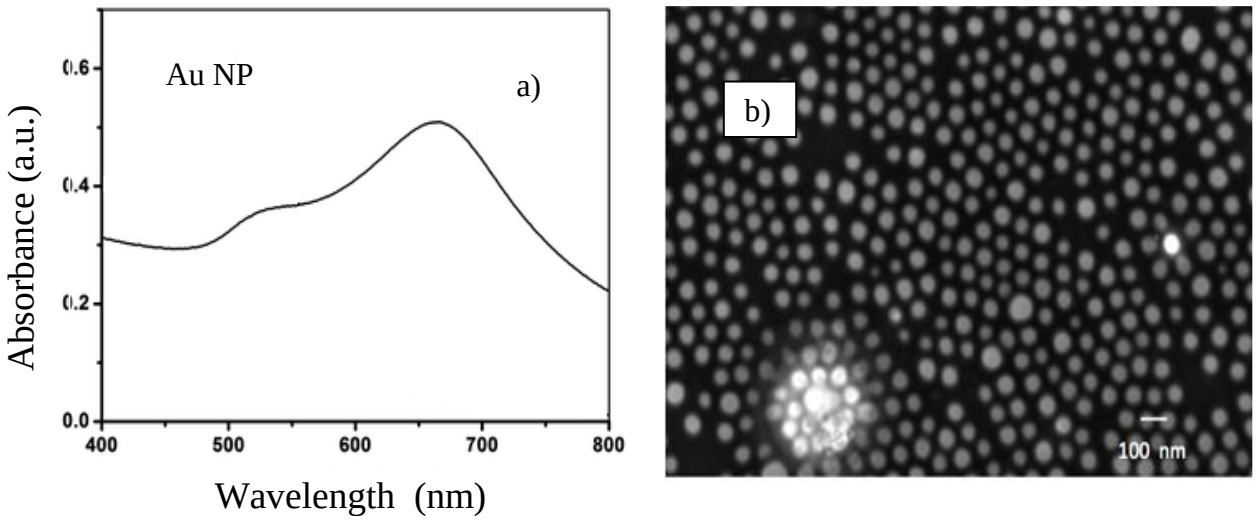


*Fig. 2: Au NP Absorbance vs. wavelength (a) and TEM image of the Au produced nanoparticles (b)*

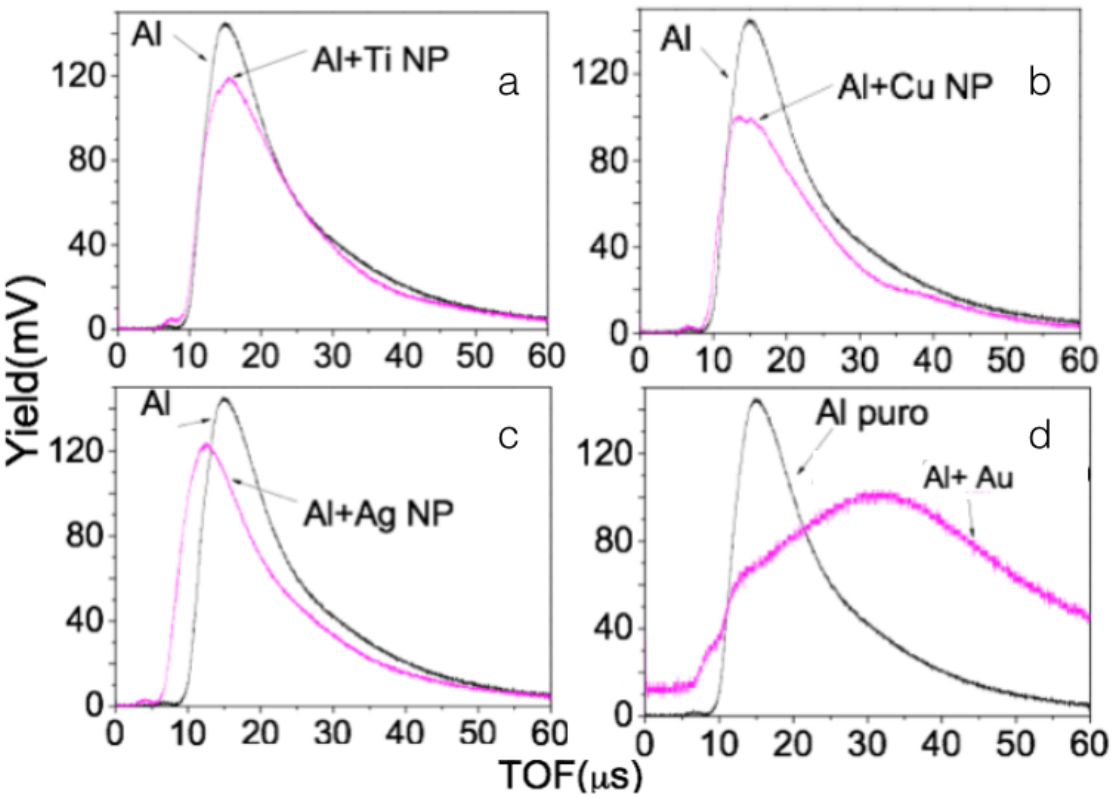


*Fig. 3: Time of Flight spectra of Al targets with nanoparticles*

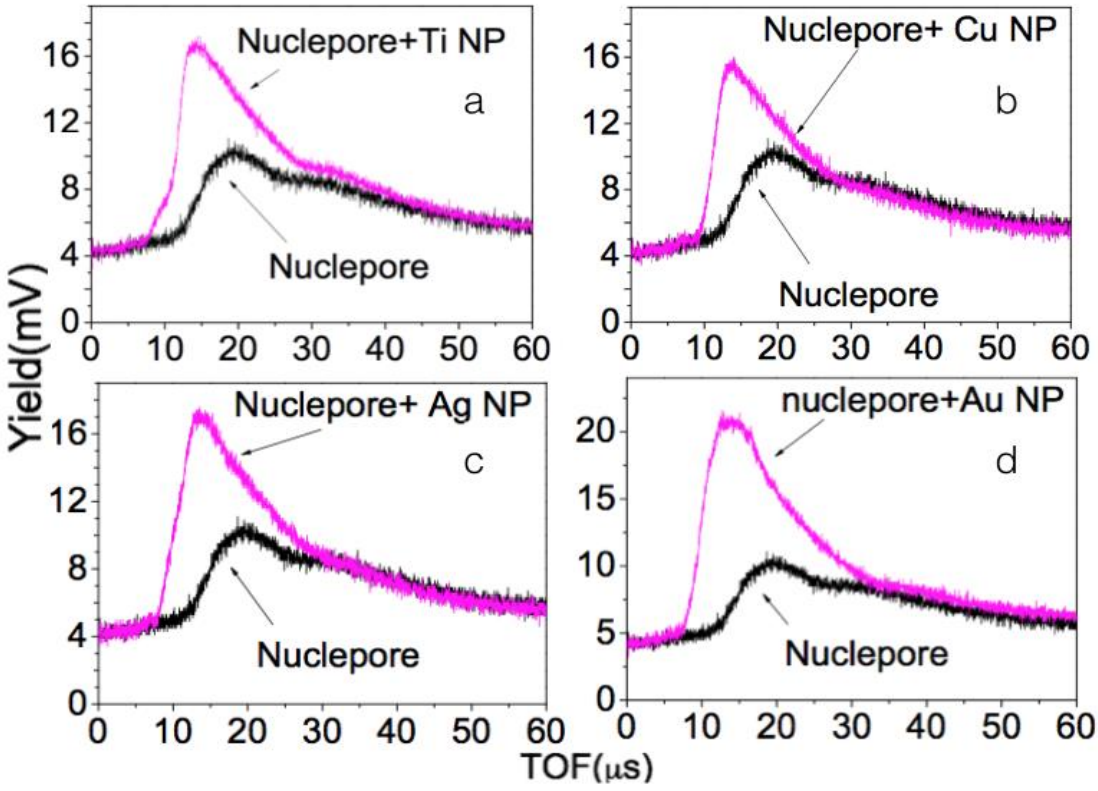


*Fig. 4: Time of Flight spectra of nuclepore targets containing nanoparticles*

Carbon ions acceleration goes from 386 eV irradiating pure nuclepore up to 1.072 keV irradiating nuclepore containing the Au NP; moreover, measurements indicate that the NP ions are accelerated proportionally to their atomic number, as reported in the plot of Fig. 5b.

A further investigation was performed irradiating the PE target, 10 µm in thickness, in which the Au NP, at the same concentration, were uniformly embedded in all volume. Using the same experimental conditions of laser irradiation, IC–TOF spectra shows a significant increment of the ion acceleration with respect to the case of Al+Au NP and Nuclepore+Au NP, as reported in the spectra comparison of Fig. 6.

The spectra are compared with that obtained irradiating pure nuclepore. The maximum proton energy was of 370 eV, significantly higher with respect to the values of 80 eV and 200 eV obtained in pure nuclepore and in pure nuclepore, or in Al surface, containing Au-NP. In this PE target the maximum energy of the carbon ions is about 2.2 keV, in good agreement with the proton acceleration measurement indicating a value of about 370 eV per charge state, corresponding to 2.22 keV for six carbon charge states.

## *Discussion and conclusions*

This work demonstrates that the presence of metallic nanoparticles in the target increases the laser absorption and consequently enhances the energy of the plasma accelerated ions.

The ion acceleration increment is greater in the case of polymers containing metallic NP on the surface or embedded NP inside the bulk. This phenomenon occurs at laser intensities of $10^{10}$ W/cm$^2$, and it is expected that the increase is more pronounced for higher laser intensity. These investigations demonstrate also that there is not a threshold for the ion acceleration mechanism at the used laser intensity. Moreover the used method of analysis of the target can be employed in order to prepare thin targets to be irradiated at higher laser intensities at which energies above 1 MeV per charge state are expected. The study on laser absorption dependence on the NP size, shape and environment deposited or embedded inside thin polymeric foils is in progress. This study is performed in collaboration with the soft X-ray microscopy laboratory at the Institute of Optoelectronics - MIT University of Warsaw (Poland).

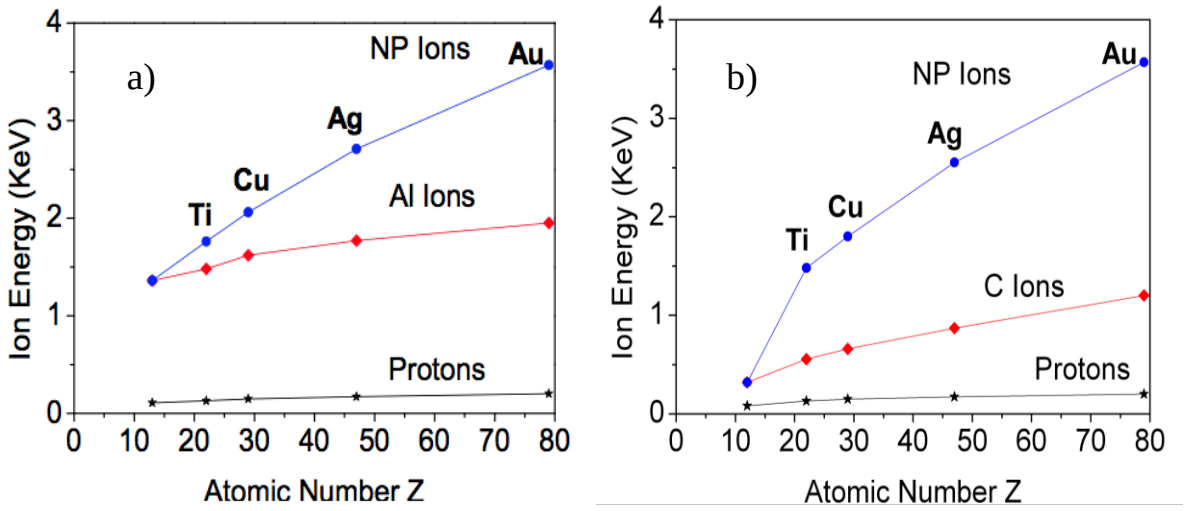


*Fig. 5: Summary plots of energy ion acceleration for Aluminum (a) and nuclepore (b) targets.*

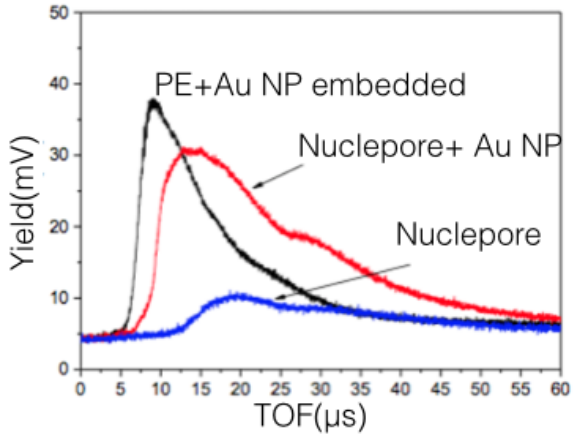


*Fig.6: Spectra comparison of nuclepore as pure, as containing surface deposited NP and containing embedded NP.*

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