Efficient Laser-Proton Acceleration from locally metal coated polyethylene foil

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Outline

• Laser and particle acceleration
• Concept of laser-proton acceleration from a locally metal-coated polyethylene foil
• Experiment and results
• Numerical analysis
• Summary
Exploit high energy density physics with lasers
Intense laser interaction with matter

Intense laser light

Matter (solid, gas, etc.)

High energetic (fast) electron

\( > 1 \text{ MeV} (\beta = 0.94) \)

Electron orbit under intense photo-electric field

\( a_0 \ll 1 \)
\( a_0 \sim 1 \)
\( a_0 > 1 \)

Laser intensity

\[ a_0 = \frac{v_{\text{max}}}{c} = \frac{eE}{m_0 \omega \cdot c} \]

\[ = \left( \frac{I (\text{W/cm}^2) \lambda (\mu\text{m})^2}{1.38 \times 10^{18}} \right)^{1/2} \]

\( v_{\text{max}} \): Maximum electron velocity

\( I \): laser intensity

\( \lambda \): laser wavelength
Sheath acceleration under irradiation of an intense-ultrashort laser pulse

Interaction between intense-ultrashort laser ($<\text{ps}$, $>10^{18} \text{ W/cm}^2$) and foil

- Solid foil
- Fast electrons
- Photons (x-ray, THz, etc.)
- Ions (e.g. proton)

Laser-accelerated protons (typically)
Maximum energy: $> 1 \text{ MeV}$
Energy distribution: Maxwellian
Divergence: $\sim 10 \text{ deg.}$

More...

- High energy
- Monochromatic
- Collimated
- Intensive

For application in other fields. (medical, industrial, and ultrafast science)
Target applications of laser-accelerated proton

Proton therapy

Compact neutron source

Illustrated by Photo Medical Research Center


To generate much higher energetic proton beam

Momentum for ion ($I^{Z+}$)

\[ p = z \cdot e \cdot \int_{0}^{\infty} E_s(r,t) dt \]

- $z$: Ionized number
- $e = 1.6 \times 10^{-19}$ C
- $E_s$: Sheath intensity

Two approaches increasing the electron density ($Q$)
- Target material (metal/plastic layered: Kishimura, APL 2004 etc.)
- Target thickness ($< 10$ nm: Kaluza, PRL 2004 etc.)

Sustaining the sheath lifetime is an other new approach to enhance the proton energy
Conductance dependence for proton acceleration

The sheath electric field on metal foil can be rapidly decayed due to flowing the free electron.
Locally metal coated polyethylene target

High electron density and long sheath lifetime is accomplished in locally Al coat insulator

Polyethylene (PE) substrate: 10 μm
Aluminum dot: 150 μm – 15 μmΦ, 0.2 μm

3 types of target foils were employed
• Polyethylene (PE): 10-μm thick PE foil
• Al coated PE: 10-μm thick PE coated with 0.2-μm thick aluminum on all laser-irradiated surface
• Al dotted PE: 10-μm thick PE coated with 0.2-μm thick aluminum on around laser spot
Experimental setup

Laser conditions:
- Central wavelength: 800 nm
- Pulse duration: 130 fs
- Spot diameter $3 \times 5 \, \mu m$
- Intensity $2 \times 10^{18} \, W/cm^2$
- Pulse contrast: $1/10^{-7}$
Maximum proton energy was increased to 3 MeV

Effect of Al coating (Black/Blue): high yield of lower energetic proton
Localizing of Al coating (Blue/Red): enhancement of the proton acceleration

Maximum energy was same in < 3 mm$^\phi$ microdot foil
$1.5 \text{ mm} / c$ (light speed) $\sim 5 \text{ ps}$ phenomena is key issue
Fast electron distribution

Fast electron from the all coated target is much emitted to lateral direction of the foil

Diffusion of the sheath field in the foil is suggested
Model calculation (not PIC simulation)

With microdot

2-dimensional charge diffusion model

Positive charge diffusion can be occurred due to the free electron flowing.

Slow acceleration (~ps) is effective for proton acceleration.
Spot-size dependence of maximum proton energy

Proton energy saturation was not until reproduced by calculation. Other possibilities:
- Faraday effect by expanding current
- Pre-plasma before irradiating the intense laser pulse
- Returning fast electron
Summary

• Intense laser has possibility to be a compact accelerator
  – Improvement of beam quality is required for applications
• Energy enhancement of laser-accelerated proton was demonstrated by using a locally metal-coated insulator foil
  – Maximum proton energy was increased to three times of whole coated target
• Fast electron distribution was also measured
  – Much electron is emitted from Al coated PE target to lateral direction of the foil
• Spot size dependence was observed
  – Maximum energy was saturated in small dot (<3 mm in dia.) targets
Thank you for your attention