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Nail-Like Targets for Laser-Plasma Interaction Experiments

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***Abstract*—The interaction of ultrahigh power picosecond laser pulses with solid targets is of interest both for benchmarking the results of hybrid particle in cell codes and also for applications in reentrant cone guided fast ignition. We describe the construction of novel targets in which copper/titanium wires are formed into "nail-like" objects by a process of melting and micromachining so that energy can be reliably coupled to a 24-μm-diameter wire. An extreme-ultraviolet image of the interaction of the Titan laser with such a target is shown.**

***Index Terms*—Cone guided fast ignition, extreme ultraviolet imaging, laser-produced electron transport in solids, laser-solid interaction.**

IN ULTRAHIGH power laser-solid interaction experiments, it is often of interest to concentrate the energy of the laser within an object of the minimum possible mass for a given target type. This enables the highest energy density to be achieved within the target as a whole and thereby permits the investigation of the most extreme physical conditions [1]. However, real laser systems possess limited pointing stability. Pointing stability tends to limit the aiming accuracy of an ultrahigh power laser to little better than 20 μm. High-energy (hundreds of Joules) CPA lasers are invariably glass-based laser systems; therefore, shot rates tend to be quite low (less than 1 mHz), and consequently, operating on the basis of hitting only a small percentage of targets in a desirable location is impractical. Therefore, the practical limiting target dimension in the transverse plane is around 50 μm and usually rather more than this particularly if the target is intended to be struck centrally.

In the present investigation [2], the intention is to couple a significant fraction of the laser energy into a wire of small diameter. This is of interest to explore the transport of high-energy (approximately megaelectron volt) laser-generated electrons over distances that are comparable to the electron mean free path (hundreds of micrometers) in a high-density initially cold system that is of sufficiently low mass to be amenable to modeling with particle in cell hybrid codes. Such codes must resolve the Debye length; therefore, solid targets usually place insurmountable demands on processor time if they are to be modeled in their entirety. The principal intention of this experiment is to provide experimental benchmarks for such codes. A narrow metal wire is also interesting because it can be quasi-transparent to its own K-shell radiation, permitting the direct observation of emission from all depths within the target. Also, as previously discussed, low-mass targets can, in principle, enable the exploration of the most extreme conditions, and it was of interest to explore the limiting current densities that could be produced with a view to fast ignition applications.

To overcome the constraints imposed by the laser pointing stability, "nail-like" wire targets were proposed. The targets, which were manufactured by General Atomics, are 20-μm-diameter solid Cu wires with an approximately 80-μm-diameter roughly hemispherical termination. They are fabricated by melting the tip of the wire with a pulse of Nd:YAG laser light and then machining down the resulting melt globule. The heating is performed in an inert atmosphere (argon) to prevent oxidation. The machined flat surface of the "nail head" has an $\sim 80 - \mu$m diameter. The Cu nail targets employed in the experiment were also sputter-coated with 2 μm of Ti prior to machining. An $\sim 90^\circ$ bend $\sim$1 mm from the flat face of the nail head is formed, allowing the farther end of the wire to be vertically mounted on an aluminum post (with nonelectrically conducting glue) with the $\sim$1-mm-long section, terminated by the nail head, horizontal. The fabrication of the targets had some irreproducibility in the radius of curvature of the nail head, and the hemisphere was also sometimes offset relative to the wire axis. The nail head is approximately an order of magnitude less massive than the cones employed in the experiment described in [3] and represents only around 50% of the mass of the horizontal portion of the wire.

An $\sim$500-fs $\sim$200-J pulse of 1.053-μm laser light from the Titan laser [4] is focused to an $\sim 20 - \mu$m-diameter spot, which is centered with a 20-μm pointing accuracy [5] on the flat face of the nail head. The striking image presented in Fig. 1 shows such an interaction in the X-UV, at 68 eV, captured with a multilayer-mirror based imaging system. The image is

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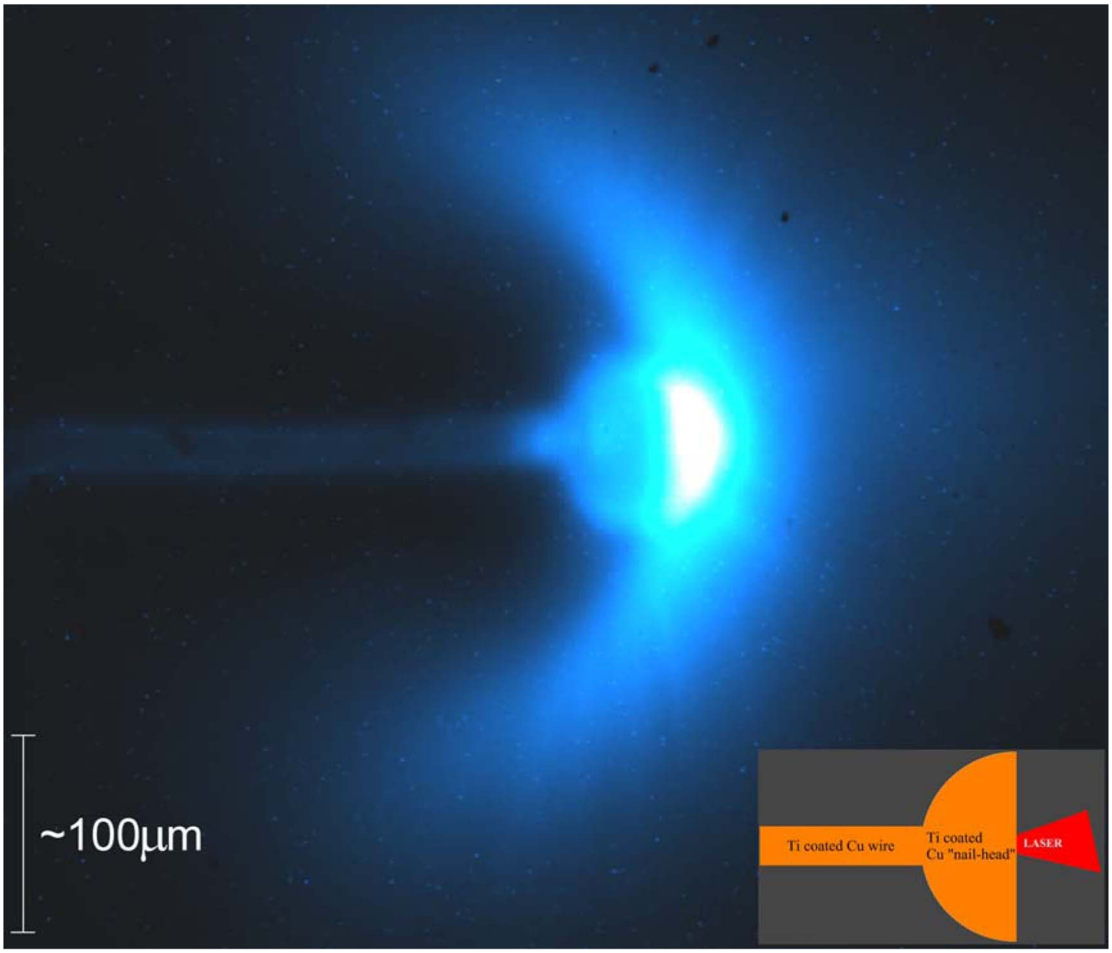

Fig. 1. Extreme-ultraviolet emission from a nail-like Cu/Ti target under the action of the ultrahigh power picosecond arm of the Titan laser. Inset: Schematic illustrating illumination geometry.

time integrated. As shown in the inset to Fig. 1, the laser is incident from the right-hand side. The regions of brightest emission correspond, primarily, to regions of low-density blow-off plasma that has been raised to hundreds of eV either by direct interaction with the laser or through heating by laser-produced energetic electrons or X-rays. To the left of the image, the wire extends. The observations of the emission from the wire portion of the target provide information as to the transport of energetic laser-generated electrons within the target. Gradients in the axial direction provide information as to the energy spectrum of the electrons, whereas gradients in the radial direction (limb brightening) may provide information as to the current density profile in the radial direction. From the image, it can be seen that the expanding plasma halo wraps around the wire. This effect is possibly due to magnetic confinement. Filamentary structures appear to extend out through the coronal plasma. The filaments are reminiscent of the coronal streams seen in the solar atmosphere. Care must be taken in interpretation, however, because this is a time-integrated image.

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