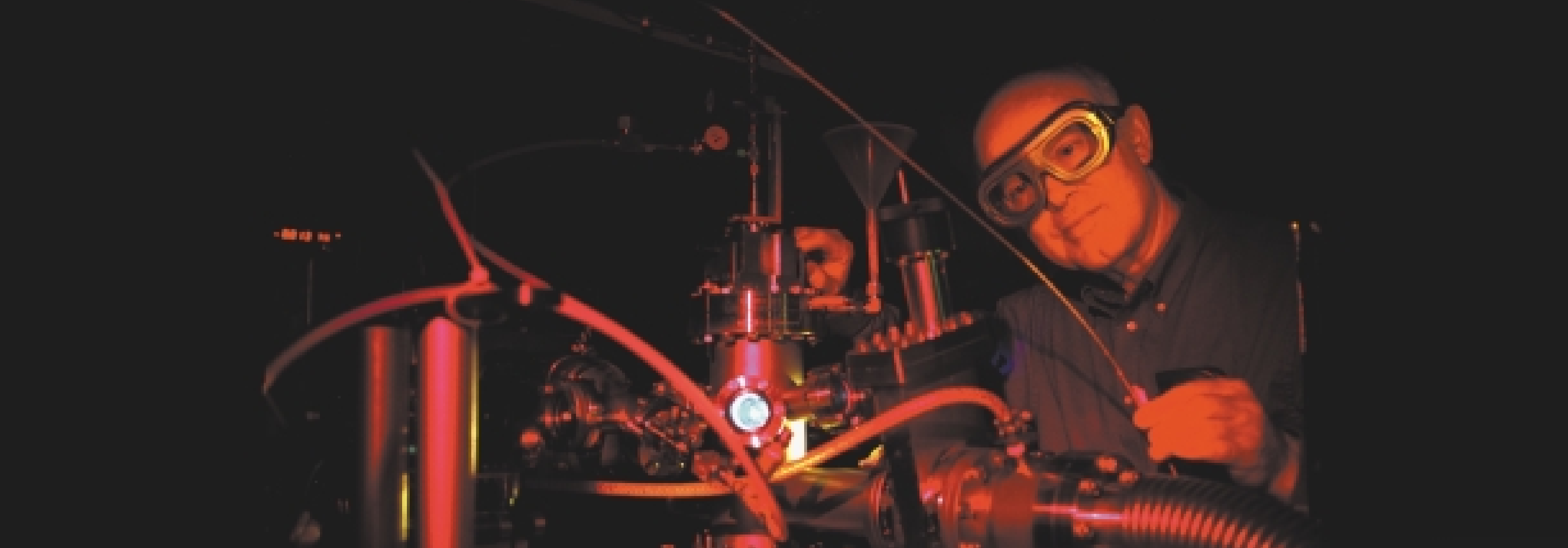

Laser-Plasma Light Source
Design and operation

John J. Joyce, Aloysius J. Arko, and Luis A. Morales

The Laser-Plasma Light Source (LPLS) developed at Los Alamos is the world's only tunable light source dedicated to transuranic photoelectron spectroscopy (PES). Our compact LPLS simulates the continuum of photon energies available at a synchrotron source, and it costs much less. The large-scale public synchrotrons generate a wide range of photons from the infrared to hard x-rays—20 kilo-electron-volts (keV)—by bending the orbit of the relativistic stored particle beam in a magnetic field. By contrast, the LPLS generates photons throughout the ultraviolet (UV) region, including vacuum UV and extreme ultraviolet (25–140 eV), by laser ionization of a metal target. The extreme power densities that are generated create a plasma in a small volume of the metal target, which emits pseudo-continuum photons over the entire UV range as a result of the recombination process between multiple-ionized multiatom interactions. The photon energy range of 25 to 140 eV includes the regions of largest 5f cross sections, greatest cross-sectional variations, and the giant 6d-5f resonances. Our current version of the LPLS consists of a krypton fluoride (KrF) excimer laser, focusing optics, a metal liquid target chamber, an energy-dispersing diffraction-grating monochromator, as well as measurement and preparation chambers.

The excimer laser system produces 800 millijoules per pulse (mJ/ pulse) at 200 hertz in 20-nanosecond pulses at a wavelength of 248 nanometers (5 eV). These 10- by 20-millimeter laser pulses are delivered to the target chamber (top photo) by turning mirrors. A two-lens assembly, which is 30 millimeters in focal length, then focuses these pulses on the target to a 50-micrometer spot size. This system generates a power density of about 1.6×10^{12} watts per centimeter squared (W/cm^2) and target temperatures on the order of 100,000 kelvins.

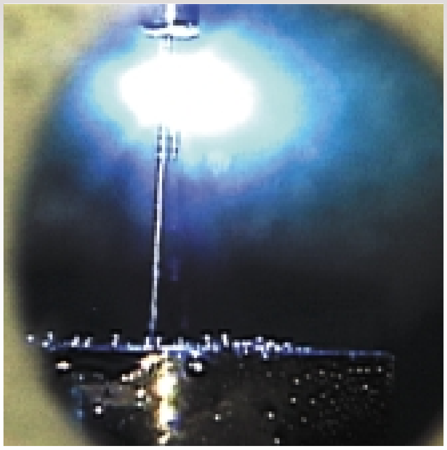

Figure 1. Mercury Stream Showing Light-Emitting Plasma

This power density is sufficient to generate a plasma at the target.

The target chamber system consists of a high-pressure mercury stream shown in Figure 1, a vacuum chamber, a mercury cold trap, a turbo pump, and magnesium fluoride (MgF_2) optics for laser input and output (for the beam portion not absorbed by the mercury stream). The plasma generated at the target produces photons with characteristic lines, as well as a broad-band spectrum covering energies from 25 to 140 eV (the entire UV region), which are used by the LPLS. The mercury target does not significantly deteriorate the input (laser) or collection (UV) optics and provides an infinite supply of plasma (source material) through the closed-cycle pumped system.

The plasma spectrum (indicated by a black line in Figure 2) is monochromatized by a variable line space, spherical-grating instrument with two diffraction gratings (nominally 450 and 900 lines per millimeter) and a resolving power of 1000 at 100 eV. We use rhodium-coated collection optics for excellent reflectivity over the UV range and inert characteristics with mercury. The monochromator portion of the LPLS (refer to Figure 2) consists of vacuum tanks and pumps that house

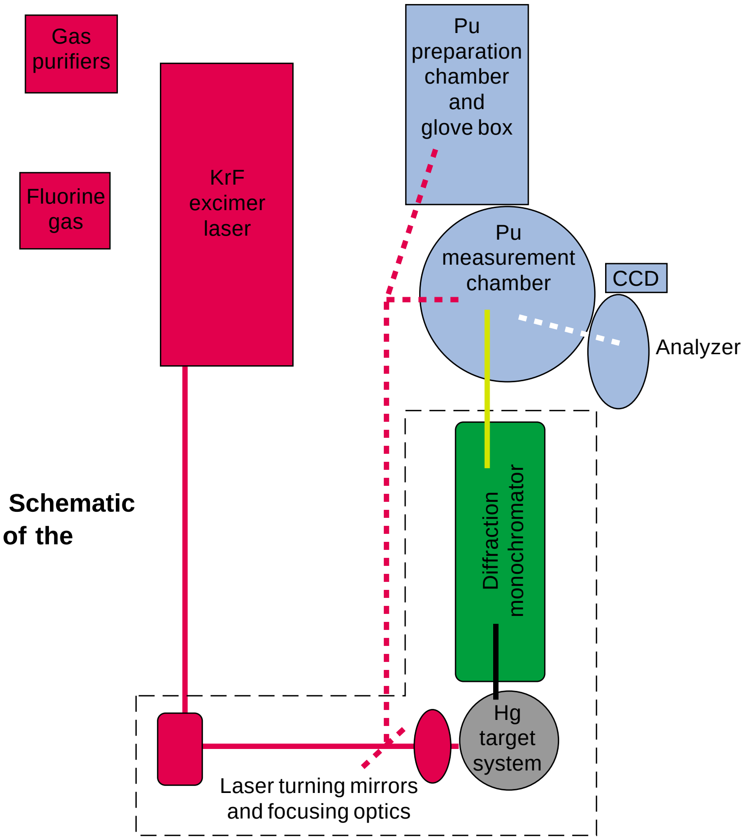

Figure 2. Schematic Diagram of the LPLS

the entrance slit (currently fixed at 75 micrometers), the plasma collection mirror, the diffraction gratings, the variable-width (35–400 micrometers) exit slit, and the refocusing mirror.

The plutonium-capable portion of the system (blue on Figure 2) consists of the measurement chamber, preparation chamber, magnetic transfer mechanisms and load locks, as well as a glove-box assembly. Samples are transported from a Los Alamos plutonium facility to the LPLS in a stainless steel magnetic-transfer arm, which is bolted onto the preparation chamber. The sample is placed behind a gate valve and is always kept under vacuum. After the load-lock region is evacuated, the plutonium samples are moved into the preparation chamber by the magnetic transport device. The preparation chamber is enclosed in a glove box.

Primary cleaning of the samples takes place in the preparation chamber to minimize contamination of the measurement system. Laser ablation, ion sputtering, and cleaving are the cleaning techniques available in the system. For laser ablation, the best method for cleaning transuranic surfaces, the laser light is diverted with mirrors onto the plutonium sample through a quartz window (red dashed line in Figure 2). We control the power density by varying an aperture and the degree of focusing and the sample heating by varying the frequency of the laser pulses.

The cleaned sample is then transferred to the measurement chamber by three additional magnetic transfer arms. Once it is in the measurement chamber, the sample is attached to a low-temperature cryostat, which can vary the sample temperature from room temperature to 20 kelvins. Many of the interesting properties of transuranic materials are observed only at cryogenic temperatures. Cleaning the surface of these materials in situ at cryogenic temperatures is essential for determining their fundamental properties and is one of the success stories of the LPLS. The cleaned, cooled sample is placed at the intersection of the monochromator focus and the electron analyzer focus. The monochromatic photon beam (green line to measurement chamber) is placed on the sample, and photoelectrons are ejected. The photoelectrons (white dashed line) are measured by a hemispherical, electrostatic analyzer whose mean radius is 100 millimeters.

For multichannel electron detection, we modified the off-the-shelf analyzer by opening the exit plane of the deflection hemispheres to 10×50 millimeters and then mounting dual microchannel plates and a phosphorus screen behind the exit plane. A charge-coupled-device (CCD) camera detects the phosphorus screen. The channel plate, phosphorus screen, and CCD camera assembly measure the energy of the photoelectrons coming through the analyzer.

The multichannel detection assembly has the potential for simultaneously collecting several photoelectron energies and angular-dispersion information. The angular information may be used to determine the crystal momentum of photoelectrons in single-crystal samples thereby expanding the usefulness of the LPLS. Future improvements in the LPLS, including an angle-resolved capability and increased photon flux, provide a path for laser-plasma sources used for transuranic research to rival the large public synchrotron facilities in capability and productivity.

Recent advances in laser technology (improved capabilities for delivering a higher laser-photon density onto the target material) now allow an increase of an order of magnitude or more in UV photon flux. Commercial solid-state lasers (Nd:YAG) now cost less than large KrF lasers and deliver a 900 mJ/pulse in 2.5 nanoseconds at 1064 nanometers, which can be focused to 25 micrometers, giving rise to power densities of about 6×10^{13} W/cm^2. Equally impressive advances in plasma technology, including photon channeling with inert gases, show promise for additional order-of-magnitude increases in plasma photon fluxes.Indeed, it is possible that such technological advances will make laboratory-based light sources comparable to the very best synchrotron facilities. ■