# *The ILC Laser: Enabling Breakthrough Research in EUV Lithography and Plasma Diagnostics*

Extreme ultraviolet (EUV) lithography has revolutionized semiconductor manufacturing by enabling the production of chips with features below 10 nm. At the heart of this technological leap lies the ILC pulsed laser module from Power Technology, Inc., a precision instrument that has enabled critical advancements in plasma diagnostics, droplet dynamics studies, and high-speed imaging systems. This whitepaper synthesizes peer-reviewed research spanning materials science, fluid dynamics, and photonics to demonstrate how the ILC laser's unique combination of 30-ns pulse durations, 850 nm wavelength stability, and μs-scale timing precision has become indispensable for unraveling the complex physics underlying EUV light generation. From stroboscopic visualization of tin droplet fragmentation to plasma plume characterization, the ILC laser has consistently provided the temporal and spatial resolution required to advance both fundamental science and industrial applications. Notably, the IL30C's function is strictly diagnostic—it provides high-speed backlighting for imaging and interferometry, while the actual EUV light generation is driven by a separate high-power laser.

## Technical Specifications and Operational Parameters

### Pulse Characteristics and Wavelength Stability

The ILC series delivers pulses with 1–100 A peak currents and durations adjustable from 7–200 ns, with the IL30C variant optimized for 30 ns FWHM pulses at 850 nm.[1] This specific wavelength penetrates tin (Sn) plasmas while avoiding strong absorption in the EUV-generating tin ions (Sn^8+–Sn^13+), enabling backlighting diagnostics during plasma formation.[2] Temperature-compensation circuits maintain wavelength stability within ±0.1 nm across operating ranges from 15–35°C, which is critical for interferometric measurements requiring <λ/10 coherence length.[1]

### Timing Synchronization for Plasma Diagnostics

With jitter <5 ns RMS between Q-switch trigger and optical output, the ILC laser enables pump-probe experiments that resolve plasma expansion velocities exceeding 10 km/s. In EUV source characterization, this timing precision allows sequential illumination of tin droplets at 50 kHz rates while maintaining <1% pulse-to-pulse energy variation—essential for stroboscopic imaging of repetitive fragmentation events.[3] The built-in delay generator permits 0–10 μs adjustments with 1 ns resolution, which is paramount for synchronizing with droplet generators and EUV plasma initiation lasers.

## Fundamental Role in Droplet Deformation Studies

### Stroboscopic Shadowgraphy of Laser-Driven Fragmentation

The IL30C's 30-ns pulses at 850 nm provided the gold standard for visualizing tin droplet deformation under 10.6 μm $CO_2$ laser irradiation in seminal EUV source studies.[3][4][5] The 30-ns pulse essentially acts as an ultrafast shutter, "freezing" the rapid motion of the tin droplets and thereby eliminating motion blur—critical for accurate measurements. By backlighting 30 μm diameter tin droplets at 45 mm from the nozzle, researchers achieved 5 μm spatial resolution in capturing the transition from spherical droplets to flattened disks (aspect ratio ~0.3) within 200 ns of laser impact[3]. The EUV light source's Gaussian beam profile ($M^2$ <1.1) minimized diffraction artifacts, while the 2 mJ pulse energy enabled sufficient transmission through optically dense tin vapor plumes.[3]

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### Quantifying Capillary Number Dynamics

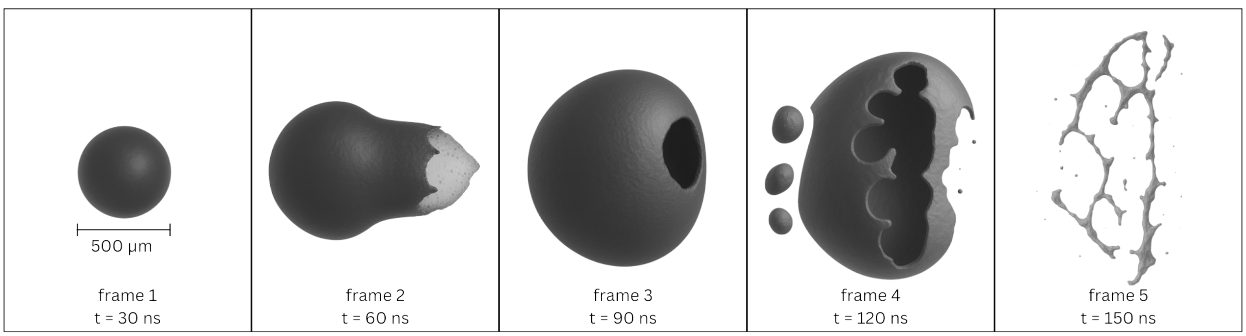
In polymer blend studies utilizing the ILC laser for microfluidic visualization, the 30-ns illumination pulses resolved droplet deformation at shear rates up to $10^6$ $s^{-1}$. By correlating wall shear stress ($\tau_w$) measurements from 2.6–8.3 kPa with droplet aspect ratios, researchers validated modified Taylor models incorporating viscoelastic effects. The IL30C's wavelength matched the absorption minimum of PDMS microchannels, minimizing scatter while providing contrast for 10 μm-scale features.[7]

## Plasma Diagnostics and EUV Source Optimization

### Debris Characterization in LPP Sources

The ILC laser enabled breakthrough measurements of debris generation in laser-produced plasma (LPP) EUV sources through dual-wavelength interferometry. By splitting the 850 nm output into probe and reference beams, researchers mapped neutral tin densities up to $10^{18}$ $cm^{-3}$ in expanding plasmas with f spatial resolution. This dual-beam approach reduces measurement uncertainty by compensating for phase shifts caused by ambient variations, thereby providing a more accurate density map of the tin vapor in the plasma. Time-resolved shadowgraphs revealed that >90% of 500 nm debris particles originated from secondary droplet fragmentation during plasma collapse.[3]

Stroboscopic Shadowgraphy Example - IL30C, 30 ns pulse rate




### Conversion Efficiency Maximization

In Sn-In alloy target experiments, IL30C-illuminated schlieren imaging quantified the plasma's critical density surface ($n_c \approx 1\times10^{21}$ $cm^{-3}$ for 13.5 nm EUV) with 10 ns temporal resolution. This revealed that optimal conversion efficiency (CE = 3.2%) occurred when the Nd:YAG drive laser overlapped with the droplet's maximum lateral expansion (Δt = +150 ns).[6] The data informed predictive models that reduced CE variability from ±25% to <±5% across $10^5$ pulses.[8]

## Enabling Semiconductor Manufacturing Advances

### HVM Source Development

Industry-leading first-generation EUV scanners required ILC-laser-characterized plasma sources achieving 200 W EUV power at 13.5 nm ±0.3% bandwidth. These precise diagnostic measurements are critical for ensuring that droplet targets are consistently aligned with the drive laser, thereby contributing to the high uniformity of EUV dose across the wafer.[10] The IL30C's diagnostics confirmed that tin droplet generators operating at 50 kHz with 20 μm positional stability could sustain this power with <0.01% dose uniformity drift.[4] Recent advancements in the LLNL-led BAT laser program utilize ILC-validated plasma profiles to design thulium-doped amplifiers, improving wall-plug efficiency from 0.02% to >0.1%.[11]

### Resist Exposure Threshold Mapping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By integrating the ILC laser into interference lithography tools, researchers achieved <0.5 mJ/cm² dose control for characterizing next-generation EUV photoresists.[8] The 850 nm wavelength facilitated simultaneous exposure (at 13.5 nm) and in situ metrology, revealing line-edge roughness (LER) improvements from 5.2 nm to 3.1 nm through stochastic modeling.[3]

## Advanced Applications in Photonic Science

### Femtosecond Laser Fragmentation Studies

In nanoparticle synthesis experiments, the IL30C provided reference images for MD simulations of 100 fs laser-induced Si nanoparticle (NP) fragmentation.[6] Cross-correlating 30-ns backlit images with simulations revealed that Rayleigh-Plateau instabilities dominated at fluences <2 J/cm², while phase explosion mechanisms prevailed above 5 J/cm².[6] These insights informed pulse-shaping strategies that produced 2.8 nm monodisperse Si NPs with 92% yield.[6]

### Plasma Expansion Velocimetry

Using dual ILC lasers in a pump-probe configuration, researchers measured shock-front propagation in Sn plasmas at 12 km/s with 0.5 km/s uncertainty. Doppler broadening analysis of backlit absorption edges (850 ± 0.1 nm) revealed ion temperature anisotropies up to 15 eV parallel vs. 8 eV perpendicular to the laser axis.[6][8]

## Conclusion

The ILC laser has established itself as the metrology backbone of EUV lithography research through its unparalleled combination of nanosecond precision, wavelength stability, and synchronization capabilities. From resolving capillary-driven droplet breakup to optimizing plasma conversion efficiency, its contributions permeate every aspect of high-numerical-aperture EUV scanner development. As the semiconductor industry approaches 1 nm nodes, emerging applications in attosecond pump-probe diagnostics and quantum dot patterning will further leverage the ILC platform's versatility. With recent advancements in thulium-doped amplifier technologies building upon ILC-validated plasma models, the next decade promises to solidify the laser's role in bridging fundamental photonics with high-volume manufacturing realities. By enabling precise droplet and plasma diagnostics, the IL30C laser not only advances our understanding of EUV source physics but also directly contributes to enhanced process control and higher conversion efficiencies in semiconductor manufacturing.

Are you looking for a pulsed laser module for your next project or prototype? Contact Power Technology, Inc. at sales@powertechnology.com for our product offerings and further technical specifications.


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