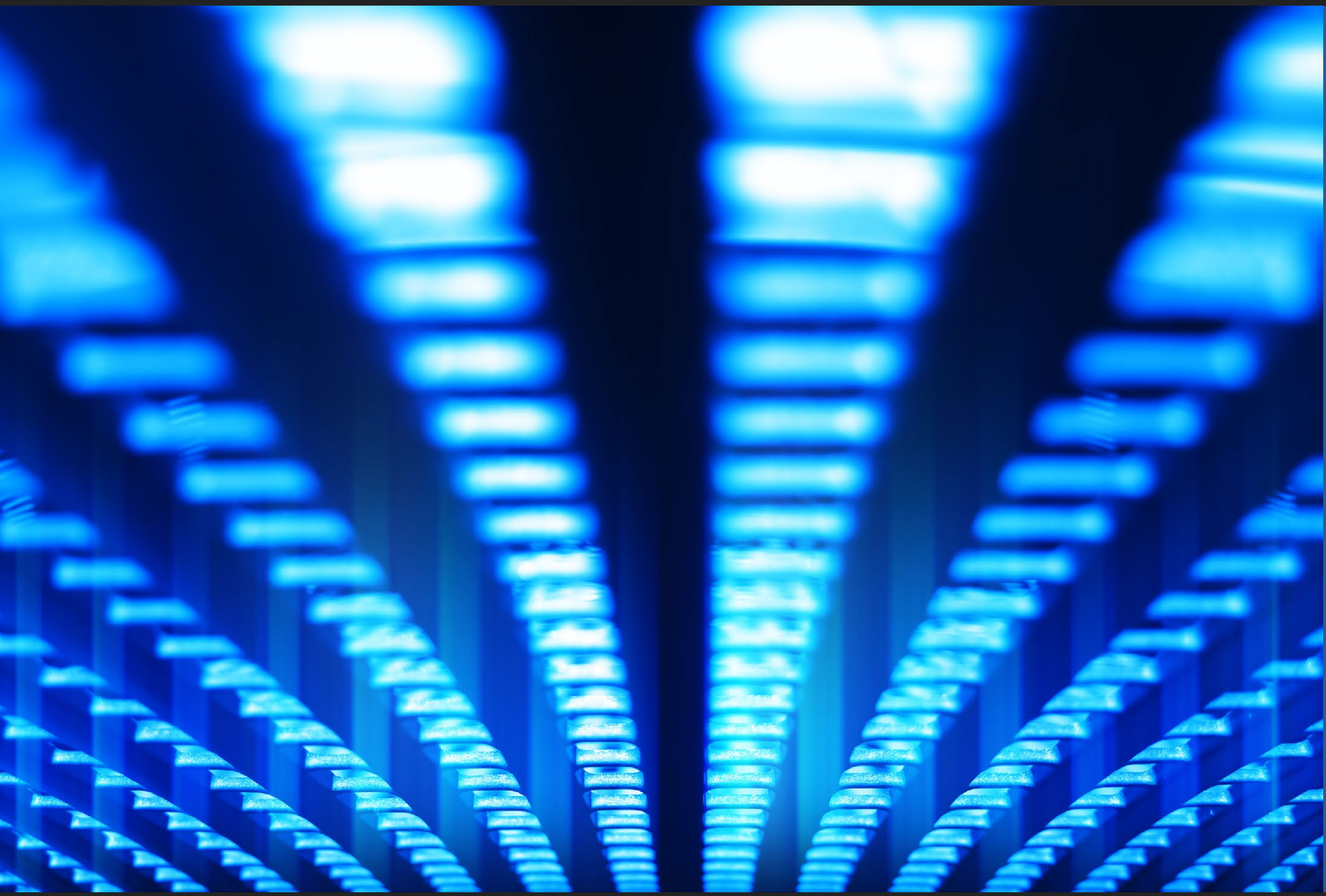
TECHNIQUIP

# 24/7 Considerations for **Semiconductor Manufacturing**

How Illumination Breaks Through Process Bottlenecks
to Improve Yield and Tool Reliability

**TechniQuip Corporation**



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# **Executive** Summary

Semiconductor fabs never sleep, and neither can the systems that support them.

Inspection tools run continuously across shifts. But even the smallest instabilities can lead to costly downtime and lost yields. Machine vision is at the heart of these operations, as they deliver defect detection, measurement, alignment, and traceability. In these, camera systems and algorithms are often the most discussed, but illumination is a hidden but critical factor of uptime, consistency, and yield.

This eBook examines 24/7 operational considerations in semiconductor manufacturing and explains why illumination stability, thermal control, firmware reliability, and serviceability matter as much as resolution or brightness.

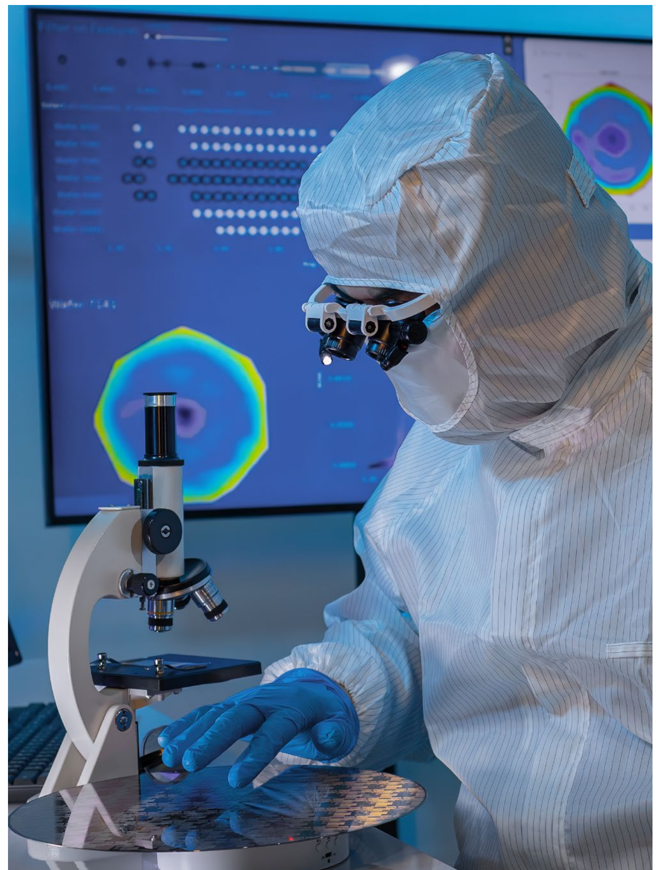
We explore how modern LED illumination is designed to support continuous, high-throughput semiconductor inspection without compromising performance.

# What 24/7 Really Means for Semiconductor Fabs

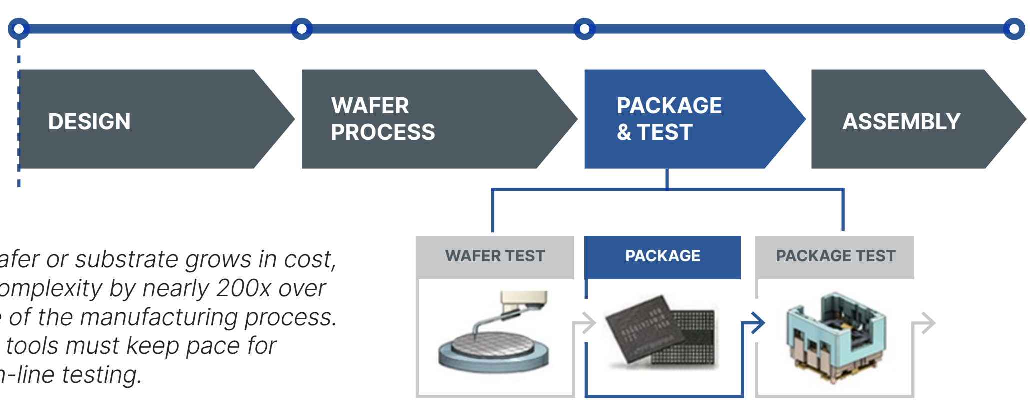
Modern semiconductor manufacturing has over **1,000 process steps**, many of which rely on machine vision and alignment systems that operate continuously. Machines must maintain consistent illumination, positional accuracy, repeatable imaging, and stable performance.

From a systems perspective, this makes the process more dependent on long-term control stability. The biggest risk to that control is drift—optical, thermal, or electrical drift.

As one of the few subsystems that couples electrical, thermal, optical, and software components, illumination in machine vision systems is a primary factor in ensuring long-term operation.



**WAFER AND PACKAGING INSPECTION PROCESS BOTTLENECKS THAT IMPACT YIELD**




*A single wafer or substrate grows in cost, risk, and complexity by nearly 200x over the course of the manufacturing process. Inspection tools must keep pace for efficient, in-line testing.*

# **Illumination:** Lighting the Way to Continuous Operations in Machine Vision

Machine vision systems are described as the core of many semiconductor processes. That's because they perform crucial visual monitoring and inspection for imaging processing workflows. Its advanced technology enables:

**24/7 Performance in Automated Processes**

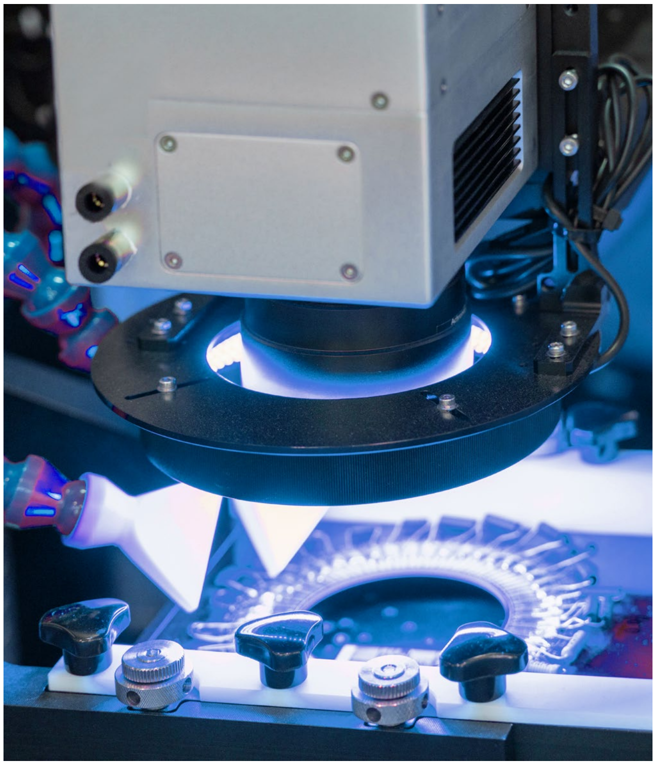
**Quick and Efficient Inspection, Taking Only Milliseconds**

**Accurate and Repeatable Results**

**Seamless Integration Into Cleanroom Environments**

But machine vision's performance depends on illumination. Illumination is a key factor in critical processes such as edge-detection accuracy, contrast formation, measurement repeatability, and scatter-signal strength.

It also affects the algorithms' radiometric input. Variations in illumination intensity or output chances algorithm behavior, even if the physical component has not changed. This makes it essential that illumination behaves as a controlled signal source.



# Illumination Technologies Used Today

Illumination technologies trade off photon efficiency, stability, and system complexity. This chart compares common illumination technologies used in semiconductor inspection, outlining their relative strengths and limitations.

| **Lamps** (Arc Lamps/Halogen/Xenon) | **LED** | **Diode Lasers** |
|---|---|---|
| Traditional broadband illumination sources that emit light over a wide spectral range and large solid angle. Historically used in bright-field inspection and microscopy. | Solid-state broadband or narrowband sources with moderate directionality, increasingly used in modern machine vision systems. | Highly directional, narrow-band sources optimized advanced defect inspection in semiconductor manufacturing. |
| **KEY BENEFITS** | | |
| • Broad spectrum enables material-agnostic inspection<br>• Mature, well-understood technology<br>• Suitable for color and multi-spectral applications | • Long lifetime and low maintenance<br>• Lower power consumption than lamps<br>• Available in multiple wavelengths<br>• Better stability than arc or filament lamps | • High directionality and small solid angle for high photon efficiency<br>• Advanced temporal and spatial stability<br>• Detection of defects below optical resolution limits<br>• Compact size, lower electrical power<br>• Beam shaping for improved uniformity and efficiency |
| **KEY DISADVANTAGES** | | |
| • Large output solid angle, meaning low photon efficiency<br>• Difficult and expensive to collimate for applications like dark-field illumination<br>• Poor temporal and spatial stability compared to lasers<br>• Higher power consumption and thermal load | • Still relatively large étendue compared to lasers<br>• Limited collimation<br>• Lower peak brightness than lasers, limiting sensitivity for sub-micron defects<br>• Less effective for high-contrast detection | • Narrow spectrum, leading to sensitivity to material reflectance<br>• Coherent speckle can be an issue in some configurations.<br>• Requires careful and precise system design<br>• Higher upfront system design complexity |

# Limits of Traditional LEDs in Illumination

Light-emitting diodes (LEDs) have transformed illumination across many industrial and scientific applications. However, not all LED-based illumination systems are suitable for continuous semiconductor manufacturing. When deployed in 24/7 inspection environments, traditional LED architectures expose a set of technical limitations that must be understood during system selection.

## LIMITATIONS OVER TIME INCLUDE:

- **Thermal Constraints from Heat Accumulation**
- **Non-Linear Output and Intensity Control**
- **Limited Power Density and Tight Illumination Geometries**
- **Inconsistent Pulse Energy and/or Jitters**
- **Gradual Output Degradation Over Time**
- **Stray Lights and Signal-to-Noise Challenges**

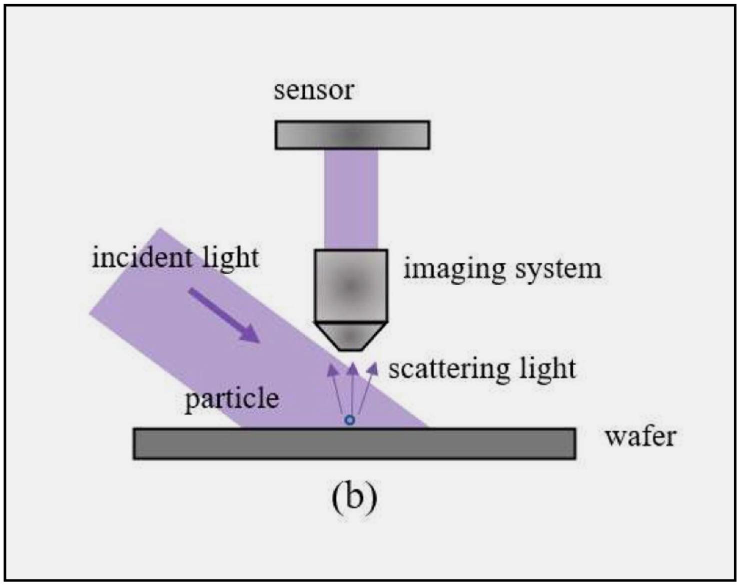
These limitations do not imply that LEDs are inappropriate for semiconductor use, but rather that illumination architecture, control, and integration matter as much as the light source itself.

# Considerations for Choosing the **Right Illumination System**

Selecting the right illumination system is not just about brightness. In high-volume manufacturing, illumination must support consistent inspection results over time and across the process. Consider the following factors and your machine vision needs:

| If you have..... | Use illumination... |
|---|---|
| **Particles / micro-scratches**<br>***Visual cue:*** *Bright specks / threads on black* | **Darkfield** |
| **RDL open / short / pattern integrity**<br>***Visual cue:*** *Crisp edges; defect flips with* direction | **Coaxial + Oblique** |
| **Hybrid bonding sub-micron defects**<br>***Visual cue:*** *Sparkle defects + subtle tone* changes | **Darkfield + Coaxial (add UV if needed)** |
| **Organic residues / surface haze**<br>***Visual cue:*** *Haze / film contrast increases* | **UV (Spectral)** |
| **Inner cracks / voids / backside concerns**<br>***Visual cue:*** *Soft subsurface outlines* | **IR (Spectral)** |
| **Warpage / micro-bumps / placement**<br>***Visual cue:*** *Fringes or height map* | **3D/Interferometric** |
| **Glass carrier grading / stress**<br>***Visual cue:*** *Brightness changes with POL rotation* | **Polarization** |
| **Laser grooving / directional marks**<br>***Visual cue:*** *Directional highlight / shadow reveal* | **Oblique / Multi-azimuth** |

# Featured System:
# Darkfield Scatter Inspection




In shorter test cycles, many illumination systems appear adequate. Over months of uninterrupted operation, the subtle instabilities become obvious.

Darkfield scatter inspection, however, is an example of a system meeting the most stringent demands of illumination stabilities. It detects defects by capturing light scattered by surface irregularities, rather than reflected features.

## HOW DOES IT WORK?

**Imagine:** you spill something in your garage. The bright overhead lights will let you see the spill's surface on the floor through reflection. But if you take a flashlight on the floor of the garage, it'll pick up the surface, dust, pattern, and the edge of the spill. Every time it hits anything, it refracts and shows a bright spot.

Darkfield is like that flashlight picking up the edge of a spill rather than just the surface.

But darkfield is highly sensitive over a long period of time because it is under strict requirements, such as:

| Precise Angular Control | High Irradiance | Aggressive Suppression of Stray Light |
|---|---|---|

Since they are subtle by design, illumination drift can easily be misinterpreted as process drift, making illumination quality and stability important over time..

# **Talon:** Purpose-Built for Semiconductor Inspection

Meeting the demands of darkfield scatter inspection and other machine vision systems, especially in 24/7 semiconductor manufacturing, requires an illumination system designed around control, stability, and long-term repeatability, not just brightness. TALON was developed with these requirements in mind.

Rather than placing high-power light sources directly at the inspection plane, TALON supports illumination architectures that separate light generation from light delivery, often using fiber-based approaches. This enables:

**Thermal Management Away From the Wafer**

**Flexible Beam Shaping and Angular Control**

**Reduction of Stray and Uncontrolled Light**

By controlling where light is generated and how it is delivered, TALON aligns with the core needs of semiconductor inspection: **high signal-to-noise ratio and minimal background interference.**

# Calibration for **Tool-to-Tool Consistency**

Semiconductor manufacturing is not a uniform process; different fabs, nodes, and tools impose different constraints. Illumination systems must therefore adapt to the process, not the other way around.

Calibration is huge because it is the cornerstone of everything in semiconductor fabs. It maintains consistency: the same exact way every day. If its outputs are trending down 10%, reset it. It's like anti-aging products, but for your machine; it makes it feel exactly the same as when it was new – when uptime was at its peak.

| CALIBRATION AS A MECHANISM IN ILLUMINATION ENSURES: |
| --- |
| Correction for non-linear LED response |
| Removal of per-unit variation |
| Definition of safe and usable operating ranges |
| Improved tool-to-tool imaging consistency |

Without calibration, even identical illumination systems will diverge due to component tolerances, aging, and environmental differences. This is a form of predictive maintenance, where illumination performance is managed proactively rather than reactively.

# Calibration with **Talon's FlightDeck**

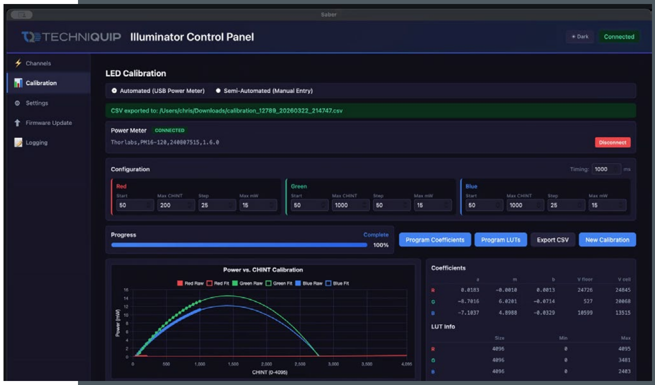
TALON's differentiator is that it supports field-configurable and field-calibratable operation, rather than locking calibration at the factory. Its recalibration allows for changes when environmental conditions change, hardware components are replaced, and long-term drift becomes measurable. Using its intuitive FlightDeck operating system, it enables:

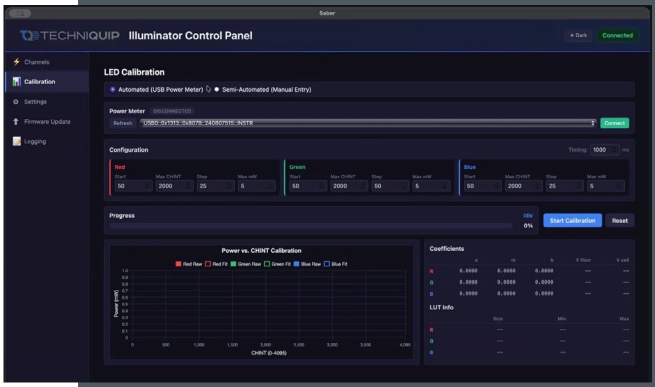
**Customer-Specific Configurations**

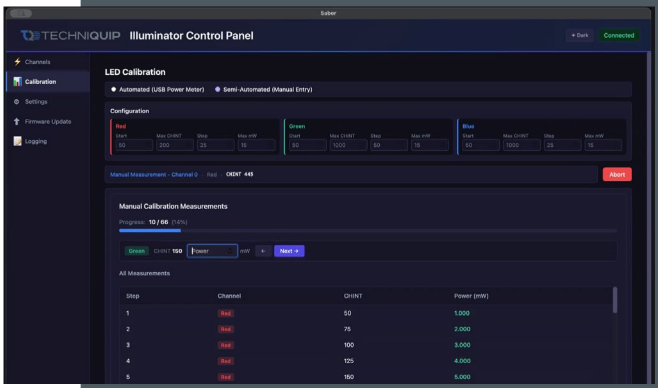
**Storage of Calibration Data**

**Fault Detection and Handling**

**Control of Operating Parameters**




This makes illumination deterministic, repeatable, and embedded directly into the OEM inspection workflow.

# Illumination Enabling **Innovation**

Across the industry, one fact remains certain:

**In 24/7 semiconductor manufacturing, illumination must be stable, controllable, and calibratable. It is a foundational system that directly impacts inspection confidence, yield stability, and tool uptime.**

TechniQuip partners with semiconductor OEMs and manufacturers to design illumination systems built for 24/7 operation, combining configurable hardware, software-driven control, and field calibration to support consistent inspection performance over time. Work alongside our team to ensure illumination aligns with your process, environment, and workflow requirements.

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*Designed and built in Pleasanton, CA*