# Laser Micromachining – Process–Material Matrix

## Technical Resource | Process Selection & Material Compatibility Guide

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### Executive Summary

This document is a standalone engineering reference focusing on laser micromachining process matching, material compatibility and industry application standards. It provides quantified laser source selection parameters, full material process matrices for metals, polymers, ceramics and glass, Suitable for process specification writing, supplier evaluation and production feasibility verification.

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## Process–Material–Application Matrix

This chapter provides actionable, production-grade reference matrices for laser source selection, material-process compatibility, and application-specific process rules. It serves as a quick-lookup engineering resource for laser micromachining specification writing, supplier validation, and process feasibility judgment.

### Laser Source Selection Guide

Different laser wavelengths and pulse regimes determine machining precision, heat-affected zone, processing speed and overall cost. The following table summarizes core parameters and applicable scenarios for mainstream laser sources.

| Source | Wavelength | Pulse Regime | Best For | Tolerance Capability | Relative Cost |
|---|---|---|---|---|---|

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|---|---|---|---|---|---|
| Fiber (IR) | 1064 nm | ns / ps / fs | Deep penetration, high-speed cutting | ±10–25 µm | Baseline |
| Green (VIS) | 532 nm | ps / fs | Balanced absorption, reduced HAZ | ±5–15 µm | 1.5–2× |
| UV | 355 nm | ns / ps | Cold ablation, polymer machining | ±3–10 µm | 2–3× |
| DUV | 266 / 213 nm | fs | Minimum HAZ, sub-5 µm features | ±1–5 µm | 4–8× |
| $CO_2$ | 10.6 µm | CW / ms | Polymers, organics, thick films | ±20–50 µm | 0.8–1.2× |

## Material–Process Compatibility Matrix

This matrix quantifies key machining indicators for mainstream industrial materials, including kerf width, HAZ, surface roughness and processing notes, supporting rapid process selection and quality evaluation.

### Metals

| Material | Recommended Source | Typical Kerf (µm) | HAZ (µm) | Surface Roughness Ra (µm) | Notes |
|---|---|---|---|---|---|
| 304/316L SS | IR / Green / UV | 15–25 | 10–50 | 0.4–1.2 | UV for minimal discoloration |
| Ti Gr2/Gr5 | UV / DUV / Green | 10–20 | 5–30 | 0.3–0.8 | Oxidation-sensitive; DUV preferred for implants |

| | | | | | |
|---|---|---|---|---|---|
| Nitinol | DUV / fs-Green | 8–15 | <10 | 0.2–0.6 | Heat-affected zone must be <20 µm to preserve superelasticity |
| Pt-Ir | UV / DUV | 10–18 | <8 | 0.2–0.5 | Noble metal; reflectivity challenges at 1064 nm |
| Cu / Al | Green / UV | 12–22 | 10–40 | 0.5–1.0 | High IR reflectivity; avoid 1064 nm for fine features |
| Invar / Kovar | IR / Green | 15–25 | 15–40 | 0.5–1.2 | Low CTE; critical for hermetic packages |

## Polymers

| Material | Recommended Source | Kerf (µm) | HAZ / Char (µm) | Notes |
|---|---|---|---|---|
| PEEK | UV / DUV / $CO_2$ | 20–40 | 10–30 | Medical grade; verify biocompatibility post-processing |
| Polyimide (Kapton) | UV / DUV | 15–30 | 5–20 | Flexible circuit substrates; clean edges critical |
| LCP | UV / DUV | 12–25 | <15 | High-performance RF substrates; minimal debris |
| PMMA | $CO_2$ / UV | 50–100 | 20–50 | Prototyping; not for implantable |

## Ceramics & Glass

| Material | Recommended Source | Kerf (µm) | Chipping (µm) | Notes |
|---|---|---|---|---|
| Alumina (96%) | UV / DUV | 20–40 | <10 | Substrate machining; avoid subsurface cracks |
| Zirconia | DUV / fs-IR | 15–30 | <8 | Dental/medical implants; surface integrity critical |
| Sapphire | DUV / fs-IR | 10–25 | <5 | Optical windows; anisotropic machining |
| Fused Silica | DUV / fs-IR | 12–20 | <3 | UV-grade optics; subsurface damage must be characterized |
| Silicon | UV / DUV | 8–18 | <5 | MEMS, interposers; crystallographic orientation matters |

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