Main Types of Lasers Used for Manufacturing- Key Properties and Key Applications

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Topics

- Laser Output Wavelengths
- Laser Average Power
- Laser Output Waveforms (Pulsing)
- Laser Peak Power
- Laser Beam Quality (Focusability)
- Key Properties
- Key Applications
- Beam Delivery Styles
Compared to standard light sources…

- Laser Light is **Collimated** - the light rays are parallel to and diverge very slowly - they stay concentrated over long distances - that is a “laser beam”
- Laser Light has high **Power Density** - parallel laser light has a power density in watts/cm² that is over 1000 times that of ordinary incandescent light
- Laser Light is **Monochromatic** - one color (wavelength) so optics are simplified and perform better
- Laser light is highly **Focusable** - low divergence, small diameter beams, and monochromatic light mean the laser can be focused to a small focal point producing power densities at focus 1,000,000,000 times more than ordinary light.
Laser Light

• 100W of laser light focused to a diameter of 100um produces a power density of 1,270,000 Watts per square centimeter!
Examples of Laser Types

- **Gas Lasers**: Electrical Discharge in a Gas Mixture Excites Laser Action:
  - Carbon Dioxide (CO$_2$)
  - Excimer (XeCl, KrF, ArF, XeF)

- **Light Pumped Solid State Lasers**: Light from Lamps or Diodes Excites Ions in a Host Crystal or Glass:
  - Nd:YAG (Neodymium doped Yttrium Aluminum Garnet)
  - Yb:Fiber (Ytterbium doped glass fiber)
  - Yb:Disk (Ytterbium doped YAG disk)
  - Nd:YLF & Nd: YVO$_4$ (vanadate)

- **Electrically Excited Solid State Lasers**: Diode Lasers
  - GaAlAs- Gallium Aluminum Arsenide Diode Lasers
  - InGaAs- Indium Gallium Arsenide Diode Lasers
Industrial Lasers by Wavelength

- **X-Ray**
  - X3 ~355nm
  - X4 ~266nm

- **Ultraviolet**
  - X3 ~355nm
  - X4 ~266nm

- **Visible**
  - X2 ~532nm

- **Near-Infrared**
  - Yb:Disk 1030nm
  - Yb:Fiber 1080nm
  - Nd:YAG 1064nm

- **Mid-Infrared**
  - GaAlAsDiode (750nm-850nm)
  - InGaAsDiode (904nm-1065nm)
  - Er:Fiber 1552nm

- **Far-IR**
  - CO2 10.6μm (9.2-11.4μm)
  - Th:Fiber ~1940nm (1800nm-2100)

**Excimer Lasers**
- ArF 193nm
- KrF 248nm
- XeCl 308nm
- XeF 351nm

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Wavelength of a Laser Source

- Specific to the Material that is in the Lasing Medium
- Physics favors higher average power lasers in the invisible regions of the near and mid-IR: 750nm-1100nm solid state lasers and 10.6μm CO₂ laser. These lasers can have powers over 20kW.
- Mid-IR lasers like 1940nm Thulium:glass lasers are available in ~150W average power units.
- 1550nm Erbium glass lasers are being used with ultra-short pulses in the ~800femtosecond range for fine machining at <10W.
- Visible lasers are typically pulsed frequency doubled 1μm lasers at ~532nm. Average powers are typically <50W.
- UV lasers are Excimer gas lasers or frequency tripled or quadrupled 1μm solid state pulsed lasers at ~266nm and ~355nm.
  - Excimer lasers have powers of a few Watts to ~125W
  - Frequency tripled lasers up to ~25W
  - Frequency quadrupled lasers up to ~5W
Laser Power Output

• Lasers operate either as Continuous Wave (CW) lasers where output power is constant over time or as Pulsed Lasers where the laser output is produced in discrete pulses.
  – CW lasers can generally be gated on and off, change their CW power level and ramp between power levels. Their output is measured in Watts (Joules/sec).
  – Pulsed lasers have an enhanced peak power during their short pulses creating kilowatt up to megawatt peak power while maintaining rather low average powers. Pulse energy is measured in Joules (Watt-sec), often in mJ or µJ.
• Pulsed lasers store energy in the power supply and/or the lasing medium during the “off-time” to create the high peak power.
Choosing CW or Pulsing

• CW lasers can process more quickly and perform deeper penetration or fast thin material processing.
  – Small focus spots create a high power density for narrow cuts and welds that keep heat input low in thin materials.

• Pulsed lasers use their high peak power pulses to process material with less heat affect by short interaction times of the pulse or by the quick release of a large energy pulse.
  – Pulsed welding creates fast spot and seam welds at low total heat input
  – High peak power and high energy pulses will cut or drill metals.
  – Still higher peak power pulses will cause ablation of the material.

• Their need to overlap pulses and generally lower average power relegates them to slower processing or high speed processing in thinner materials or surface layers.
Laser Pulsing Characteristics

Q-switched or amplified pulses
Up to ~50kHz
1nsec-200nsec

Ultra-Short pulses
Up to ~100kHz
100s of femtoseconds
100s picoseconds

Power supply pulsed laser
Laser Ablation

• Removal of material with minimum heat input.
  – Laser pulse duration very short: <~10μsec
  – Laser peak power density very high
  – Laser absorption in thin layer of target’s surface
• Material ejected faster than heat can be conducted to lower layers.
• Very common in UV lasers due to short pulses and vigorous action of UV light in thin surface layer
• Possible at all wavelengths with high peak power density and absorbing target material.
Laser Choice by Wavelength?

• Target material must absorb the laser beam for good processing.
• Initial low absorption by metals becomes high absorption once the metal begins to melt.
• All iron alloys, superalloys, and aluminum alloys process well with 1\( \mu \)m and 10\( \mu \)m lasers.
  – Copper and precious metals often processed more efficiently with 1\( \mu \)m and 532nm lasers.
• Plastics, organics, wood, and paper react best to 10\( \mu \)m lasers.
• Many plastics and polymers require testing and trials to determine the best laser wavelength and/or the polymer formulation.
Laser Focusability (beam quality)

- Lasers have good focusability but some are better than others.
- Laser Physicists measure focusability by their comparison to a diffraction-limited beam which could be focused to the minimum spot size—about 3 times the laser wavelength.
- Lasers with good beam quality can make a narrower cut, ablate material more efficiently, and use a longer focal length lens for the same focus spot size.
- A long focus lens provides more depth-of-focus.
- Near-perfect beam quality is often needed for nano and micro processing.
- For larger parts and high laser power, excellent beam quality is not necessary.
Laser Beam Quality

• Lasers with very good beam quality are called many things- Single Mode, TEMoo mode, Gaussian Mode, or $M^2=1$ beams. Trust your laser vendor and process trials to help you determine what works best for your process. Fine features that are less than ~10X the laser wavelength will require a single mode laser or special imaging techniques.

• Higher power lasers will be more efficient and less costly when allowed to have poorer beam quality so there is savings in not needing perfection. Many laser processing operations today are carried out by laser beams that are more than 50X worse than “perfect”. Focusing to a spot size of 600um will often do the job better than focusing to 10um.
Laser Beam Quality Definitions

- Diffraction limited lasers are Single Mode or TEM\textsubscript{00}. They have an M\textsuperscript{2} value of <1.1 (better than 1.1X diffraction limited). These lasers must be mirror delivered lasers except for single mode fiber delivery from Fiber Lasers. Fiber size is typically ~10\textmu m dia. This is the highest beam quality possible. Low power lasers can all produce a diffraction limited output.

- High beam quality does not mean perfection and is generally related to the laser’s average power, also. For example, delivering 1000W with a 50\textmu m fiber has an M\textsuperscript{2} value of about 6-6X diffraction limited- this is high beam quality for a 1kW fiber delivered laser. A 16kW Disk or Fiber laser delivered with a 200\textmu m fiber will have an M\textsuperscript{2} value of about 24. That is also very good beam quality.
Laser Beam Quality Definitions

- $M^2 = (\pi/4\lambda) \times (\text{Dia.} \times \text{div.})$ ($\lambda$ in $\mu$m, Dia. in mm, div in mrad.)
- Some Use the term Beam Parameter Product (BPP) which is similar to the diameter $\times$ divergence term in the $M^2$ definition but uses the radius and $\frac{1}{2}$ angle divergence (mm-mrad). BPP can be used to compare lasers of the same wavelength.
  - BPP = Radius $\times$ $\frac{1}{2}$ angle divergence = $M^2 \lambda/\pi$
    - For 1$\mu$m lasers the BPP is about $(1/3)M^2$
    - For 10.6$\mu$m laser the BPP is about 3$M^2$
- Note that from the definition of $M^2$- A CO$_2$ laser at 10.6um will have an $M^2 = 1$ but produce a focus spot size that is 10X that of a 1.064um solid state laser. That means that a solid state laser with 10X worse beam quality will be comparable in focus power density to a diffraction limited CO2 laser.
- For High Power lasers- high beam quality will generally be related to $M^2$ values of 1-3 for CO$_2$ lasers and 1-30 for 1$\mu$m lasers. (BPP $<$10 for 1$\mu$m and 10.6$\mu$m lasers)
Types of Lasers

- CO2 Sealed
- CO2 High Power Sealed
- CO2 Flowing Gas
- TEA CO2
- Excimer
- YAG Flashlamp Pumped
- YAG Diode Pumped
- Disk
- Fiber
- Ultra-Short Pulsed Lasers
- UV solid state lasers
- Diode Lasers
Sealed CO2 Lasers

• Sealed gas volume
  – RF energized (pumped)
    • Laser cooled by chilled RF electrodes near discharge
    • Average power up to 1kW- a large number in the 10-200W range- air cooled option at low power
  – High Voltage DC pumped
    • Diffusion cooled to flowing water in glass envelope near discharge
    • Average powers up to ~200W, typically 50-100W
• Wavelength can be selected: 9.4um, 10.2um, or ~10.6um
• Some have high peak power pulsing
• High beam quality for good focusability- M² <1.5
• Mostly non-metals processing below 200W.
SEALED CO2 Lasers
SLAB and Diffusion Cooled Coax CO2 Lasers

- 1kW- 8kW similar to sealed units but have internal gas recharge cylinders, $M^2 < 1.1$
Flowing Gas CO2 Lasers

- Gas moved by turbine or blower through heat exchangers and discharge area
- Small continuous gas usage (He, N2, CO2)
- 1kW-20kW average power, M2<2
- RF and DC high voltage power supplies can be used
TEA CO2 Laser

- Transverse Excited Atmospheric Laser - 1 atm gas
- No vacuum system
- High peak power ~1MW level, ~25-100W average power
- Ablative processing and marking - ~1 μsec pulse duration
- Rectangular Beam, low beam quality, M² ~20 (BPP~60)
Excimer Lasers

- Similar to TEA CO2 laser but ~4atm gas fill
- Vacuum system for gas replacement
- Special gas cabinet for fill gases
- ~15nsec pulse duration
- Rectangular beam $M^2 \sim 100$
Nd:YAG Flashlamp Pumped

- CW, Pulsed or Q-switched
- High peak power when pulsed
- Require water cooling
- Different lamps and power supplies used for pulsing vs. CW
- Pulsed YAGs and q-switched units are the most common
- Many configurations for beam quality and peak power
- $M^2$ from 1 to ~132. $M^2$ ~1 at up to 40W
- Drilling and Cutting YAGs have $M^2$ ~20-50
Nd:YAG Pulsed Lasers

- Many manufacturers have whole families from ~25W to 600W
- Most are fiber delivered
- Some high peak power units designed for drilling are mirror delivered
Nd:YAG: Diode Pumped

- Pumped by Diode Lasers that are fiber delivered or mounted near the laser rod. Can be side or end-pumped.
- Much higher efficiency and better focusability- pumped with the exact light to convert to laser output. M2 < 4
- Typically less than 100W average power.
- Used extensively for marking lasers with q-switched output.
Diode Pumped Lasers
Disk Lasers

- Use of a Ytterbium Doped YAG disk that is diode pumped.
- Physics of Disk and large flat surface for pump light makes a very efficient source that can be scaled from a few watts to over 16kW. High beam quality CW laser.
- The output can be q-switched and frequency converted at lower average powers for marking and fine material processing.
- BPP from 4-8 mm-mrad from 1kW-16kW ($M^2 = 12-24$)
Disk Lasers

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Fiber Lasers

- Diode laser pumping of a long Ytterbium doped glass fiber produces laser light efficiently and already contained in a fiber.
- This laser can be scaled from a few watts to over 20kW with high beam quality at all power levels. $M^2$ 1-24 from 1- 20kW.
- Can use a pulsed seed laser for high peak power pulses.
- The output can be q-switched and frequency converted for marking and fine material processing at lower average powers.
- With pulsed pump diodes - high energy and high peak power pulsed operation like an Nd:YAG laser- termed QuasiCW (QCW)
Fiber Lasers

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Short and Ultra-Short Pulsed Solid State Lasers

- Rod, Disk, and Fiber lasers that employ q-switches and pulse compression hardware to produce laser pulses in the ~150nsec to femto-second range.
- Cannot be fiber delivered due to their high peak power.
- Used for ablative processes such as marking, surface texturing, drilling, and cutting with very low heat input.
- All high beam quality $M^2 < 1.5$

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UV Solid State Lasers

- Frequency Tripled and Quadrupled solid state lasers (~355nm and ~266nm)
- High peak power, short pulse width lasers
  - 40nsec pulses
  - 6kW peak power
- High beam quality $M^2 < 1.3$
Diode Lasers

- Instead of only pumping solid state lasers, the Diode Lasers themselves can be use for laser processing
- Can be a stack of laser diodes or fiber-delivered sources.
- Their focusability is poorer than other lasers but they have the highest laser efficiency. $M^2 \sim 75++$ (BPP $\gg 20$
- Can be delivered directly, with fibers, or with mirrors.
- Can choose wavelength over a broad range
- Rectangular output fits cladding and heat treating applications
- Can be easily scaled from a few watts to over 10kW.
Diode Lasers

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Defining the Key Laser Properties

• The Key Properties can be sorted by:
  – CW Power- High and Low (above/below ~500W)
    • High Power CW CO2, Fiber, Disk, and Diode
      – Higher Beam Quality – CO2, Fiber, Disk
        » 1μm lasers- metals- Fiber, Disk (fiber delivery)
        » 10μm lasers- CO2- metals and non-metals (mirror delivery)
      – Lower Beam Quality- Diode, Green
  – Pulsing Characteristics
    • Long Pulse, ~0.1msec and longer
    • Short Pulse, ~1nsec – 200nsec
    • Ultra-Short Pulse, ~ 1000femtoseconds
  – Wavelength
    • CO₂ vs. Solid State vs. Green vs. UV
## Key Breakdown

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### Key Breakdown

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## Key Breakdown - high power CW

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**Key Breakdown - high power CW**

- **CO2**: High (CW, >500W)
- **YAG**: Low (<500W)
- **QCW Fiber**: Pulsed (Long, >0.1msec)
- **FIBER**: Ultra-short (Ultra-Short, <1nsec)
- **DISK**: High (CW, >500W)
- **DIODE**: Low (<500W)
- **Green SS**: Short (Short, 1nsec-0.1msec)
- **UV SS**: Ultra-Short (Ultra-Short, <1nsec)
- **Excimer**: High (CW, >500W)

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Key Property- CW High Power, High BQ

- CO2, Fiber, and Disk lasers are all similar in focus spot size, power levels, and depth of focus, all can process metals
  - Metal Cutting
  - Keyhole Welding
  - Brazing
  - Heat Treating
  - Cladding
- Flat Sheet Cutters, 5-axis Cutters, Welding macro parts
- Beam Quality Sufficient for Remote Welding
- 1μm lasers have a ~4X absorption advantage in Brazing, Heat Treating and Cladding.
- 1μm lasers have an advantage in electrical efficiency
- 1μm lasers can use fiberoptics
- 10μm lasers have the advantage in non-metals and processing legacy
### Key Breakdown - CW CO₂

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**CO₂**

- **High (>500W)**
  - High BQ
  - Low BQ
- **Low (<500W)**
  - High BQ
  - Low BQ

**YAG**

- **High (>500W)**
- **Low (<500W)**

**QCW Fiber**

- **High (>500W)**
  - High BQ
  - Low BQ
- **Low (<500W)**
  - High BQ
  - Low BQ

**Fiber**

- **High (>500W)**
  - High BQ
  - Low BQ
- **Low (<500W)**
  - High BQ
  - Low BQ

**Disk**

- **High (>500W)**
- **Low (<500W)**

**Diode**

- **High (>500W)**
- **Low (<500W)**

**Green SS**

- **High (>500W)**
- **Low (<500W)**

**UV SS**

- **High (>500W)**
- **Low (<500W)**

**Excimer**

- **High (>500W)**
- **Low (<500W)**

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Tom Kugler - Laser Mechanisms
Key Property CW CO$_{2}$

- 10.6um wavelength allows processing of most all non-metals as compared to 1um lasers
- Excellent beam quality for high power density and fine work across all power ranges
- Many laser sources have enhanced peak power pulsing for lower heat input
- Choosing 9.4um, 10.2um or 10.6um enhances these lasers capabilities in polymer processing
- ~40 years of advancement is producing high quality systems
High Power CW Apps

Tom Kugler - Laser Mechanisms
High Power CW Apps
Non Metal Cutting

Tom Kugler - Laser Mechanisms
### Key Breakdown - Low power 1 μm

#### Groupings for Key Laser Properties

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<th>MID IR</th>
<th>NEAR-IR</th>
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Key Property- CW Low power 1µm

- The key to these lasers is focusability and absorption
- Low power 1µm lasers have the beam quality to keep producing keyhole welds and fine kerfs in metals where the CO2 laser’s larger focus spot size results in lower power density.
- Welding to depths of a few mm at lower power CW levels introduces a whole new level of distortion free welding of fine components.
- 100W single mode fiber lasers can produce ~10um focus spot sizes for fine cutting with their single mode output.
Key Low Power 1um Apps

- Battery welding, Fuel Injector welding, Fuel Cell welding, medical device welding, consumer goods
- Medical device cutting, fine mechanical component cutting
- Marking
- Laser Sintering
### Key Breakdown - Diode BQ, $\lambda$, s, eff.

#### Groupings for Key Laser Properties

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Key Property- Diode Laser BQ, Wavelength(s) and Efficiency

- Diode Lasers do not have the Beam Quality for Keyhole Welding and Fine-Kerf cutting at this time but:
  - The poorer beam quality results in a better fit of the laser beam shape to heat treating, cladding, and brazing operations.
  - Diode laser wavelength is strongly absorbed by the metals
  - Conduction mode welding of some components is a natural effect of the larger focus spot size.
  - The laser wavelength(s) can be chosen to optimize the interaction with materials, especially when welding plastics.
- Diode Lasers have electrical efficencies in the 50% range for economy.
Key Diode Laser Apps

- Cladding, Heat Treating, Brazing, Conduction Welding, Plastic Welding
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**Key Property Breakdown**

- **CW**
- **PULSED**
  - **Long Pulsed SS**
    - High (>500W)
      - high BQ
      - low BQ
    - Low (<500W)
      - high BQ
      - low BQ
  - **Short Pulsed SS**
    - high BQ
    - low BQ
  - **Ultra-Short Pulsed SS**
    - high BQ
    - low BQ

**Laser Mechanisms**

- CO2
- YAG
- QCW Fiber
- FIBER
- DISK
- DIODE
- Green SS
- UV SS
- Excimer

**Tom Kugler - Laser Mechanisms**

**Groupings for Key Laser Properties**

- **MID IR**
- **NEAR-IR**
- **VIS**
- **UV**

**Key Breakdown**

- **High (>500W)**
- **Low (<500W)**
- **Long (>0.1msec)**
- **Short (1nsec-0.1msec)**
- **Ultra-Short (<1nsec)**
Key Property- Long Pulsed Solid State

- The peak power of solid state lasers with long pulses allows them to input high energy into materials for:
  - Spot Welds
  - Overlapping Spots for Seam Welds
  - Drilled Holes
  - Cutting
- Achieving kW peak powers in a ~10-600W avg. power laser is their niche.
- Configurable for beam quality and the ability to use fiber delivery for most welding tasks and mirror delivery when the peak power is very high for drilling and cutting.
- Operating at M2=1 they can be used for fine cutting and welding
- Operating at M2 = 20 and peak powers in the 20-40kW range. they can drill through up to 20mm of superalloy.
- Operating at M2 = 75 they can produce large strong spot welds.
Key Apps- Long Pulsed SS Lasers

- Spot and Seam Welds
- Medical Devices
- Spark Plugs
- Batteries
- Fuel Injectors
- Electrical Connectors
- Hermetic Packages
Key Apps- Long Pulsed SS Lasers

- Aerospace cooling hole drilling
- Aerospace component cutting
- Oil hole drilling in gears
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- **CO2**: Continuous Wave, High (>500W)
- **YAG**: Pulsed Wave
- **QCW Fiber**: Long Pulse Wave
- **FIBER**: Ultra-Short Pulse Wave
- **DISK**: Short Pulse Wave
- **DIODE**: Long Pulse Wave
- **Green SS**: Short Pulse Wave
- **UV SS**: Ultra-Short Pulse Wave
- **Excimer**: High (>500W)

**Tom Kugler - Laser Mechanisms**
Absorption of the laser energy in pulsed welding is key to weld repeatability—iron alloys, titanium alloys, superalloys, and even aluminum alloys absorb well enough for consistent processing.

Copper & gold alloys show variations in laser absorption form one pulse to another due to variations in surface conditions and the generally high reflectivity to 1 μm light.

Using a green laser the absorption of the light increases from about 5% to about 50% creating a consistent energy absorption for repeatable spot and overlapping spot seam welds.

Some laser systems will produce both 532nm light and 1064nm light so that once absorption creates melting the higher energy 1064nm light can create more weld volume.
Key Green Long Pulse Laser Apps

• Welding Copper and Gold Alloys
## Key Breakdown - Short Pulse SS

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<th>MID IR</th>
<th>NEAR-IR</th>
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**Tom Kugler - Laser Mechanisms**
Key Property- Short Pulse Solid State Laser

- All these lasers have Near IR or visible output, all have M2 ~1 beam quality. Their differences are generally related to their pulse energy, average power, and wavelength.
- These lasers all process by ablative interactions with their target materials, even metals.
- With cutting nozzles these lasers can process thin metals for medical devices and fine mechanical components.
- With galvo beam delivery these can be marking lasers, scribing lasers, or sculpt the surface of materials with multiple passes to produce 3-D surfaces or to texture material.
Short Pulse Solid State Lasers Key Apps

- Marking
- Fine Machining
- Scribing solar cells and “trimming” electronics
- Deep Marking and Surface Sculpting
- Surface texturing
## Key Breakdown - Ultra-Short Pulse

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**Groupings for Key Laser Properties**

- **CO2**: High (CW), Low (Pulsed)
- **YAG**: Low (CW), High (Pulsed)
- **QCW Fiber**: Low (CW), High (Pulsed)
- **FIBER**: Low (CW), High (Pulsed)
- **DISK**: Low (CW), High (Pulsed)
- **DIODE**: Low (CW), High (Pulsed)
- **Green SS**: Low (CW), High (Pulsed)
- **UV SS**: Low (CW), High (Pulsed)
- **Excimer**: Low (CW), High (Pulsed)
Key Property- Ultra-Short Pulsed Laser

- Using pulse compression techniques, ultra-short pulsed lasers produce pulses so short and peak powers so high that:
  - The material is removed with virtually zero HAZ
  - Nearly any material can be processed since these peak powers cannot be transmitted
- Average power of approximately 5W limits processing rates but there is no clean-up of dross required and the lack of HAZ can improve quality.
- Polymers and other “transparent” materials cannot withstand the laser intensity so most all materials are candidates.
Key Ultra-Short Pulse Applications

• Medical Device Machining
• Fine Mechanical Devices
• Surface Sculpting/Texturing
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Key Breakdown:
High BQ Short Pulse
CO₂
Key Property- High BQ Short Pulse CO2

- 10μm wavelengths and short pulses allow processing of non-metals and coated metals or foils with low heat input.
- Minimizing heat input minimizes charring, burning, and cracking.
- High reflectivity by metals and their higher conductivity means that the 10μm will stop at these substrates
- Selecting 9.3-9.4μm vs. 10.2μm, vs. 10.6μm can tune the interaction with certain plastics and polymers.
- High frequency pulsing is needed for pulse-to-pulse overlap and high speeds.
Key Applications - High BQ Short Pulse CO2

- Marking/Engraving
- Non-metals Cutting
- Scribing Ceramics
- Fabric Cutting
Key Applications- High BQ Short Pulse CO2

- Polyimide Processing
  10.6µm vs. 9.4µm

- 10.6µm, not through to substrate

- 9.4µm, clean surface at ~30% the laser power
Plastic “Conversion”

- Laser perforation for longer shelf life, venting, easy opening
- Laser sealing
Plastic “Conversion” Cutting

- Removing Layers, Weakening, or Perforating materials for future access—usually a web process with CO2 lasers
- 10.2um wavelength processes PP without damaging PE
- Paper cut without damage to thin foil underneath
### Key Breakdown - Low BQ Short Pulse

**CO₂**

- **CW**
  - High (>500W)
    - high BQ (X)
    - low BQ
  - Low (<500W)
    - high BQ (X)
    - low BQ (X)

**PULSED**

- **Long (>0.1msec)**
  - high BQ (X)
  - low BQ
- **Short (1nsec-0.1msec)**
  - high BQ (X)
  - low BQ (X)
- **Ultra-Short (<1nsec)**

**UV**

- high BQ
- low BQ (X)
Key Property- Low BQ Short Pulse CO2

• What this type of laser gives up in Beam Quality, it makes up for in peak power, pulse energy, and potential processing area per pulse.
• 1MW peak powers and over 5J per pulse produces an ablative interaction that can only Ultra-Short and Excimer lasers can beat.
• TEA CO2 lasers produce a laser beam that can be nearly 25mm square
• Poor beam quality requires that the laser is imaged through a mask to produce the desired shape or shapes on the target. Very fine features can be produced.
• Stencil Mask allows marking of parts
Pulsed TEA CO2 laser marking

- Mask Image Marking
  - Electronics, Consumer Labels, Tablets, etc.
Pulsed TEA CO2 laser processing

Cross section of PC board drilled hole

Wire Stripping
Insulator removal
Paint Removal

Pharmaceutical tablet drilling

Polymer removal on stents
### Groupings for Key Laser Properties

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Key Breakdown - Low BQ UV

- **Mid IR**
- **Near-IR**
- **Visible**
- **UV**

Tom Kugler - Laser Mechanisms
Key Property- Low BQ UV

• Excimer lasers are very similar to TEA CO2 lasers but for their UV wavelength.
• Wavelength can be chosen for the target material.
• Breaking bonds in polymers as well as their ablative pulsing parameters means that these lasers are capable of processing almost all polymers and some very thin metallizations.
• Their poor beam quality also requires mask imaging but features smaller than a few nm are possible.
• Multiple features per mask are common but producing large area interactions requires a step-and-repeat motion.
Excimer Laser Processing

- Marking - aircraft wire, chip capacitor
- Diffractive Optic patterning
- Wire stripping
- Printer Head Drilling
- Glass Marking
# Groupings for Key Laser Properties

## Key Breakdown - High BQ UV

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**Tom Kugler - Laser Mechanisms**
Key Property- High BQ UV

- The short pulses of a q-switched solid state laser, the nearly diffraction limited beam quality, and the UV wavelength create a system that can process polymers, crystals, and coatings very precisely and with nearly zero heat input.
- Used extensively on electronic devices, solar cells, and medical devices these lasers are usually delivered by a galvo system or through a standard focus lens over a moving part.
- Average powers are limited but the interaction areas are usually small to match.
Key Applications - High BQ UV

- Marking
- Medical Device Cutting/Texturing
- Circuit Board Drilling
- Solar Cell
Basic Laser Beam Delivery

• Lasers in the 400nm to 2\(\mu\)m can be delivered by fiber optics except for high peak power and short-pulse lasers.

• Lasers in the UV and 10\(\mu\)m range must be delivered with mirror delivery.

• Many laser beam delivery systems require assist gases for processing and/or to keep optics clean

• Galvo Mirror Systems can be used for beam motion in marking, welding, and some cutting applications.
Mirror Beam Delivery

- Beam Benders with Adjustable Mirrors - path enclosure tubes
- Beam Switches to redirect the beam
- Beam Splitters
- Focus Heads specific for: cutting, welding, drilling, cladding, etc.
- Lenses or Mirrors (high power) for Focusing
- Focus Adjustment - manual and motor-driven
**Fiber Optic Beam Delivery**

- Multiple fibers can be multiplexed from one laser source
  - Time-Shared or Energy-Shared
- Beam diverges out of fiber to a collimator, parallel after the collimator to the focus lens
- Focus Dia. is image of fiber

\[
\text{Spot Dia} = \text{Fiber Dia} \times \left( \frac{\text{Focus FL}}{\text{Col FL}} \right)
\]
Fiber Optic Beam Delivery
Galvo Scanning System

- High Speed Beam Motion
- Marking, Welding, Ablation, Sintering
Lasers and Beam Delivery

- CW and Long Pulse Lasers from visible to ~2μm can be fiber delivered.
- Short Pulse lasers cannot be fiber delivered unless the fiber size is large, creating a huge loss in beam quality taking away much of their ablative power density.
- Once collimated, all beams are manipulated with mirrors and/or lenses, even if over a short distance.
- CO₂ lasers employ ZnSe lenses and silicon or copper substrate mirrors.
- 1μm lasers employ fused silica or glass lenses and fused silica or copper substrate mirrors.
- High power systems tend to favor reflective metal optics due to their ruggedness and direct cooling.
Fiber vs. Mirror Delivery

- Fiber Optics make multi-axis systems simpler and free-up the positioning of laser and workstation.
- Multiplexing allows more use of the laser source
- Fibers must be routed correctly and kept from excess twisting and stretching.
- Fiber Ends must be kept clean.
- Mirror systems must be mounted to the system correctly and be initially aligned.
- Multiple axis mirror systems must have moving mirrors or articulated arm systems.
- Lower power density on mirror system and separate components keep damage and replacement costs down.
- Fiber or Mirror Delivery- final processing focus heads are required
Conclusions

• All factors lead to choosing a laser type:
  – Wavelength
  – Power
  – Pulsed or CW
    • Pulse Duration
    • Peak Power
  – Beam Quality
  – Beam Delivery
Thank You

• Thank you for your attention.

• Thank you to: