LASER MATERIALS PROCESSING USING A MULTIPLE WAVELENGTH HYBRID BEAM

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Abstract

Laser processing has been applied to a wide variety of materials including polymers, metals, glasses and ceramics. The type of laser that is used for each material is chosen to match the optical absorption characteristics of the material. This is straightforward for homogeneous materials. However composites, by definition, are not homogeneous. They are often composed of materials that have dramatically different properties. For these materials, two or more laser beams with different wavelengths need to be combined to provide optimum laser processing performance.

Introduction

Laser materials processing is widely used for research, product development and high volume manufacturing. It provides a non-contact method for cutting and marking a wide variety of materials. Parts can be created on-demand because there is no need to fabricate tooling or fixtures. These attributes make laser processing an ideal technology for rapid prototyping and flexible manufacturing.

Laser Technology

The term LASER is an acronym for “Light Amplification by Stimulated Emission of Radiation.” Stimulated emission is the key physical process necessary for creating a laser beam [1]. This phenomenon is illustrated in Figure 1, which depicts a photon coming into proximity with an atom that is in an excited state. When the photon (hν) interacts with an atom that is in an excited state, the atom gives up its excess energy ($E_1 - E_0$) to the laser cavity in the form of an additional photon. The added photon has the same wavelength, direction, phase and polarization as the original photon that “stimulated” its emission. Stimulated emission is the driver of the light amplification that takes place in the laser cavity.

The wavelength of a laser beam depends upon the energy difference between the excited state and the ground state of the atom or molecule that is undergoing stimulated emission. For this work we will focus on a CO_2 gas laser with a primary wavelength of 10.6µm and a secondary wavelength of 9.3µm, and an Ytterbium (Yb) -doped fiber laser with a wavelength of 1.062µm.

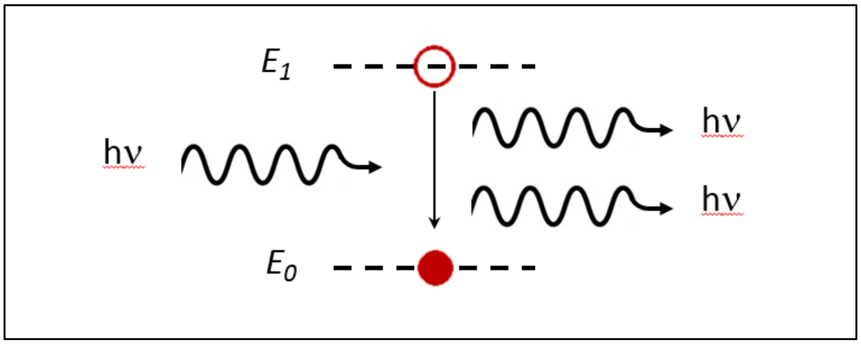

Figure 1. Schematic representation of a photon (left) coming into proximity with an excited atom, causing an energetic electron to drop to the ground state, leading to the stimulated emission of a second photon (right).

Laser Materials Processing

The two most common laser types for materials processing are the CO_2 gas laser and the Yb-doped fiber laser. The CO_2 laser is principally used for cutting and marking organic materials such as plastic and rubber because of the high optical absorptivity of these materials in the mid-IR regime of the CO_2 laser. Material that is directly in the path of the laser beam will absorb the 10.6μm wavelength and vaporize, creating a clean and straight cutting path. Marking can be accomplished with the CO_2 laser by limiting the power density of the beam so that only a thin layer of material is removed from the surface.

Metallic materials tend to reflect the mid-IR wavelength of the CO_2 laser. However, metals absorb well in the near-IR range. Therefore, the Yb-doped fiber laser is largely used for metal processing. The metal that is directly in the path of the laser beam will absorb the 1.062μm wavelength and melt. As it melts, the molten metal is ejected from the cut path by a high pressure gas stream. Laser marking of metals can also be done using the Yb-doped fiber laser.

Challenges of Processing Composites

Composites are constructed by combining materials with different properties to create a new material system with a unique set of properties (e.g. high strength and low weight). Carbon Fiber Reinforced Plastic (CFRP) is created by encasing carbon fibers in a polymer matrix material. The carbon fibers provide mechanical strength along their axes while the matrix material holds the fibers in the proper orientation. These two materials have different optical properties and different vaporization temperatures. The extreme difference in material properties makes cutting through the CFRP with a single wavelength laser beam very challenging [2].

In this work, we overcome this challenge by combining two laser wavelengths into a single beam. Each wavelength is selected to match the optical and physical properties of one of the component materials. Combining wavelengths to form a hybrid laser beam provides optimum performance for laser cutting composite materials.

Experimental Methods

All laser processing was done on an XLS10 MultiWave Hybrid™ (XLS10MWH™) from Universal Laser Systems. This system features MultiWave Hybrid technology, which allows up to three laser beams with different wavelengths to be combined into a single hybrid beam. Figure 2 is a schematic representation of the MultiWave Hybrid optics. It shows three laser beams with different wavelengths (indicated by different colors) entering from the left. Each laser beam is expanded in such a way that when they are combined (right) and passed through a focusing lens (bottom) they converge to the same focal plane. All three beams have the same spot size, which is 25µm.

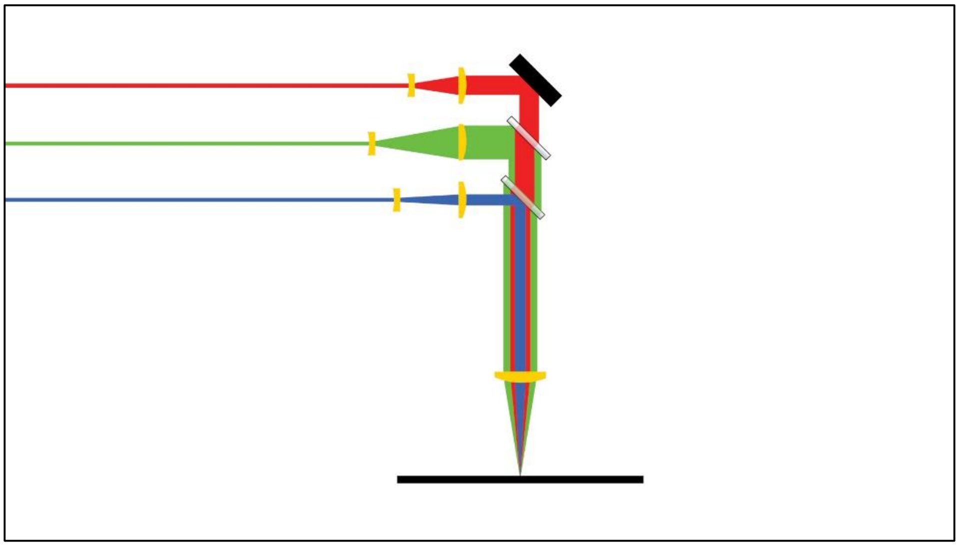

Figure 2. Schematic representation of MultiWave Hybrid optics, showing three laser beams with different wavelengths (indicated by different colors) being combined into a single hybrid beam.

The system was equipped with two CO_2 lasers; a 75 watt laser with a wavelength of 10.6µm, and a 50 watt laser with a wavelength of 9.3µm. The system was also equipped with an Yb-doped fiber with a wavelength of 1.062µm. These laser beams can be combined to form a single hybrid beam, as mentioned above. They can also be used independently for processes that require multiple laser processing steps.

Results and Discussion

Carbon Fiber Reinforced Polymer (CFRP) is composed of materials with very different optical and thermal properties. As mentioned earlier, this poses a problem for conventional laser processing. Figure 3a is an optical micrograph of a cut that was made through a 2.0 mm thick sheet of CFRP using the fiber laser by itself. It shows a rather large heat-affected zone, of about 0.4 mm. The micrograph also reveals several detached carbon fibers. This damage near the cut edge can have a detrimental effect on the mechanical integrity of the composite.

Figure 3b shows a CFRP sheet that was laser cut using MultiWave Hybrid technology. Here the 10.6µm CO_2 laser beam and the 1.062µm fiber laser beam are combined to form a hybrid beam.

The heat-affected zone near this cut edge is half that of the fiber laser by itself (0.2 mm versus 0.4 mm). Also, there are no detached fibers. Furthermore, the cut speed was doubled using the MultiWave Hybrid technology (from 10 mm/s to 20 mm/s). Combining the two laser wavelengths into a hybrid beam creates an improvement not only in cutting quality, but also in manufacturing efficiency.

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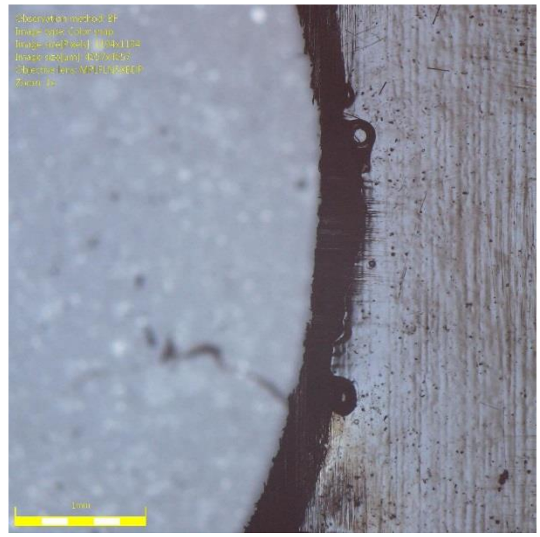
b) 

Figure 3. CFRP cut using only a fiber laser (left) and using MultiWave Hybrid technology (right).

The reason for the observed improvements in quality and speed is highlighted in Figure 4, which shows the optical absorptivity for the carbon fiber and for the plastic matrix material. The carbon fibers absorb very well in the 1.062µm regime, but the epoxy matrix material is nearly transparent at this wavelength. The carbon fibers absorb the laser energy and transfer heat down their length. The heat causes the plastic to delaminate from the carbon fibers.

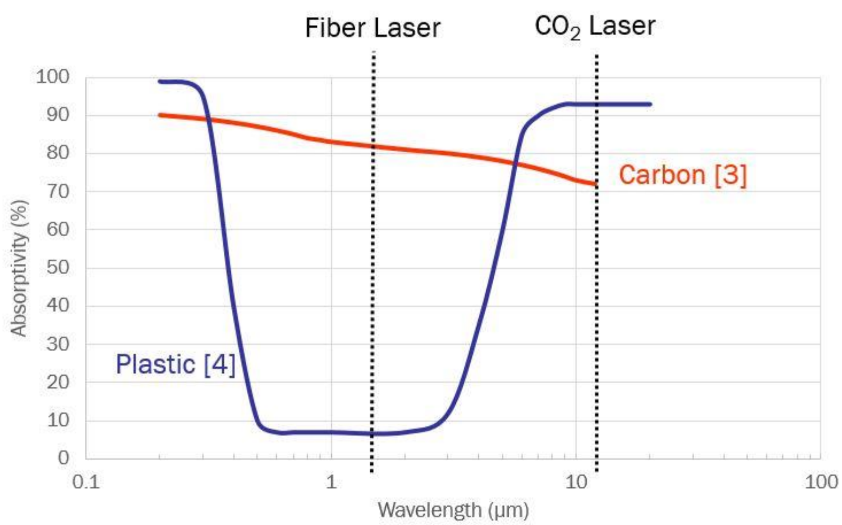


Figure 4. Optical absorptivities of carbon fibers and plastic matrix material [3, 4].

With MultiWave Hybrid technology, the fiber laser vaporizes the carbon fibers while the CO_2 laser simultaneously ablates the plastic, minimizing damage to the CFRP while enabling more efficient laser processing.

In addition to combining laser beams with different wavelengths, MultiWave Hybrid technology allows each laser to be operated independently. Independent control of each laser allows for process steps that require different laser wavelengths to be completed sequentially. One example of a sequential process is the fabrication of a flexible electronic circuit using three different laser wavelengths. The starting material is carbon ink that has been silk screened onto a PET substrate (Figure 5a). The carbon ink absorbs strongly at 1.062µm, and the PET is nearly transparent at this wavelength. Therefore, the carbon ink can be selectively ablated using the fiber laser to delineate the conductive paths for the circuit as shown in Figure 5b. The next process step is to mark the PET substrate with a serial number as shown in Figure 5c. This step is done using the 9.3µm CO_2 laser. The PET has a very strong absorption band at this wavelength, creating a distinct mark without substantial material removal. Finally, the finished part is cut from the PET web using the 10.6µm CO_2 laser. The high peak power of this laser provides the most efficient cutting.

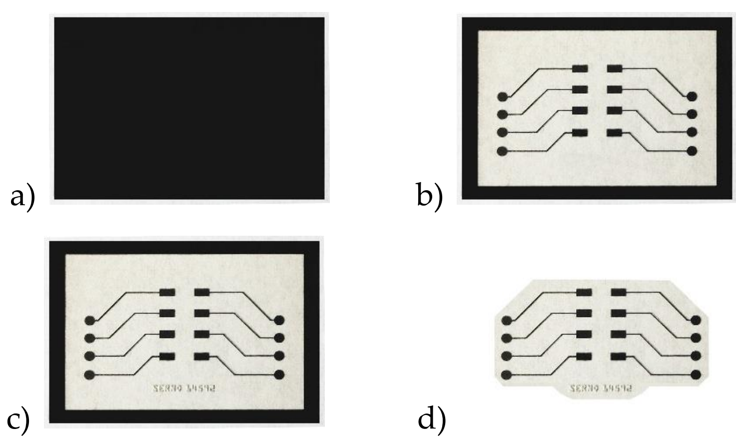


Figure 5. Sequential process steps for flexible circuit fabrication: (a) Carbon ink silk screened onto a PET substrate; (b) Selective laser ablation of the carbon ink from the conductive elements; (c) Marking the PET substrate; (d) Cutting the circuit from the web.

MultiWave Hybrid technology has been demonstrated for other conductor-insulator systems including silver on PET and copper on polyimide. In each case, the fiber laser is used to selectively ablate the conductive layer to form the circuit elements. The CO_2 laser is then used to mark, and then cut the insulating substrate.

Conclusions

MultiWave Hybrid technology extends the capabilities of conventional laser materials processing. This technology enables laser cutting of composite materials by combining laser beams with different wavelengths into a single hybrid beam. The hybrid process provides optimal laser processing performance for materials that are made up of components that have different optical and physical properties.

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