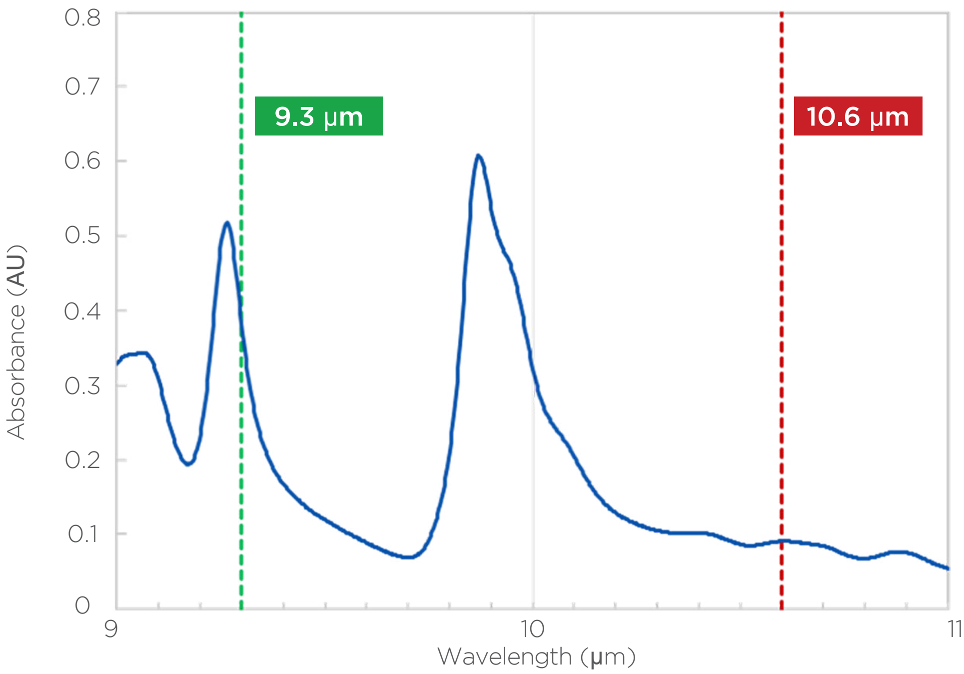
# Synrad - Optimal Polycarbonate Processing with $CO_2$ Lasers

## Introduction to Polycarbonate and its Applications

Polycarbonate (PC) is a material that, due to its excellent physical and chemical properties, is in high global market demand. The advantage of this thermoplastic lies in its higher toughness, breaking strength and transparency as well as high heat resistance. These attributes make polycarbonate attractive in the automotive, medical and mechanical engineering industries. Additives can be used to further improve the properties of polycarbonate and allow its use in different environments.

## Chemical Properties and Absorption Characteristics of PC

In general, $CO_2$ lasers are particularly suitable for cutting plastics due to their long wavelength and the corresponding absorption curves of the plastics. Despite the high absorption of polycarbonate, when cutting it with a $CO_2$ laser the cutting quality is low. Although it is easy and fast to cut, the resulting cutting edge often shows yellow to brown discolorations. Due to its optical properties PC is an excellent substitute for traditional material such as glass. But applications in headlamps and displays require a clean cutting edge since every discoloration can induce unwanted color effects in the material. Further, due to its high toughness and stability it is hard to cut using mechanical processes, therefore the aim is to find the optimal laser processing parameters to achieve the best possible cutting quality. In the end we want to help PC manufacturers and users, to better understand the $CO_2$ laser cutting process of polycarbonate and how to use this for their advantage.




*An experimental measurement of a Polycarbonate sample using an FTIR spectrometer shows a strong peak at the expected position*

Absorption describes the interaction between material and laser and is one important factor that influences the cutting quality. When a polymer absorbs infrared radiation, its chemical bonds will vibrate, resulting in stretching and bending of those bonds. To achieve an efficient absorption the energy of the photons must match the distinct vibrational energy of the molecule bond. Polycarbonate shows an increased absorption at 1080 $cm^{-1}$ which corresponds to a wavelength of 9.26 µm. This absorption peak represents the Carbon-Carbon bending vibrational modes in the backbone of the polycarbonate polymer chain. The calculation of this bending mode is complex and outside the scope of this paper.

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## Polycarbonate cutting examples

How does the absorption help to improve the cutting quality? To evaluate this behavior three different polycarbonate types, with a thickness of 2mm, were tested. The materials are described as Makrolon® 2405 (standard grade), Makrolon® AL 2447 (UV-stabilized), and Makrolon® 6555 (flame-retardant).

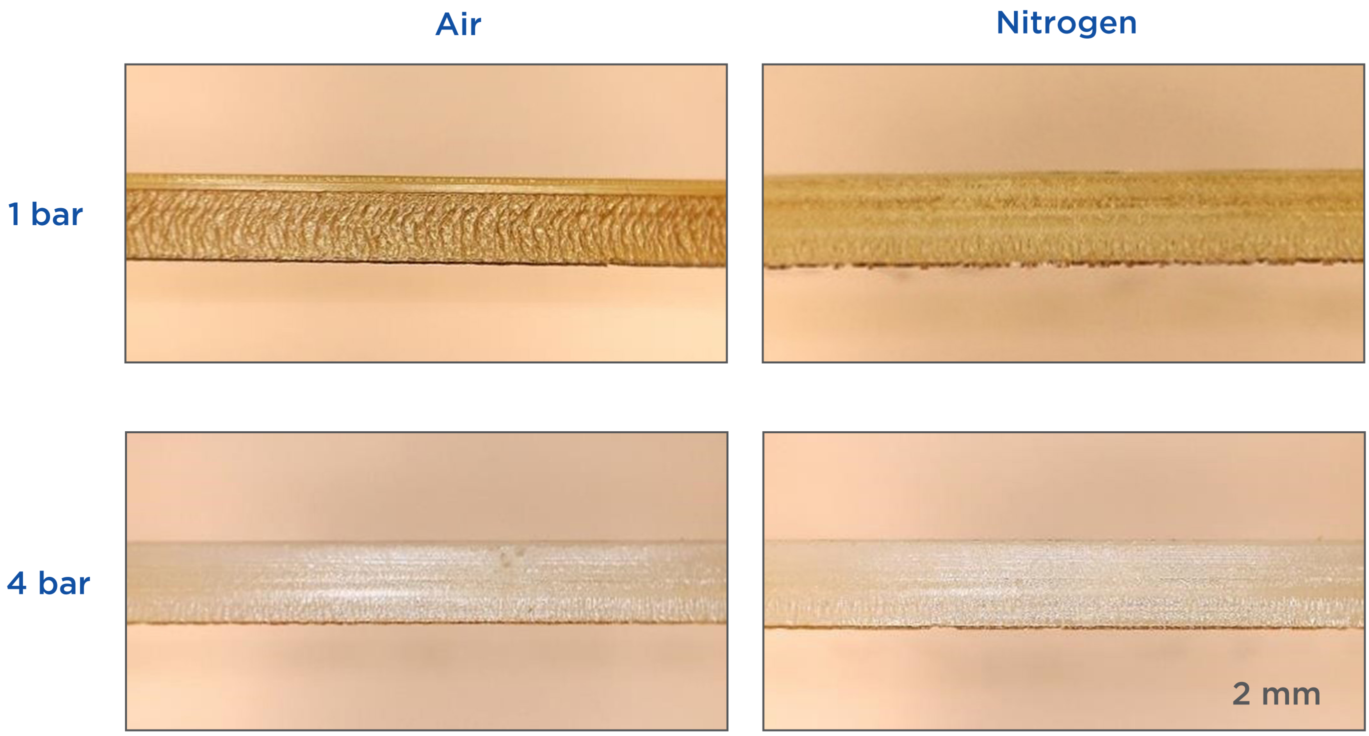
For the cutting tests two Synrad $CO_2$ lasers were used, one at the standard wavelength of 10.6 μm and another at the alternate 9.3 μm wavelength. In addition to wavelength, assist gas type, assist gas pressure, and laser frequency variations were also tested to determine impact on cut quality.

## Summarizing the processing scheme

One parameter variable was tested while all other parameters remained fixed. The influence of the gas pressure and the laser frequency was varied within a certain parameter range. All tests were performed with pressured air and nitrogen as an assist gas. Additionally, every cut was repeated with a laser wavelength of 9.3 μm and 10.6 μm. The cutting speed was selected to be as high as possible, while still achieving a complete cut-through. The laser power was kept at a constant average power of 100W for all cuts.

## Influence of the assist gas

The assist gas is an important factor for the cutting quality. It pushes the melt out of the laser cutting zone. For polycarbonate this means a high gas pressure is needed to expel the discolored melt and decomposition products as fast as possible. The difference between 1 bar and 4 bar of air pressure are shown in the pictures below. While the pressure of the gas is important, the gas type seems to have no effect on the cutting quality.




*Standard grade PC cut with pressured air and nitrogen at 1 bar and 4 bar*

## Influence of the frequency

Frequency testing was done in incremental 1 kHz to 50 kHz steps, revealing linear behavior in cut edge quality. As the testing frequency increased, discoloration of the cut edge was reduced. This observation indicates that pulsed laser operation, especially at low frequencies, results in a more discolored cutting edge. The low heat affected zone in the surrounding area in combination with the long off-time between the pulses results in the quick solidification of the discolored melt and decomposition products, before they can be expelled by the assist gas. In order to achieve a clean cutting edge, cutting in a quasi-continuous mode is required.



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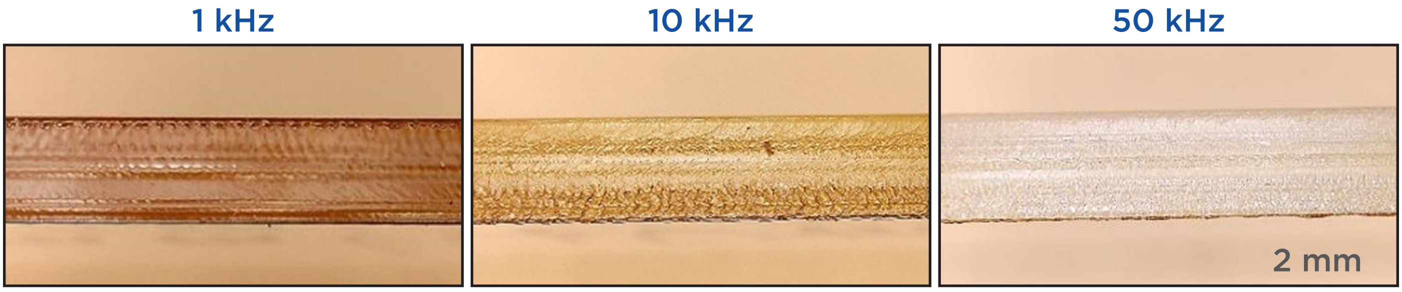



*Standard grade PC cut with different frequencies*

## Influence of the material composition

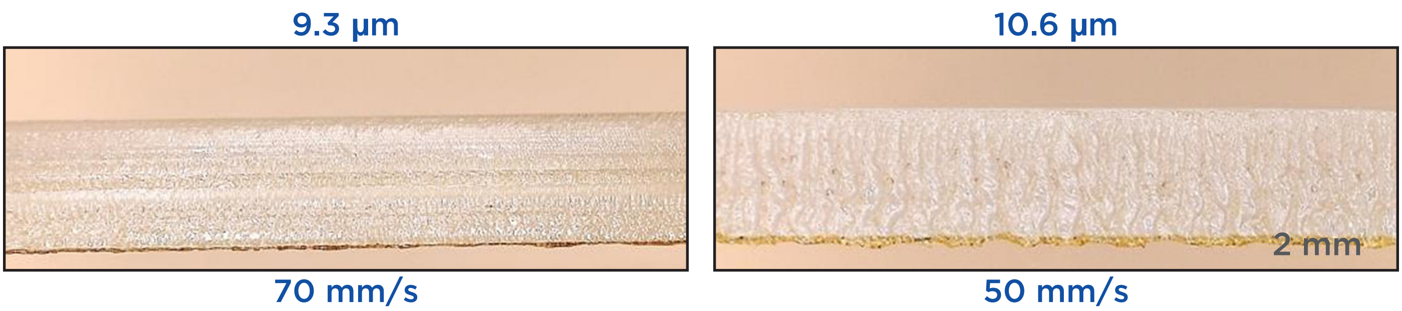
As mentioned above three polycarbonates with different additives were provided. An absorption measurement with the spectrometer did not show a difference in the absorption behavior, but a difference in cutting quality is visible.


*Three different types of PC cut with the same processing parameters*

For all tests the standard grade and the UV-stabilized polycarbonate show similar results. These two materials can be cut close to perfection with the right choice of parameters. The polycarbonate with the flame-retardant additive behaves differently and no suitable parameter was found during our tests. In the flame retardant image above the cutting edge shows (red arrow) distinct black ridges, most likely the result of carbonization that occured during the laser cutting process.

## Influence of the laser wavelength

Both the 9.3 µm and 10.6 µm wavelengths were tested at the same average laser power. Further a high pressure of 4 bar and a frequency of 50 kHz was used, as in the previous tests these parameters show the best cutting results. Due to the difference in absorption, the maximum cutting speed at 10.6 µm is 50 mm/s instead of 70 mm/s at 9.3 µm. The cut with 10.6 µm produces a completely colorless edge but a very rough surface. The surface produced with 9.3 µm is much smoother but show some residual tint on the edge.




*Standard grade PC cut with the non-standard wavelength of 9.3 µm and the standard wavelength of 10.6 µm*

At 10.6 µm wavelength laser energy scatters inside the material due to lower absorption. Dissipation of the laser energy into the material causes a larger melting zone resulting in higher surface roughness. The higher surface roughness suggests that decomposition particles could be expelled more efficiently with an assist gas due to the larger meling zone. Further, the 10.6 µm wavelength test showed less discoloration due to lower absorption and subsequent laser energy scattering, yielding less energy for chemical decomposition.



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## Conclusion

This paper provides an overview of the influences of several processing parameters on the cutting quality of polycarbonate. The table below summarizes the results and offers the best parameter to use. Our findings lead to the conclusion that there is an optimal temperature regime, where the material melts without decomposition. Cutting PC with a $CO_2$ laser above the optimal temperature regime results in decomposition and thus discoloration takes place.

| Parameters | Best Parameter | Result |
|---|---|---|
| Wavelength | 9.3 µm for highest speed<br>10.6 µm for best quality | Better absorption for higher speed but more decomposition<br>Lower absorption results in more melting than decomposition |
| Frequency | 50 kHz or higher (quasi-continuous) | Pulsed operation results in better cooling effect of the gas<br>→ discolored melt gets solidified inside the cut area |
| Assist gas type | Pressured air | No advantage of nitrogen over air |
| Gas pressure | 4 bar or higher | Stronger gas flow casts out decomposition products more quickly |

It was observed that the additives have a significant influence on the cutting result, therefore knowledge about the exact composition of the material is crucial for industrial applications. Utilizing a high frequency results in a quasi-continuous wave mode, and leads to much better cutting results in comparison to pulsed operation.

When using a $CO_2$ laser for polycarbonate cutting, the quality of the cut is affected by assist gas pressure. Using the highest possible assist gas pressure (> 4bar) results in cleaner edge cuts. High pressure assist gas quickly casts out melt particles to yield a clean, polished edge, making $CO_2$ laser cutting more efficient.

A comparison between the two wavelengths 9.3 and 10.6 µm reveals a difference in cutting quality and speed. The best result, in terms of avoiding discoloration, was achieved in quasi-continuous mode with a wavelength of 10.6 µm and a high assist gas pressure. Overall the weaker absorption leads to a reduced cutting speed by approximately 30%. The economically most viable choice is a 9.3 µm laser in quasi-continuous mode. The resulting cutting edge suffers only from a very small discoloration but allows a higher cutting speed and surface smoothness at the same average output power. Furthermore, as nitrogen and pressured air result in a similar edge quality, pressured air should be chosen to reduce cost.

## Interested in speaking to one of our knowledgeable representatives?

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