

Optimal Processing of Polypropylene Films with CO₂ Lasers

Polypropylene, commonly abbreviated as PP, is one of the most common and important plastics used today. It is a thermoplastic that has practical applications in many different industries. Its strength, flexibility, and resistance to damage means polypropylene film is an excellent material for various types of storage and labeling applications. In addition, polypropylene's ability to withstand heat combined with chemical resistance to organic compounds makes it a good choice in particular for food and beverage packaging.



In recent years, the digital revolution has changed the landscape of the flex-packaging and labeling industries, challenging manufacturers to meet demands for high design flexibility and shorter time to market. Digital laser converting provides the solution with on-the-fly customization, zero contact processing, and repeatable results. Synrad high performance CO₂ lasers are ideally suited for many of these applications due to our long wavelength's superior absorption in many common film materials. In the specific case of polypropylene films, simply changing the CO₂ wavelength slightly from the standard 10.6 μm to more optimally absorb into that particular material can result in significant speed and process quality improvements.

Chemical Properties and Absorption Characteristics of PP

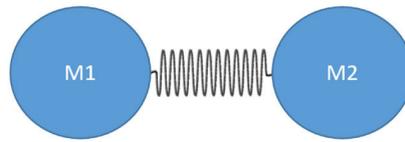
To efficiently use the laser energy in the process, the photons of the laser beam must be absorbed into the material rather than transmitted or reflected back. This leads to efficient vaporization of the material with little energy lost due to passing through the material, melting, or chemical degradation processes.

When absorbing Infrared Radiation (IR), a polymer molecule's chemical bonds will vibrate. These vibrations will stretch and bend the bonds within the polymer chain. However, for that absorption to occur, the energy level of the IR photons at a specific frequency must match the distinct vibrational energy differences within the molecule. This can be expressed by this equation:

$$\nu = \frac{1}{2\pi} \left(\frac{k}{\mu} \right)^{\frac{1}{2}}$$

ν is the frequency of the photons (Hz) k is the force constant of the molecule (N/m) μ is the reduced mass (kg)

In a generalized sense for the stretching case, these vibrational energy differences in the molecule can be thought of in a classical mechanics sense as a two body system connected by a spring:



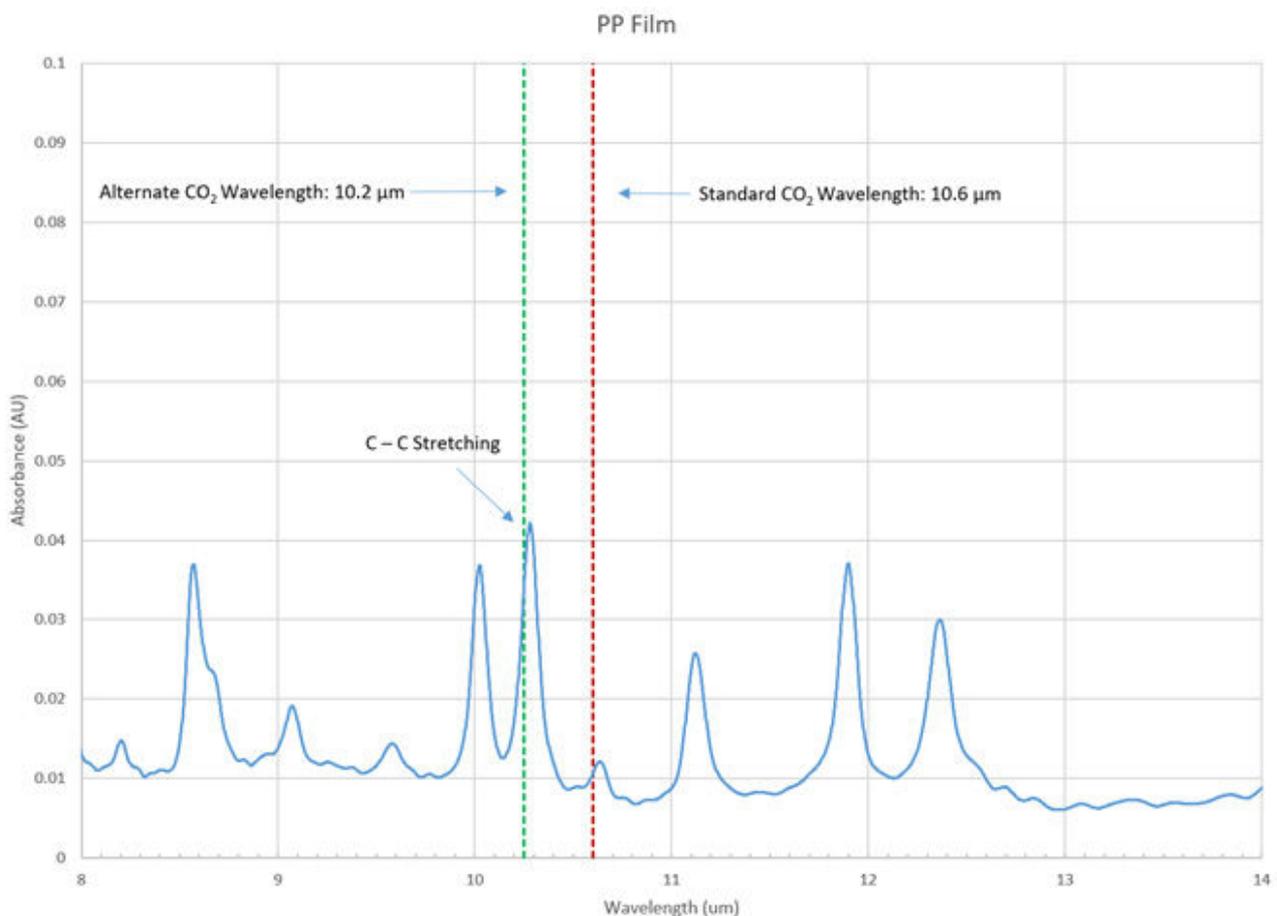
The reduced mass constant of this simple system is found by:

$$\mu = \frac{M1M2}{M1+M2}$$

Long polymerized polypropylene molecular chains are typically linked together through single bonds between the carbon atoms (C) in the chain: C-C, with a force constant, k , of approximately 335 N/m between them in many common propylene orientations. So in the above diagram the two spheres would be carbon atoms.

The mass of a carbon atom is 1.99×10^{-26} kg, so setting both $M1$ and $M2$ to this value gives us a reduced mass, μ , of 9.97×10^{-27} kg. Solving for the frequency, ν , in the first equation, we find a value of 29.2 terahertz. Converting this to the wavelength of IR radiation needed through the relation $\lambda = c / \nu$, where c is the speed of light: 3.00×10^8 m/s, we find a value of about $10.27 \mu\text{m}$. This is the specific wavelength of light required to provide photons at the energy level that matches the vibrational energy to stretch the C-C bond in the polypropylene chain. These vibrations quickly heat the molecule until the material vaporizes.

When we experimentally measure the absorption curve of polypropylene film with an FTIR spectrometer, we find that there is indeed a very strong absorption peak at that wavelength.



It should be noted that there are also more complex bending vibrations of the molecule that contribute to this absorption curve as well, but this is outside the technical scope of this paper.

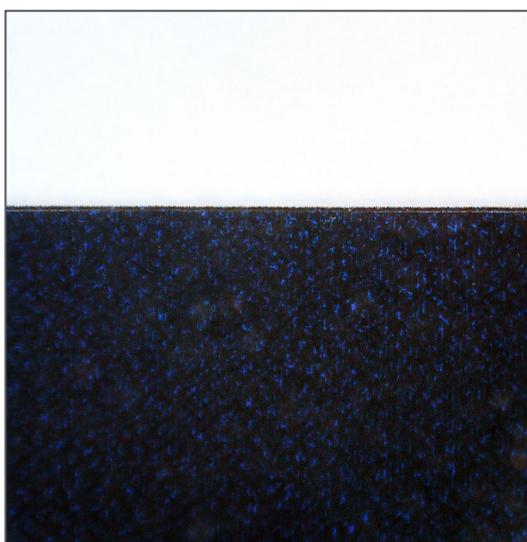
Label Cutting Examples

So polypropylene absorbs the 10.2 μm significantly better, but how does this translate to actual speed and quality improvements for a real application? To examine this specifically for label cutting applications, the Novanta Applications Lab looked at a number of different samples and cut them with Synrad p150 lasers at both the standard wavelength of 10.6 μm and also the alternate 10.2 μm wavelength. This alternate wavelength is achieved with band-select optics inside the laser to only release the narrow wavelength band centered around 10.25 μm .

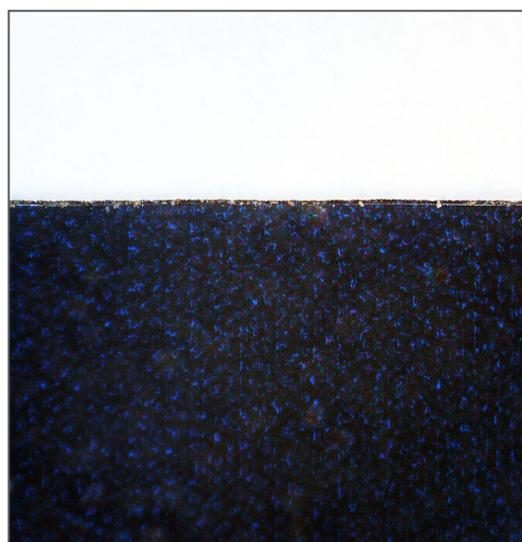
Clear and opaque polypropylene films were examined, as well as ones that had additional lamination on top. Each laser tube was set to output the same amount of power so any speed differences would only be attributable to the wavelength change. The resulting cut speed differences between the two wavelengths were most notable on the thinner labels, with around 80% speed increase being typical for 80 μm thickness, while a 22% increase was seen on thicknesses of 140 μm .

Base Material	T (μm)	Coating	10.6 Velocity (mm/s)	10.2 Velocity (mm/s)	% Increase
Polypropylene - Opaque	140	Polypropylene Laminate	2794	3429	22.73%
Polypropylene - Clear	80	None	4318	7620	76.47%
Polypropylene - Opaque	80	None	4572	8255	80.56%

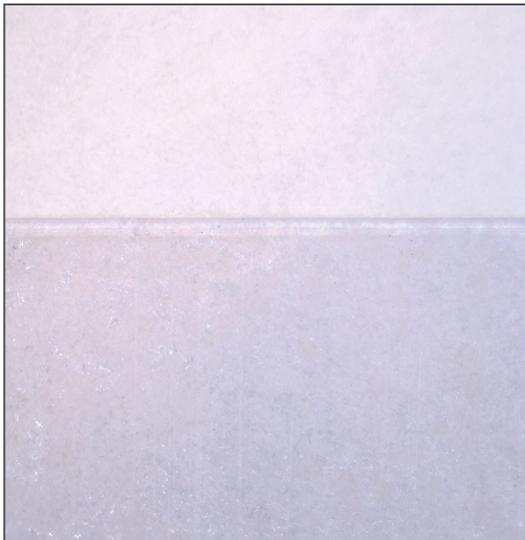
The cut edge quality differences were most obvious on clear PP labels in the unprinted regions. At 10.6 μm , yellowing of the film was commonly seen and heat affect zones were evident between the liner and base label materials where residue and hot vapor was trapped. The high transmission at 10.6 μm also meant that scoring of the bottom liner material was very noticeable. These issues were completely eliminated when the 10.2 μm wavelength was used instead.



Opaque label cut edge 10.2 μm wavelength

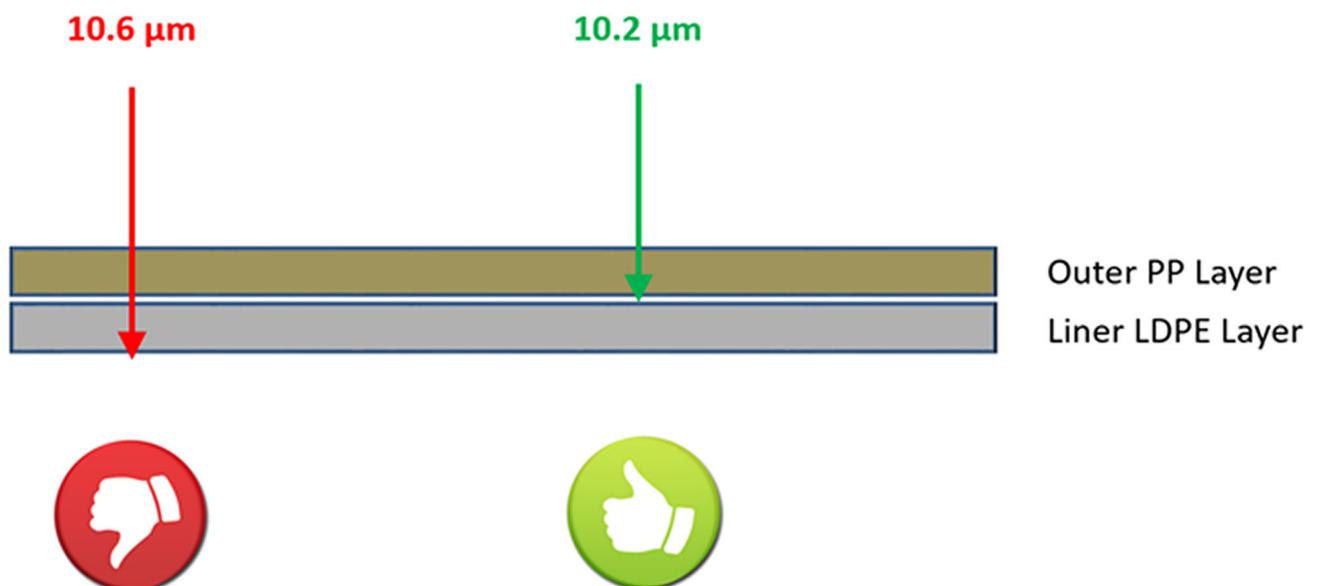


Opaque label cut edge 10.6 μm wavelength

Clear label cut edge 10.2 μm wavelengthClear label cut edge 10.6 μm wavelength

Food Packaging Examples

Labels are not the only application that benefits from the ability to selectively process polypropylene film layers. A common food pouch design consists of a two layer stack of films. This includes an outward facing top PP layer and a bottom LDPE liner. Laser perforating pouches is commonly done for easy-open tear lines. However, you do not want to penetrate completely through the bottom liner, exposing the food while laser processing.



By carefully controlling process speed, laser power, and wavelength, selective perforation of multi-layer pouches can allow the upper PP layer to be processed while the bottom liners remains intact. In this example of a multi-layer pouch, a p150 - 10.2 μm laser was carefully chosen to only perforate the top polypropylene layer. This was impossible to do using the standard 10.6 μm wavelength which blasted through both layers due to its high transmission characteristics through the PP layer.

Conclusion

In this paper you learned one of the basic mechanisms governing how CO₂ laser radiation is absorbed by polymers, specifically polypropylene, and how this can be optimized to maximize the absorption through wavelength selection. Using a 10.2 μm wavelength laser can greatly increase the process speed while improving the edge quality on polypropylene products. Further, where selective layer processing is needed for fine labeling and packaging applications, the 10.2 μm wavelength offers a much wider successful processing window.

As the markets for polypropylene film grow, especially in the labeling and flexible packaging spaces, the importance of 10.2 μm processing will increase as well, especially for projects with highly demanding application requirements. Novanta is there for you with application expertise and the laser products to help push the limit on your most demanding film applications.

Interested in speaking to one of our knowledgeable representatives?

Americas & Asia Pacific

Novanta Headquarters
Bedford, USA
P +1-781-266-5700
Photonics@Novanta.com

Europe, Middle East, Africa

Novanta Europe GmbH
Wackersdorf, Germany
P +49-9431-7984-0
Milan, Italy
P +39-039-793-710
Photonics@Novanta.com

China

Novanta Sales & Service Center
Shenzhen, China
P +86-755-8280-538
Suzhou, China
P +86-512-6283-7080
Photonics.China@Novanta.com

Japan

Novanta Service & Sales Office
Tokyo, Japan
P +81-3-5753-2460
Photonics.Japan@Novanta.com