PLASMA OPTIK

Optical Filters in Lidar Systems Applied to Autonomous Vehicle Applications

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Executive Summary

Interest in commercializing Lidar technology for vision systems in autonomous vehicles is very high. Recent advancements in compact, low-cost and high-performance lasers have pushed Lidar technology to the brink of widespread adoption. Optical filters play an important role in the Lidar optical engine. Plasma Optik bandpass filter manufacturing efforts geared toward this application are discussed. Resolution limits of radar and Lidar technologies are compared. Practical vision system performance challenges are discussed as they relate to automotive Lidar applications.

Lidar – Light Detection and Ranging is an application that has been in the photonics news quite a bit lately. Lidar technology is a derivative of radar technology in many respects. Many of the Lidar pioneers were trained in the 1940's with the then new radar technology. The idea of bouncing radio waves successfully off objects to determine range opened minds to the possibility of doing the same with light waves. With the invention of the ruby laser in 1960, Lidar systems became possible. One early Lidar system was used to bounce laser light off the moon and record the amount returning. This effort, in Lexington, Massachusetts by Raytheon scientists reportedly recorded the return of forty photons from the round-trip journey[1].

For cost reasons, radar has been the predominant technology of choice for determining range and identifying objects at long distance for terrestrial applications. Radar involves the use of radio waves to make measurements. By contrast, Lidar involves the use of coherent light waves. Challenges have remained in manufacturing inexpensive Lidar systems at scale. The reason for the current excitement about Lidar has to do with both the improved performance as compared to radar along with recent dramatic cost reductions as companies work to miniaturize the technology.

Radar typically operates with either 24 or 77GHz systems. Since the wavelength of the 77GHz signal is significantly shorter, the use of the 77GHz systems is considered state of the art[2]. Wavelength is the paintbrush with which we assemble the images in a vision system. Human vision is defined by visible light which involves a range of wavelengths. Commercial Lidar and radar vision systems typically use a single wavelength.

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VISION SYSTEM COMPARISON		
Vision System Type	**Frequency**	**Wavelength – Defines Resolution**
Radar	24GHz	12.5mm
Radar	77GHz	3.9mm
Lidar	193 THz	1550nm or 0.00155mm
Lidar	331 THz	905nm or 0.000905mm
Human	380-750 THz	400-780nm or 0.0004 to 0.00078mm

Table 1. Vision System Comparison

You can see the dramatic increase in resolution between radar and Lidar based on the wavelengths involved. The 1550nm range is the longest wavelength typically used for Lidar and this has over 2500x the resolution of 77GHz radar. The 1550nm spectrum provides 580,000 data points per meter resolution. Compare this with the 80 points/meter available with 24GHz radar or 256 points/meter with 77GHz radar. Using Lidar for vision system applications provides exceptional resolution.

One might argue that the 3.9mm resolution provided with 77GHz radar is sufficient for a vision system. Consider the forty photons received back from the moon on that Lidar experiment long ago. That this return signature could be measured at all was amazing. We expect lots of the electromagnetic bandwidth sent out to be lost. When counting on receiving back every bit of spectrum which is sent out, disappointment is certain. It's not just darkness but rain, snow and fog which can frustrate the human vision system. Lidar, radar and cameras can also suffer from lack of illumination and scattering in a similar way. Better to have extra bandwidth that you don't need than to rely on perfect performance in a machine vision system.

Tesla motor company has recently dropped the radar from their automotive vision system and is now relying entirely on cameras. The resolution is very high in their camera-based system due to the very short wavelengths in the visible light spectrum. There are a few obvious issues to contend with when relying on cameras, though. Darkness is common, so you need a light source that can provide the photons for camera-based detection. It would be preferable to always have the high beams on when relying on an autonomous vehicle vision system to get one home safely.

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Nighttime highway image using Lidar[3]

This brings us to Lidar. 905nm and 1550nm are the common wavelength choices available for commercial Lidar systems. These wavelengths are both outside the range of human vision. Both are also commercially viable due to available inexpensive laser amplifiers at these wavelengths. 1550nm has been in use for telecom applications for more than twenty-five years. 1550nm is the best wavelength for long distance communication due to the low loss of optical fiber at this wavelength. These common and low cost 1550nm lasers also work well in free space for the distances useful for Lidar. Low cost 905nm laser amplifiers are also available and provide slightly better resolution than 1550nm.

One benefit of using a single wavelength vision system is the ability to eliminate noise from the return signal using filtering. If a Lidar signal is sent out at 905nm, the return signal can be expected very specifically at 905nm. This allows us to use optical filters to eliminate stray light from other wavelengths. The following are examples of Plasma Optik designed bandpass filters for these wavelengths.

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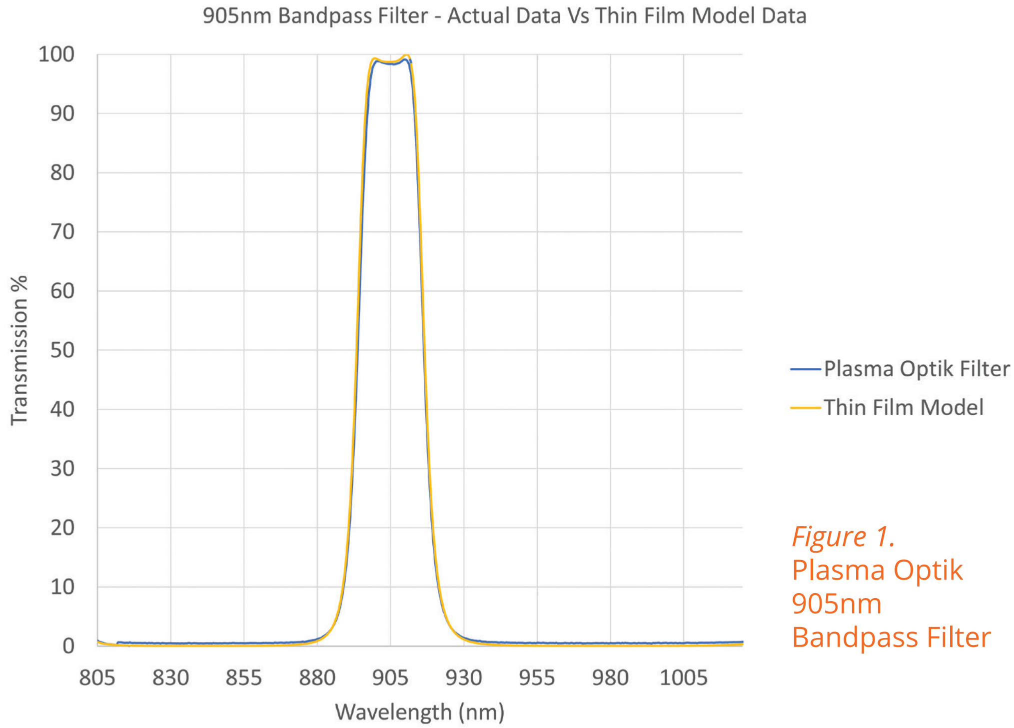

Figure 1. Plasma Optik 905nm Bandpass Filter

For this 905nm optical filter example, all light in the 805nm to 1025nm spectral region apart from light localized within +/-10nm of 905nm would be rejected with the use of the Plasma Optik filter. These optical filters can be optimized for customer specifications to have a more narrow or less narrow range of rejection. Also, the rejection range of the above filter can be broadened to exclude the visible and NIR wavelength ranges. This eliminates noise from the return signal, isolates our wavelength of interest and improves signal to noise ratio.

This type of optical filter is composed of alternating layers of high and low index materials deposited on customer specified substrates. These substrates might be fused silica, silicon or other optical materials. Tailoring the layer structure allows the customization of the filter design to match customer requirements. For example, a similar design could be used to create the same type of bandpass design at 1550nm. This filter could also be optimized to reject further out of band light such as the visible light spectrum.

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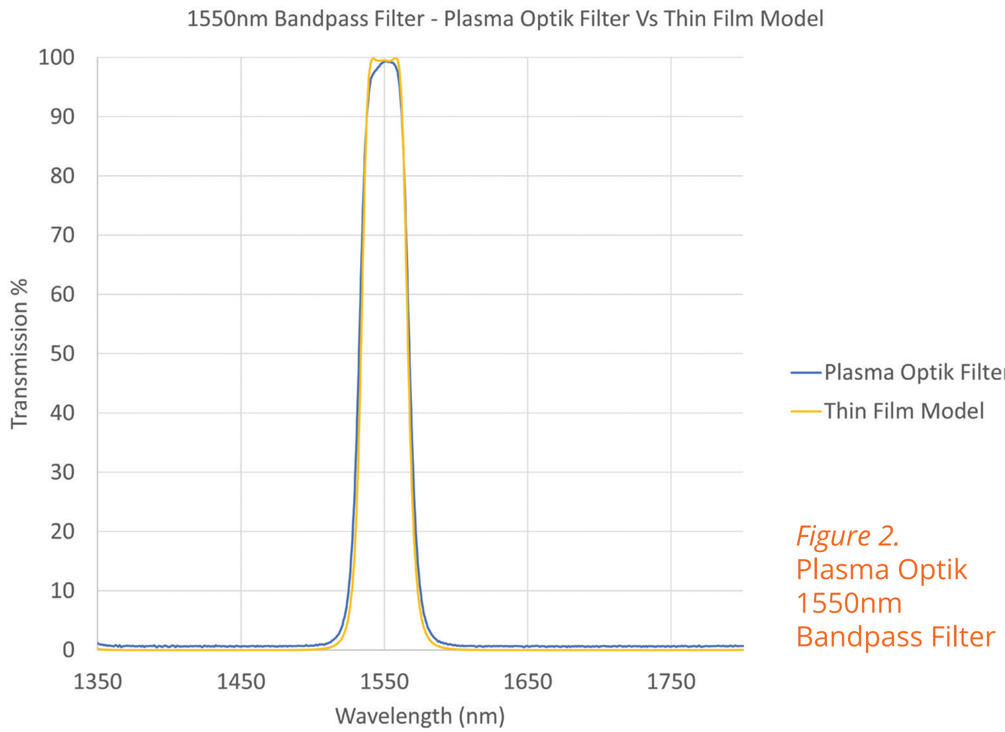

Figure 2. Plasma Optik 1550nm Bandpass Filter

Optimizing resolution in a vision system requires sufficient illumination. An optimal vision system utilizing artificial intelligence for autonomous driving, for example, needs not only to see an oncoming object. The vision system also needs to uniquely identify what it is. Artificial intelligence algorithms can be trained to identify objects[4]. Sufficient illumination is required to fully define the object for this identification, however. In one deadly example, on a clear night in Arizona an autonomous vehicle struck a cyclist at full speed. Review of the digital data recorded by vehicle revealed that the vision system flipped rapidly between various incorrect identifications of the cyclist prior to the accident, unable to make a clear determination of what lay ahead. Being able to clearly identify objects is one critical component a machine vision system requires to make good decisions[4].

There are some concerns with the use of 905nm lasers for vision systems due to driver eye safety. If 905nm Lidar is not legalized due to these concerns, the next best choice will be using the telecom and eye-safe wavelength band around 1550nm. The resolution at 1550nm is not quite as sharp as using visible light but the upside is that you can use more of it safely. With a capable Lidar system, artificial intelligence is capable of superior night vision as compared to a human driving with headlights.

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One other fun note about these vision systems: What is the trade-off with using a single wavelength for an artificial intelligence vision system as compared to a wavelength range as our human vision systems utilize? The range that the distinction between 470nm (blue), 585nm (yellow) and 660nm (red) and everything in between gives us. The artificial intelligence in our vision systems is forced to live in a monochromatic world. So sad!

References

1. Neff, Todd. *The Laser That's Changing the World.* Prometheus Press. 2018.

2. Driving Safely with Automotive Radar Systems: https://www.mwrf.com/technologies/systems/article/21849983/driving-safely-with-automotive-radar-systems

3. "Highway image using Lidar" by Oregon State University is licensed with CC BY-SA 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-sa/2.0/

4. Alex Davies, Tristan Morris et al. *Driven, The Race to Create the Autonomous Car.* Simon Schuster. 2020.

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Plasma Optik manufactures bandpass filters, notch filters, edge filters, polarizing beam splitters, non-polarizing beam splitters, mirrors and anti-reflective coatings. Our optical monitoring capability combined with ion beam sputtering technology allows us to manufacture precision optical coatings from the ultra-violet to near infrared wavelength ranges. Lidar is just one interesting application.

We would be happy to speak with you about your application and what we can do to help you succeed with your optical coating requirements.