Diffuse Reflectance and the Process of Laser Engraving

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1 Introduction

The idea for this experiment arose from a former colleague of my advisor, Dr. Noe, named Richard Migliaccio. Mr. Migliaccio is president of East Coast Optical Technologies, an optical design, measurement and analysis corporation. He is currently consulting a company that has interest in the field of laser engraving. Their hopes are to find a material that can be made into a master copy to use for printing that has the properties of durability and strength. After discussing the project with Mr. Migliaccio we decided that I would record data of a lasers interaction with a surface to better understand the process of diffusive reflectance, Lambertian surfaces and scattering.

2 Theory

The area of laser drilling, cutting and engraving is a very popular and widely utilized technology currently. It is a much sought after process because it has many advantages compared to the older method of using metal bits to perform the cut. A laser, for instance, can produce extremely accurate cuts and has the ability to replicate a specific cut or design excellently. Because the tool is "light" it never wears out or needs to be changed or replaced and costs are reduced significantly. Based on these advantages it is no wonder that classical methods for performing cuts are being phased out. With all the distinctions between the older drilling and cutting techniques and the laser processes there is still a common ground that the two share and cannot change, which is their dependence upon the type of material being used in the actual process. More specifically, depending on the material one is working with there will be different requirements based on how much power is required to make the actual cut. Drilling a very dense material will obviously require more power than for a sparse one. When engraving, drilling or cutting, the objective is to get as much power as possible concentrated on doing the work itself and having the minimum amount as possible expended as a loss.

In laser processes it is not too difficult to measure the power lost during the procedure. When light is shined on a surface it can reflect in a couple ways: through specular reflection, where the lights angle of incidence = its angle of reflection, where this usually happens on very smooth, shiny surfaces such as mirrors; or by diffuse reflection. As opposed to specular reflection where all the intensity is reflected in one specific direction, in diffuse reflection the reflected light "spreads out" in every direction and does not uniformly reflect. This scattering is mainly due to surface roughness and inequalities.

The way in which the light behaves in diffusive reflection follows Lambert's Cosine Law, which states the irradiance hitting a surface changes with the cosine of the incident angle. Materials exhibiting this trait are known as Lambertian surfaces. A good example of a Lambertian surface is a physics textbook with a shiny coating on it; if one views it at an angle it will be as bright as if viewed from perpendicularly (try it in a bright room!). When light strikes a Lambertian surface, or any type of material for that matter, one can ask the question what then happens to the lights power? The light can either be reflected or scattered, absorbed or transmitted and depending on the surface it can be a combination of all three or just a few of them.

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$$\text{Power} = \text{Reflected} + \text{Absorbed} + \text{Transmitted}\ . \tag{1}$$

Mr. Migliaccio is trying to find a suitable material to use for a master copy that absorbs the most power, thereby minimizing the time needed during the laser engraving process. If there is less time needed to fabricate a master it allows the company more time to make other engravings, which therefore leads to increased revenue. Maximizing the power of a laser striking a surface means there should be a minimal amount scattered and transmitted, where most of the laser's power is absorbed.

3 Experimentation

As stated before, to have the largest amount of power hitting a surface there must be little or no transmittance and reflection. To select a material that meets this requirement we set up a 633 nm HeNe laser with a power output of about 15 mW and illuminated it on a bright white test surface. When I visited Mr. Magliaccio he had already made a series of tests on various types of materials, ranging in everything from ceramics to metals. Because he was using such a powerful laser there were little square shaped indentations in the surfaces. My goal was not to find a specific material that maximized the absorption, but rather to fully understand the process that took place and how the scatter varied and was related to the incident angle of the beam.

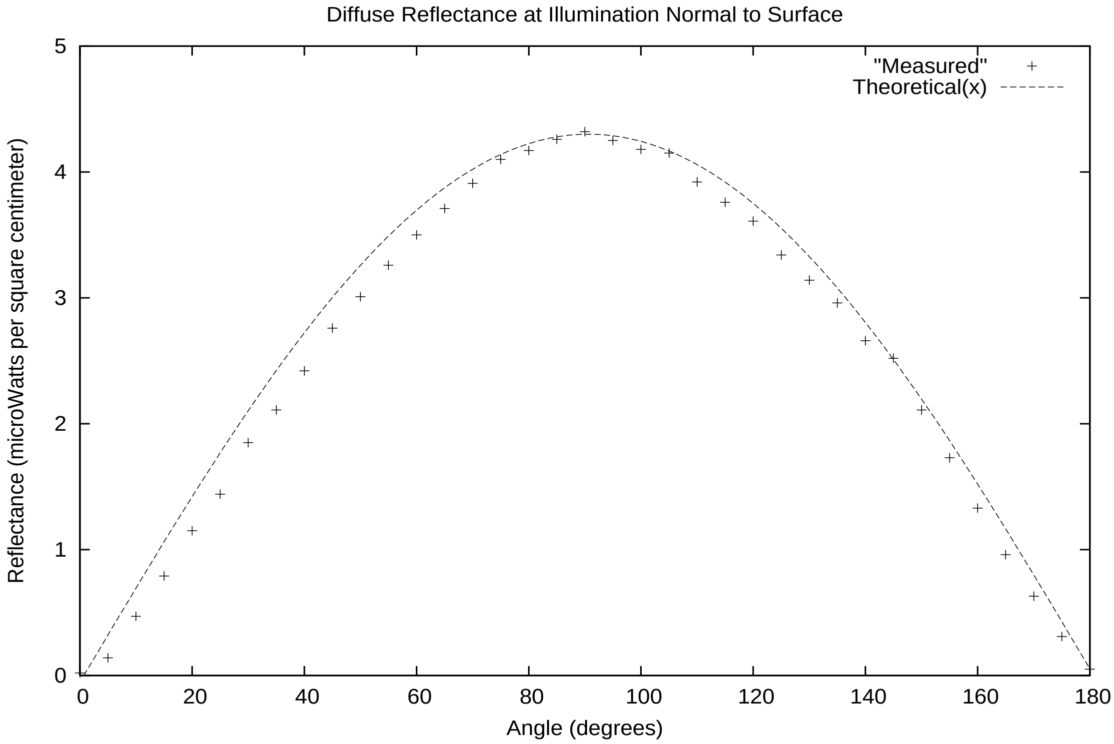
To measure the scatter of light a multiprobe detector was arranged such that its angle could be adjusted so the reflected irradiance could be viewed from 180 degrees around the surface (a goniometer). Ideally, measurements should be taken in three-dimensions, however because the equipment needed to perform such an experiment were not available to me I was only able to take data in two-dimensions. Due to space constraints I ran the laser through a prism and a mirror to illuminate it on the appropriate point, normal to the Lambertian test surface.

3.1 Results

Shown below are the results illustrated numerically and graphically:

Table 1: **Measured Scatter at Illumination Normal to the Surface**

Angle (degrees)	Reflectance (μW/cm^2)
0	0.02
5	0.14
10	0.47
15	0.79
20	1.15
25	1.44
30	1.85
35	2.11
40	2.42
45	2.76
50	3.01
55	3.26
60	3.50
65	3.71
70	3.91
75	4.10
80	4.17
85	4.26
90	4.32
95	4.25
100	4.18
105	4.15
110	3.92
115	3.76
120	3.61
125	3.34
130	3.14
135	2.96
140	2.66
145	2.52
150	2.11
155	1.73
160	1.33
165	0.96
170	0.63
175	0.31
180	0.05



By moving the photodetector around the test material in an arc of 180 degrees and in a radius of 30 cm we see the scattered light ranges from almost nothing at low incident angle (0.02 μW/cm^2 from more precise measurements) to almost 4.5 μW/cm^2 when normal to the surface. Comparing the measured results with the theoretical values given by Lambert's Cosine Law shows a good agreement between the two.

3.2 Future Work

After the formal end of the REU program I plan to continue conducting similar research to find materials that have the property of minimal reflectance. Instead of making measurements with a HeNe laser I will be using a 1.06 micron laser, which is the wavelength of the high-powered YAG laser that will be used for the laser engraving.

4 Conclusion

This project was started thanks to work that was being performed on laser engraving by Dr. Noe's former colleague, Mr. Migliacci. Since Mr. Migliaccio was testing the optical absorbance of materials, an understanding of the basic principles of reflection and scattering was needed. Research began on a Lambertian surface to better understand the relationship between specular and diffuse relfectance. Knowing the diffusive scatter of a material would allow us to learn about its optical absorbance. This was quite important because the ultimate goal was to find a material that exhibited a maximum absorption with minimal scatter. I began collecting measurements in the optical range by using a HeNe laser that operated at a of wavelength around 633 nm. The eventual goal of the project would take place after the REU program came to an end; data would be collected using a 1.06 micron laser, which was the same wavelength of the high-powered YAG laser that would be used in the engraving.