Proposal for
Diamond Optics Measurement System

ECE 480 Senior Design - Team 12

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**Executive Summary**

The Fraunhofer Center for Coatings and Laser Applications is interested in improvements to the accuracy and sensitivity of their diamond optical properties measurement system. Fraunhofer grows some of the highest quality diamond in the world. A senior capstone team was tasked with creating the measurement system in the spring of 2013, and Fraunhofer was dissatisfied with the result. The goal of this project is to improve upon the previous system in all areas. This includes the computer interface, the hardware components, and the resulting measurements.
Customer Needs/Requirements

Our customer, Fraunhofer Center for Coatings and Laser Applications, needs to a system that is capable of measuring and locating the impurities of an artificially grown
diamond. These impurities can be detected as a result of the optical quality known as birefringence. A birefringence measurement is calculated based on the difference between the light intensity that shines through the diamond. This birefringence calculation creates quantifiable data of diamond stress and allows Fraunhofer to exchange diamond data without needing to have physical diamonds present.

![Birefringence Diagram](http://www.hindsinstruments.com/techniques/birefringence/)

The first parameter that must be met is to create a system that disallows the transmission of ambient light into the system. If ambient light is capable of entering the system, it will alter the light intensity of the diamond image and, thus, skew the birefringence calculation. To account for this error, the outer shell containing the diamond sample must be thick enough to block out all exterior light. If the shell is too thin, the structure will not be strong enough to protect the contents and will not be able to shield ambient light.

Another requirement that must be fulfilled to meet the customer expectations is to have a light source that is capable of illuminating the entire diamond sample. When the source is illuminating light, it must do so in such a way that the light is being distributed uniformly. This is important, because this will allow all image pixels to receive the same amount of light and, thus, create an accurate representation of light intensity.
The customer also expects to have the resolution of the camera accurately depict the diamond image. This is a critical parameter, because in order to calculate the exact value of birefringence, the diamond quality must be represented as accurately as possible. In order to accomplish this, a high-resolution camera source must be used. This camera must be located in a position to capture every pixel of the diamond as well as be in focus for the user. There are not any limitations on the size of the design, but it makes more sense to have a design that is compact and portable. The camera must also have USB capability so that the image can accurately be transferred to the software program to calculate light intensity.

Finally, in order to meet the customer expectations, the software must be user-friendly. The software to be used must, therefore, specifically be made for creating graphical user interfaces. In addition, the software must calculate the birefringence correctly. This means that the software to be used must focus on image processing. This is a very important parameter, because the software is the driving force behind the implementation of the design and is responsible for accurately calculating birefringence.

**Background**

Synthetic diamonds contain imperfections and lattice irregularities. Using the optical property birefringence, these imperfections can be quantified. When linearly polarized light travels through an unstressed diamond, it will act according to its regular refractive index. When that same light travels through a stressed portion of a diamond, its refractive index will change. To detect this change, a polarizing filter
that is perpendicular to the transmission light will be placed on the other side of the diamond. In perfect areas of the diamond, the light will come through the entire system polarized. Because of the second polarizer, light that was not perfectly polarized will make it through the system. In stressed areas, there will be amounts of non-polarized light. The strength of this non-polarized light will be used as a reference for measuring birefringence, which correlates with stress.

![Polarization of Light Waves](http://www.microscopyu.com/articles/polarized/polarizedlightintro.html)

**Design Specification**

Often times, diamonds have stresses within them, which can be detected though an optical quality known as birefringence. The sponsor requires an optical measurement device to detect the level of birefringence that occurs in artificially grown diamonds. There are several specifications that are required to be implemented in this design. The team will follow the step-by-step approach, so the demonstration of the design specification will occur in a particular order.

First, to detect birefringence, the design should be immune to exterior light sources. A stable light source and a shell that is impervious to ambient light are required. The previous team used a laser pointer as their light source. However, the laser had a non-uniform distribution of its light, which created spots on the diamond. The current team
chose Light Emitting Diodes (LED) as new light source. Compared to the laser, LED’s can generate the same amount of power, but with more uniform and crisp light beams. To obtain and calculate multiple measurements, the team chose six different colors of LEDs, each emitting light at different wavelengths (white, blue, lime, green, orange and red). For an effective and efficient light source system, the team will test and analyze the different spectrums and characteristics for each LED, resulting in a convincing final lab report. Furthermore, to integrate these LEDs into one light source system, a voltage regulator is required that provides different voltages for each LED. Eventually, a knob switch might be needed to turn on a single output LED.

In addition, the design needs a high-resolution measurement of birefringence. In this case, a high-resolution camera that can effectively detect LEDs is required. The sponsor requests a highly reliable grid resolution of ten micrometers, with a maximum possible error of 1%. Indeed, any higher resolutions are usable as imperfections in diamonds are typically in the parts per million. Additionally, an advanced camera can avoid mechanical movement of the crystal sample because an image movement can be conducted by software. This specification is a significant element for the design and can be completed by a good combination of LEDs and camera.

Finally, the system should interface with a computer and display the data on the computer in the form of a 2-D image, including birefringence associated with a position vector. This image and data are vital to the study of the faults in artificially grown diamonds; locating common patterns will allow the sponsor to determine better possible implementations to achieve a better process. In order for a design to be considered
pliable, these sets of data must be present. This specification can be implemented by
codes in the advanced software, Visual Studio.

**Set of Conceptual Designs**

There are a few different possible designs for this project. This can essentially be
divided into three different sections that are each independent of each other. The first
section is the light source whether one LED light source or multiple LED light sources
should be used. The second section is the design of the outer shell and whether or
not a high quality one should be used. The third section deals with the camera and
measurement system, whether a camera or a photodetector should be used.

**Light Source Design 1:**

One way to design the light source section of this project is to use a single LED
light source. The light from a single LED is much easier to design because there it does
not require too much space and does not need a very complicated voltage regulator. It
is also slightly cheaper because the outer shell will not have be as big

**Light Source Design 2:**

Another way to design the light source section of this project is to use six LED
lights. These LED light sources would be Red, Green, Blue, Orange, Lime, and White.
Since each color functions at a different wavelength, having all of these LED light
sources would give more accurate results

**Outer Shell Design 1:**
One way to design the outer shell section of this project is to use a cost effective and cheap outer shell. The outer shell’s function is to shield the inner design from ambient light and give a platform for the design.

**Outer Shell Design 2:**

Another way to design the outer shell of this project is to use an expensive outer shell. This would better shield inner design from ambient light. Even though this design would cost more, it would give an extra benefit in that it is more robust than the first design.

**Measurement System Design 1:**

One way to design the measurement system is to use a camera. A camera would be able to map out the entire diamond with images and locate physically where the stresses in the diamond are. However, this option would be a lot more expensive than the alternative option.

**Measurement System Design 2:**

Another way to design the measurement system is to use photodetector. This option would be much cheaper and be better able to detect light differences than the first design option. Since the measurement system would have to compare light intensities, this design would do a better job of that.

Below is a decision matrix which allowed the team to decide what the final design would look like. The determinations were first made by each team member individually then discussed as a team and with the company sponsor.
<table>
<thead>
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<th>Cost (20)</th>
<th>Safety (40)</th>
<th>Size (10)</th>
<th>Performance* (30)</th>
<th>Total (100)</th>
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<tr>
<td>Multiple LED Light Source</td>
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<td>Expensive Outer Shell</td>
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<td>Camera Measurement System</td>
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<td>Photodetector Measurement System</td>
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<td>45</td>
</tr>
</tbody>
</table>

*Performance Includes Light Immunity, accuracy, and resolution

**Key:**

- **100%**
- **50%**
- **0%**
- **Not Included**

**Proposed Design Solution:**

The proposed design solution focuses around the light source, which will be an LED. The light from this laser pass through a linearly-polarized filter. This polarized light will then pass through and illuminate the entire diamond sample. The light will then pass through another linearly-polarized filter, which will be offset from the
first polarizer by 180 degrees. The remaining light that passes through the final polarizer will be picked up by the high-resolution camera. This camera will then send the image to the software program via its USB capability. This software will be integrated with Visual Studio so that this program will calculate the birefringence based on the light intensity of each pixel, create a 2-D image of the birefringence, and then display that image. The outer shell that will contain all the hardware contents will be designed in AutoCAD and will be constructed through 3-D printing. This outer shell design will position the camera on top, with its lens facing the ground. Likewise, this design will have the LED light source on the bottom, shining upwards toward the camera lens. The LED light source and polarizing filters need to be tested before they are attached to the shell to ensure they work together. In addition, the camera, user interface, and calculation of the birefringence will be tested once images are able to be developed and measurements can be extracted from these images.

![Diagram of the setup with polarizer, LED, diamond sample, and camera.]

**Risk Analysis**

The parameters specified by Fraunhofer presents two possible risks for the design. These risks include the use of a LED and the transmission of ambient light.
First, there is a potential hazard to the team members while operating a high-powered LED. Wearing safety goggles at all times can minimize this danger. The power of the LED has to be kept under a threshold for accurate results. As mentioned before, the White LED is powered by 36 volts, while the other single color LEDs are powered from 2.5-3.5 volts. An accurate result also requires a stable power supply, a rotating switch, and a precise connection between voltage regulator and the rotating switch.

In addition, ambient light inside of the system would also yield inaccurate results. Ambient light is hard to eliminate since exterior light all around us. Additionally, humans can only detect a small range of light spectrum. Thus, one cannot recognize whether some light exists and this “invisible” light may impact the birefringence calculation. Therefore, the team has decided to follow the previous team’s idea that a shell is to be built that contains the diamond and measurement contents. This may greatly reduce the presence of ambient light around the camera. As this risk can interfere with the measurements, it can be considered as high risk as well. In this way, the system can be designed so that the LED is the only light source inside.

**Project Management Plan**

The tasks that need to be completed for this project are divided among five team members. The divided tasks were assigned based on each team member’s strengths and weaknesses. It is important to note that even though a certain task might be assigned to one team member, there is no one portion of the project that is completely done by one person. Often times there will be multiple members working on a task that was only assigned to one person.
The team manager, Dan Schulz is responsible for the overall management of the group. He is responsible for communication between the team, the facilitator, and the sponsor. He is also designing the implementation of the polarized slides for the birefringence measurement system. The polarization of the two slides must be perfectly perpendicular for the results to be accurate.

Team member Allen Lin is responsible for presentation preparation. He is also responsible for designing the outer shell which contains all the circuitry and equipment. One of the challenges is that the outer shell must be able to shield the inside from all ambient light otherwise the device will have inaccurate measurements. Mr. Lin is also in charge of presentation preparation so the final presentation and the proposal presentation will be organized by Mr. Lin.

Team member Adam Tayloe is responsible for document preparation. He is also responsible for the User Interface/ Image Processing. One challenge of User Interface is designing an interface that is user-friendly enough to be used by any given client. In addition to the User Interface, Image Processing presents a challenge. In order to successfully process images from the camera, one must find software that is capable of accomplishing this. Mr. Tayloe found and implemented software that is capable of doing this. Mr. Tayloe’s final role is that of the Document Prep. This role is responsible for organizing and maintaining all of the necessary documents throughout this project.

Chunyu Li is the team’s lab coordinator and is responsible for the light source design. One of the challenges is that the results of previous designs (both green and red lasers) did not work properly, so Mr. Li needs to think of more effective solution for the light source. One way is to find a different type of light source, such as using a white
light emitting diode bank to accomplish the project requirements. Thus, Mr. Li’s goal is to test the light source designs, to research in the lab and to select the best light source. Additionally, as a lab coordinator, Mr. Li is responsible for testing all the team’s design and recording the corresponding lab’s data.

Team member Dan Kuang, is the webmaster and he is responsible for creating and updating the team website.

The following are the FAST diagram and GANTT chart for this project. The following includes a diagram, the FAST diagram which displays a brief process of the project. It starts from the first objective and progresses to secondary objectives like a horizontal directional tree diagram. Under the FAST diagram is the GANTT chart which describes a series of tasks to be completed with a given time line.

*FAST Diagram:
*GANTT Chart:

**Cost & Budget**

The team is given a $500 budget to complete the project. The most expensive part of this project is the camera and measurement system. The camera needs to be of decently high quality because the pictures the camera is taking needs to be able to map out the defects in the diamond. The estimated cost for this camera is $250.

Another very important part of the project that has to be purchased is the polarizers. Since Birefringence can only be seen under polarized light, it is important that the light source is polarized. The best way to deal with this is make sure that there is a polarizing filter between the light source and the diamond sample. The team expects the polarizers to cost around $10.

An outer shell is also needed in order to mount the design and to shield the interior design from as much ambient light as possible. An outer shell can be created
with the use of 3d printing and depending on the material used this can be very cheap or very expensive. The team would like to use cost effective material so that the price of the outer shell will not be too high, however cheaper material also presents a few problems that a more expensive outer shell would solve. The team expects to spend around $100 for an outer shell. At $100 the outer shell should be of high enough quality to shield the interior circuitry from ambient light and provide some robustness to the design.

One of the most important parts of this project is the LED lights. The team has purchased six different colored LED lights. The white LED costs $24.44, the blue LED costs $4.11, the green LED costs $3.64, the lime LED costs $4.11, the orange LED costs $3.32, and the red LED costs $3.16. The combined cost of these LED lights is $42.78. Since there might be unforeseen costs that could show up, the team has estimated this part of the budget to be $50.

When all the estimated costs are added up together, it only totals to a little bit more than 80% of the total given budget. This was done on purpose so that there would be some extra room in case there are any unforeseen costs. There are many scenarios where new parts might have to be ordered such as replacing broken parts or discovering that a new part needs to be ordered during testing. Furthermore, many of these costs are slightly over estimated, which is done for the purpose of leaving room for unforeseen costs. Given that there is extra room in the budget even after many of the parts have been slightly over estimated, there should be plenty of room for error in case something does not go as planned.
References