Problem Definition

1.1 Introduction

Plasmon-Polaritons is a term that is used to describe a very specific type of electromagnetic wave that exists at a unique interface between a metal and a dielectric. Such a wave is produced when light is shone upon a metal surface. Under specific boundary conditions (including light incidence angle) energy and momentum from the light photon is used to excite a wave that exists at the boundary between thin metal and dielectric. This Surface Plasmon-Polariton, (SPP), is thus named because of its self-sustaining nature; the electric field of the electromagnetic wave induces the charge density "wave", and vice versa. This means that the characteristics of this wave are extremely sensitive to the optical properties of the thin metal – dielectric boundary. Any change in the index of refraction of the dielectric results in a change in required photon incidence angle, SPP width, SPP intensity, etc… which means this wave can be utilized to measure and analyze the properties of a liquid dielectric.

The project, proposed by Dr. Wataru Nakagawa, involves the modification of a previous surface Plasmon-polariton sensor whose design does not allow for the physical observation of the surface wave. This system uses the Kretschmann configuration in a vertical position, using a PDMS (Polydimethlysiloxane) cube to hold the liquid dielectric flush to the metal surface and a flow cell to hold the prism, metal, and PDMS cube together. A HeNe (Helium-Neon) laser, $\lambda = 633$nm, is shone through a cylindrical lens which turns the parallel rays into a group of converging rays. This allows for precise angular measurements. These rays are directed into the flow cell and the flow cell is rotated around its vertical axis to change the laser's incidence angle upon the gold film. The light that does not get turned into the SPP gets reflected through the prism onto a 3" automated rotational mirror, which rotates to scan the elliptically shaped reflection across an iris and power meter. The iris is used to separate the light angles.

Since this system only measures a secondary effect of a SPP there is room for improvement. The proposed modification to this system would allow for direct analysis of the SPP wave, including the ability to capture light being scattered off of nanostructures at the gold boundary. This project also includes the potential for observing the way that SPP waves interact with surface nanostructures, opening up new possibilities for SPP characterization. Such a sensor would have widespread multidisciplinary applications, including the ability to identify biological liquids from miniscule amounts, and the ability to analyze chemical/biological reactions.

The timeline of this project is three months allocated for the design building and design analysis process, and three months allocated for physical building of the system and system testing. The budget for this project is $2500, but is flexible within reason. The tasks involved in building this sensor are Preliminary Design, Detailed Design, Critical Subsystem Prototype Demonstration, Final Design Report, Fabrication and Assembly, Product Testing, Final Assembly and Test, Final Product Report. This calendar is illustrated in Figure 1.1.

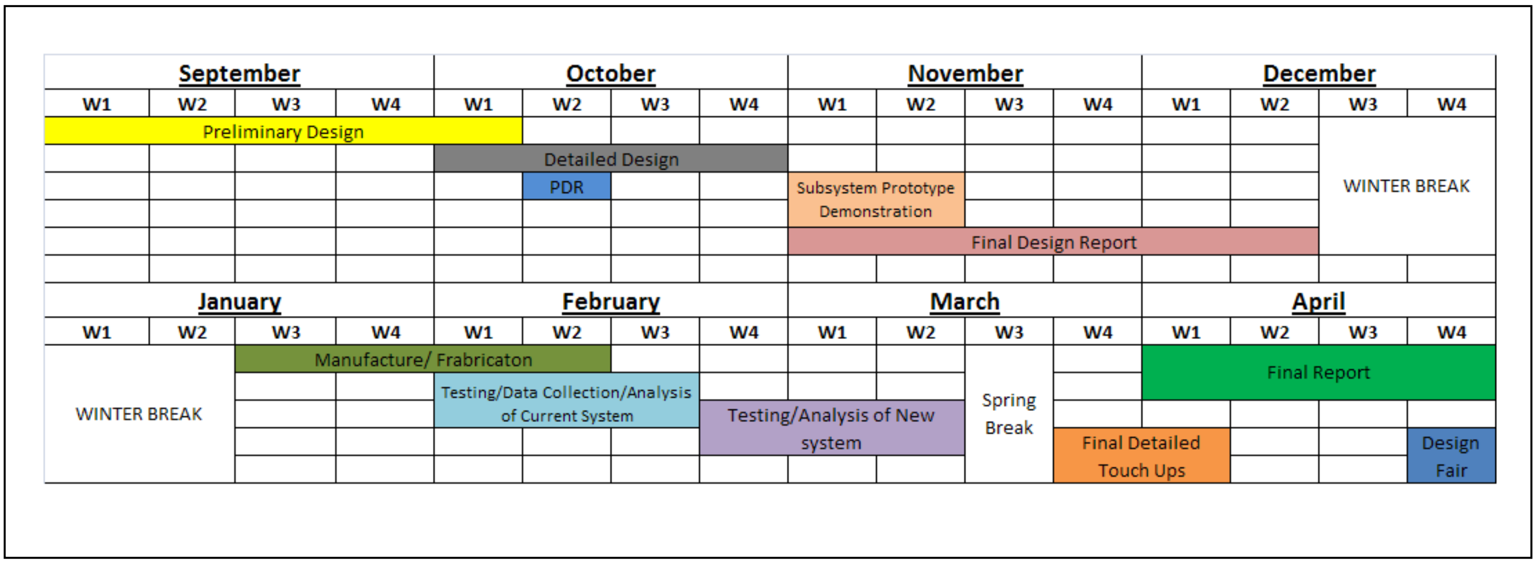

Figure 1.1: Timeline of the Senior Design Project over eight months; this includes all presentations, and a sensor fabrication period as well as a new system testing period and time to prepare for the Design Fair.

1.2 Statement of Need

The goal of this project is to modify the current surface Plasmon-polariton sensor. The aim is to allow for direct analysis of the surface wave as well as retaining the ability to use the original SPP setup.

1.3 Stakeholder List

A list of stakeholders who would potentially benefit from this modified surface Plasmon-polariton sensor has been categorized as shown below:

Dr. Wataru Nakagawa: Dr. Nakagawa is the sponsor of this project. His interest in using the sensor in an interdisciplinary manner fuels the expansion of the sensor's capabilities

Chemical/Biological Departments (MSU): As stated above, the sensor has the potential to measure and examine the optical properties of chemical or biological liquids. This includes being able to verify the presence of intermediate molecules.

Optics Community: Having the ability to characterize the properties of the SPP wave would be a great tool for the optical community. While other systems do exist, this one could prove to be unique, especially in the hands of the faculty and students at Montana State University.

1.4 Project Team Members

Tou Vang is a senior in Electrical Engineering with a focus in power and micro fabrication. He has previous experience in clean room environments.

Rajit Podder is a senior in Computer Engineering. He has worked on zoom lenses and aberrations on microscope objectives. He has prior experience working on the optical bench and his programming skills would bring in valuable inputs to this project.

Krista Drummond is a senior in Electrical Engineering, with a focus in Optical Engineering. She has had previous optical experience on the SPP sensor, and has also worked on other optical design problems.

1.5 Client Stated Objectives and Requirements

Our end product will be a surface Plasmon-polariton sensing system that allows for direct observation of the self-sustaining surface wave. The current SPP system exclusively senses the photons not transferred to the surface wave. Modifying the system to include the ability for direct detection would improve the liquid dielectric characterization process. The objectives of the design process are the ideal system end goals, while the requirements are those objectives which are big picture goals for the project; the Level One Requirements.

Objectives:

Physical Observation of the SPP: As stated before, the main priority of the modification to the original SPP sensor is to allow for a camera to observe the actual surface Plasmon wave. Since light will not be observed at the dielectric-gold boundary when the SPP wave is perfectly absorbed the boundary surface must be either illuminated, or intentional scattering at the boundary must be made to occur. The camera must be close enough to see the full standing wave but far enough away to not interfere, and must also have some way to identify the surface section being imaged. Imaging on the nanostructure level will require a magnifying camera (microscope) with a magnification of ≈10μm). Since the properties of the surface wave change when the metal is changed (in the case of a non-metal multilayer in place of the gold) the absorptive and refractive properties of the metal change what the camera might see. Also the input light beam must be p-polarized to produce a SPP wave.

No Optical Interference Seen by the Camera: Ideally, the camera should not be separated from the wave by any media that would introduce an optical error or aberration. If however there is an imaging error introduced by some optical element then it must be characterized and corrected for.

System Performance: The system must be able to measure a liquid dielectric. It must also be capable of measuring the reflection of the light (minus the light coupled into the surface wave) off of the gold surface, so that the measurements from this new system can be directly related to measurements from the current system. If the design chosen is an alteration to the existing vertical system then the sensitivity, resolution, and accuracy seen currently must be matched. If the design chosen is a completely new sensor setup, then the sensitivity, resolution, and accuracy results of the new design must be at least three times the current systems results, but all three values seen below should not have this error margin.

Previous Senior Design Team's Numerical Values for System Performance:

Test Reproducibility	*=*	*0.4° error*
Test Stability	*=*	*0.09° error*
Test Sensitivity, (Δn)=	*0.0022*	

Angular Range Needed: According to the previous senior design team the angular range that the current system was designed to handle was a range of 79°-108° (Note that the angular range needed for a Winspall angle of 86°). Any modifications to the current system must allow for this range (or larger) to be accessible with the laser beam.

Little to No Changes to Original Setup: The original set up works well for imaging the gold reflection and should be part of a multifaceted SPP sensing system. This design project must add to this setup, while keeping intact the integrity of the current SPP system.

Complete Laser Beam Containment: Since the HeNe laser available for use in this project is a level 3b, the beam should be properly contained within the plane of the optical table.

Single Mirror "Switch": To efficiently move the laser between the two different setups, a single mirror should be used as a switch.

User Interface and Input Data Compatibility: Any measurements taken need to be compiled by the computer in a way that the program Matlab can understand. This requires the building of a LabView program to interface with both the computer and optical equipment, and to compile data in an ordered fashion.

Requirements:

Physical Observation of the SPP: Since this is the main goal of this senior design project, the completion of this objective is a must.

System Performance: While this design project involves building a completely new setup, the performance of the system should be a huge part of determining the success of this team.

User Interface and Input Data Compatibility: The measurement control interface must be able to control all electrical optical components of the design, and be able to record data in a format compatible with the analysis process. This is a level one requirement of the project because parts must be controlled and angles must be measured and if this process isn't proscribed by a computer than the data collection process would be very inefficient.