Proof of Design for the Advanced LASER Mining Array (ALMA)

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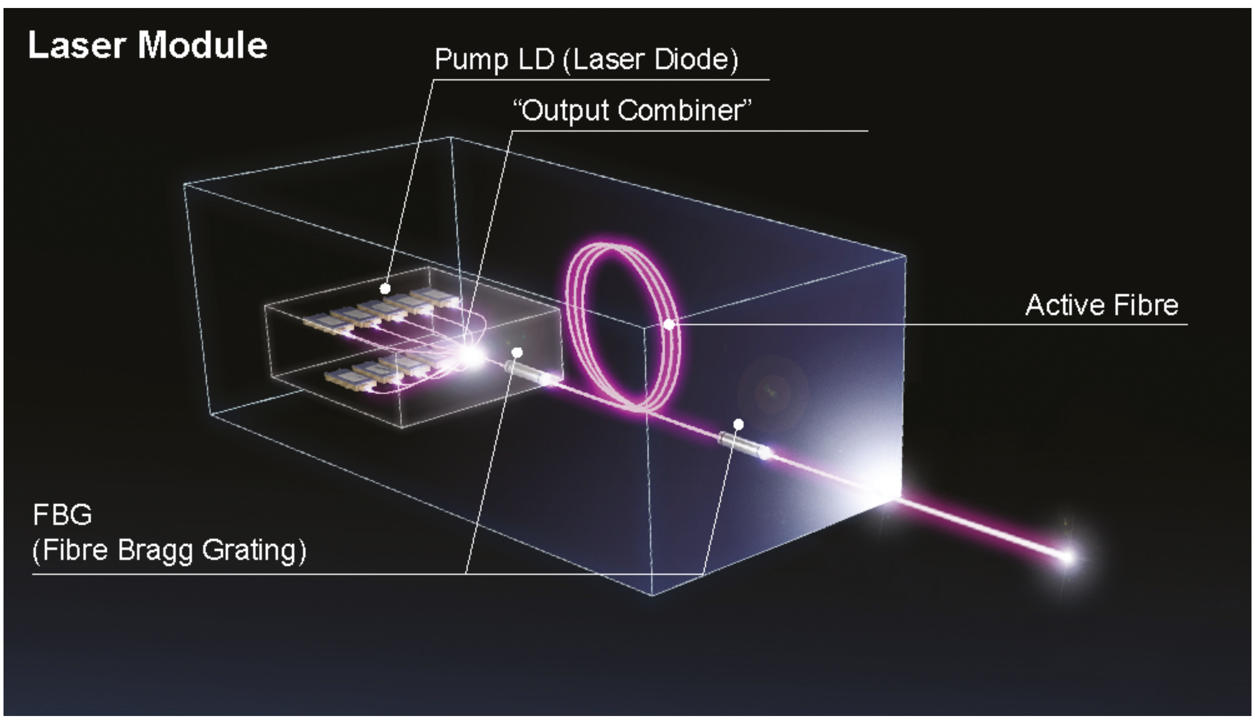

Nomenclature

$\mu =$ 10^{-6}

$C - Type =$ Carbonaceous chondrites

$EPPL =$ Engineering Physics Propulsion Lab

$Er =$ Erbium

$FBG =$ Fiber Grating

$FBL =$ Fiber LASER

$K =$ Kelvin

$LASER =$ Light Amplification by Stimulated Emission of Radiation

$nd : YAG =$ neodymium-doped:Yttrium Aluminium Garnet

$NEO's =$ Near earth objects

$PPE =$ Personal Protective Equipment

$SOP =$ Standardized Operating Procedure

$Tm =$ Thulium

$Yb =$ Ytterbium

1 Abstract

The goal of the ALMA project is to design and create an apparatus to test the ability of a FBL to mine water ice in space. This includes ice on the moon, NEO's, and asteroids in the asteroid and Kuiper belt (which mainly consist of C-types and comets) [3]. ALMA is a down-sized version of the full lASER, being able to melt smaller chunks of ice. The reason for using a FBL versus a nd:YAG or CO_2 gas LASER is to make use of the efficiency and accessibility of the FBL. The FBL is a more cost effective, and energy efficient laser, while also more compact than its counterparts [5]. The simpler design, allows it to be both reliable and maintenance-free during use [1]. Most high powered FBL's have a recorded 30% - 50% power efficiency, much greater than other options [4]. Because of this the FBL was found to be the best option.

The basic design of a FBL utilizes: coupled diodes, a combiner, a Yb doped fiber cable, FBG (one of higher polarization on the input and another of low polarization on the output), and a FBG to protect the inside of the cable (*Fig. 1*). Due to the fact this project is researching means of mining in space, where the resting temperature is approximately 2.7K, there would be no use for cooling. More likely a means to find ways to shield the FBL from the space environment will need to be developed, because temperatures do not remain consistent once on the surface of the moon and other bodies in space. Because of this, the components will need to be changed based on the FBL based on its environment it is mining.

To complete the project and its goals, there will be a safety plan implemented as follows. The downsized model will have a system of precaution, including PPE, a safe and isolated environment for testing, and documentation with information disclosing safety measures.

2 Background

After Albert Einstein discovered the math that describes lasers in 1917, work stagnated until the 1950s with the first successful design in 1960. It wasn't until 1963 when Elias Snitzer demonstrated a FBL [6]. This work was evolved to create lasers that are used to cut precious metals or in communication systems. In recent years the most common point of discussion is for mining, as it is the most rewarding possibility for FBLs to be used.

The function of a FBL works by using a diode coupled to a doped fiber optic cable, with amplification by stimulation. Some dopants for the amplification process are the elements Yb, Er, and Tm [6]. This process is called population inversion, defined as the redistribution of energy levels by collisional excitation of the electrons in the atom [7]. When electrons collide with a photon, from the pump source, it becomes energized and jumps to a higher energy level (*Fig. 3*). This process can be mathematically described by the elementary equation: $E_2 - E_1 = \Delta E = hf$, where h is Plank's Constant and f is the frequency of light. Once the electron goes back to the ground state and re-emits the photon, it gets reflected from the high reflective FBG, thus exciting more electrons and emitting more photons. From this quantum phenomena, a single photon can start a domino effect and amplify the input significantly and quickly.

The cladding of the fiber cable, surrounding the doped core, allows the light to have total internal reflection (*Fig. 2*) allowing minimal energy loss and scattering. This effect comes from Snell's law: $\sin(\theta_c) = \frac{n_{clad}}{n_{core}}$, where n is the refractive index. For this to work and there to be total internal reflection: $n_{clad} < n_{core}$. There can be some scattering loss due to bending of the cable, which can be calculated and accounted for. The FBG on each end of the fiber filter the photons so that it can be reflected and energized to the correct wavelength (λ). For the current setup, ALMA will have $\lambda \approx 1070nm$. The input grating has a larger reflectivity, thus no light can re-enter the diode and it is reflected to be amplified. Once the photon has reached the max wavelength (1070 nm), it is transmitted through the low reflectivity FBG.

3 Methodology

ALMA will be a down-scaled version of the theoretical FBL at about 1.2 Watts of peak output power, giving a pulse energy of .24μJ at a pulse width of 20μs. There will be a control board with the diode soldered on, giving us the ability to change the pulse-width parameters and input/output power. Within the lab, we plan on building a test cell made from 80/20 linear rails, the laser will be contained in the cell. Around this test cell will be a polarization screen, explained in section **Safety Precautions**. The apparatus will show mining techniques and collect spectra data from ice. This spectra data will be used when compiling the simulations, deriving the power needed to complete this task in different environments. The goal is to see how applicable this idea is with current technology. If not at all, the simulations can tell us why and what we need for it to come to fruition. It is also a lot more inconvenient and expensive to do tests with a higher powered FBL. Thus with the smaller version, ALMA is still able to experimentally derive the necessary processes that the simulations will be sourced from.

Currently, there is no precise value for the absorbance of ice, which is the lowest power requirement to melt ice. The basic definition of the absorbance, stated as the Beer-Lambert Law: *An absorbance of 0 corresponds to a transmittance of 100% and an absorbance of 1 corresponds to 10% transmittance* [11]. This comes from: $A = \alpha cl$ and $\alpha = \frac{4\pi k}{\lambda}$, where A is absorbance, α is absorption coefficient, c is molar concentration, l is optical path length, k is extinction coefficient, and λ is wavelength. The absorption coefficient is defined: *How far into a material light of a particular wavelength can penetrate before it is absorbed* [12] and the extinction coefficient: *How efficiently light is absorbed or reflected from a material* [12]. Because of this, we will need to experimentally derive k and α to solve for A. This is important because without these values λ for the system is essentially an educated guess, which is what we are currently doing. Thus in the future, ALMA will need to incorporate different FBG, testing with different λs to derive the best absorbance value for the system.

Some other examples of why testing with different FBG will help ALMA's progression include power output, beam quality, mining techniques, etc. Completing any of these experimentally will help the theoretical process and also make it more accurate for our goals.

	TASKS	START DATE	COMPLETION DATE
1	IGNITE grant is rewarded	07/2023	-
2	Order components for FBL and apparatus	07/2023	08/2023
3	Make apparatus to mount FBL	08/2023	08/2023
4	Start testing FBL	08/2023	08/2023
5	Research Symposium	Fall TBA	Fall TBA
6	Collect spectra and mining data	09/2023	11/2023
7	Testing w/ more FBG(if enough $)	11/2023	01/2024
8	Repeat 6. with other FBG	01/2024	02/2024
9	Discovery Day	Spring TBA	Spring TBA
10	Compile sim with spectra data	03/2024	05/2024
11	Publish research	05/2024	05/2024
12	Reach out for more opportunities	05/2024	07/2024

4 Safety Precautions

The EPPL in room 123.1 of the COAS is a very secure environment to preform experiments. Storing ALL of ALMA's equipment, including PPE, the apparatus, and experimental tools. There is also a test cage in which all of the experiments will be preformed along with a protective screen that blocks all light emission. The screen is present so that if light gets scattered or reflected it will not injure any researchers or damage sensitive equipment. The researchers working on ALMA will be wearing PPE at all times, including polarized goggles and latex gloves. In the test cage, there will be designated spot for NO crossing, where the beam would be active along with a sign outside the lab door signaling the use of a LASER. Money will also be allocated to buying a downsized test cell with the ability to install polarization features, in the case the screen cannot be purchased.

4.1 Storage's SOP

Money for the FBL equipment will be allocated for secure, pelican crates for the equipment. It will be stored in a room behind a locked door, and will only be available to the PI once stored. Only 3 research interns and the supervisor have access to this door inside the lab once locked. The PPE will also be stored in pelican crates inside the test cage along with the equipment. The PPE includes polarized goggles, grounding cables, and protective gloves. Along with this, there will be NO jewelry of any kind when handling/experimenting with equipment.

4.2 Experiment's SOP

The experiments will always be conducted inside the test cage, behind the locked door, inside the lab. There will be warning lights when the FBL is active and will be warning signs on the locked lab door and test cage at all times. Inside the test cage, there will be warning tape, at all times, where the beam would cross while active. The FBL will also have a switch to turn power on/off and a shutter on the output lens to block any light coming out of the FBL, on or off. Stated above, the test cage will have polarization tint so that if the beam gets reflected towards the cage, it will not be transmitted through the cage.

5 Significance

Space mining is one of the "Big Talks" in fields of science and business alike. Once pioneered and efficient, mining in space will rid the need for ripping earth of its materials. If we continue to mine earth, we will eventually run out of resources within the millennia. Mining in space also gives humans the ability to complete space travel easier and generate new processes of wealth. This project introduces the concept of using a FBL to mine in space. From this project, the aerospace industry will have a new, optimized process of extracting water ice from space, allowing companies to make fuel from hydrogen or steam and have an oxygen supply. ALMA will also exponentially increase this team's knowledge in areas of lab competency and safety, experimental processes of LASERs, physics of LASERs, and mathematics. Feeding this team the knowledge we need to be successful in each of our fields.

6 Communication Plans

The findings of ALMA will first and foremost be shared with Embry Riddle Aeronautical University. An accumulation of the findings, data, and simulations will also be shared to multiple journals in hopes of publication regarding the project. We will also apply for more grants and reach out to companies in hopes of partnership to further the research of ALMA.

7 Adequacy of Resources

All experiments will be conducted in the EPPL, room 123.1, in the College of Arts and Sciences at Embry Riddle Aeronautical University. There is sufficient space to include all measures for storage and operation, along with adequate tools and additional resources. The EPPL comes with 10 3D printers, including a 0.6 cubic meter printer, that are available for the ALMA team to use when needed. Dr. Sudesh, who has more than 20 years of experience in conducting experiments with FBLs, solid state LASERs, and optics, will be a mentor for the team. His knowledge and industry connections will help in many ways throughout this project. Also Dr. Drakunov, who is the founder of the lab, will provide an excellent source of knowledge when applying the results to the simulations.

8 Appendix

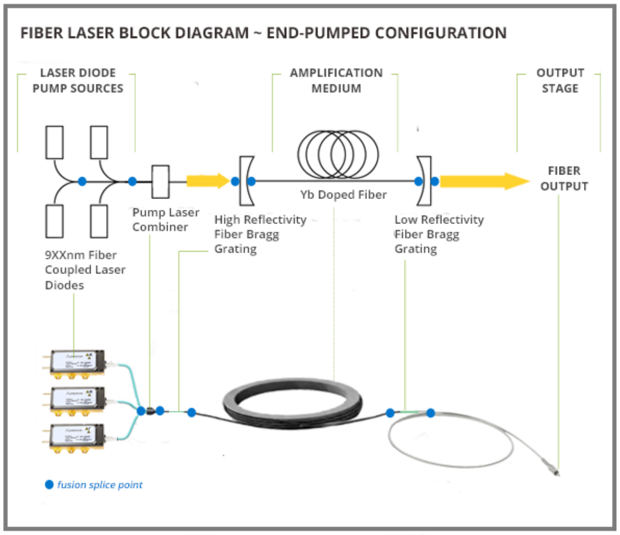

Figure 1: FBL design setup for amplification [7]

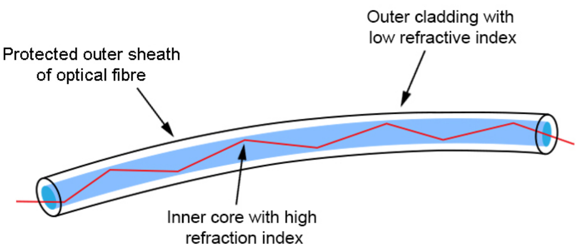

Figure 2: Example of total internal reflection in cable [8]

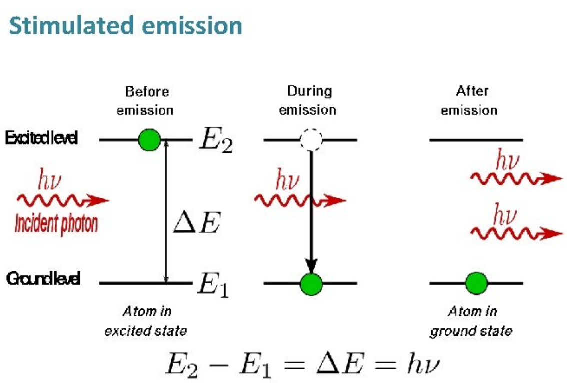

Figure 3: Population inversion cartoon example [9]

9 References

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[12] Absorption coefficient. PVEducation. (n.d.). Retrieved February 24, 2023, from https://www.pveducation.org/pvcdrom/pn-junctions/absorption-coefficient

10 Student Group Resume

Jacob Romeo: A second semester junior in Astronomy and Astrophysics with research experience in applied and theoretical physics, astronomy, electrical and software engineering, and control theory. Over 4 years of experience with electronics (PCB development) and coding in python. Experienced using Fusion360 CAD software, C++ and java, and development with raspberry-Pi's and Arduino's.

Phoebe Fleshman: A second semester junior in Engineering Physics with a focus on spacecraft systems. Roughly 2 years of technical experience designing and building robots. Along with roughly 2 years of budget creation and management . Experienced using Autodesk Inventor Pro, MatLab, and CNC mills.

Joseph DeMartini: A third year Engineering Physics student with professional experience in software development and simulation. 5+ years of experience in Java, C#, and Unity3D development with an understanding of advanced software development practices. Experience in applying numerical methods and modern physics concepts to create high fidelity 3D physics simulations in optics, orbital mechanics, and electromagnetism.

Nathan Honderick: A second semester freshman in Aerospace Engineering, specializing in Astronautics. Experienced using Matlab, Onshape, Inventor, and Catia CAD software. Currently working on a CubeSat, a laser mining array, a hybrid rocket engine, and developing a patent for an eco-friendly product crafted from up-cycled beach plastic.

11 Detailed Budget

Est. Total for All Items Requested:	$7,600.00	Actual Total:	$7,571.78

Line #	Vendor	Item	Product # / SKU	Ordering Instructions / Notes	Link	Quantity	Price Each	Est. Shipping Cost	Estimated Total	Actual Total - Inc. Shipping Fee (Purchaser will complete this)	Notes from Purchaser
1	Lumics	BTF LASER diode	LU0975M500		Contact for purchase	1	$2,175.00			$2,175.00	
2	Analog Modules	Seed diode Control board	Model 762		Contact for purchase	1	$1,405.00			$1,405.00	
3	Fibercore	Yb doped fiber cable	custom		Contact for purchase	1	$1,000.00			$1,000.00	
4	Technica	High reflectivity Fiber bragg grating	custom		Contact for purchase	1	$250.00			$250.00	
5	Technica	Low reflectivity Fiber bragg grating	custom		Contact for purchase	2	$300.00			$600.00	
6	Uline	Welding screen (Also getting a small one from SPARK)	H-5179S8	MAKE sure to get the 'Shade-8' color under the color specifications	https://www.uline.com/Pro	2	$150.00			$300.00	
7	Amazon	80/20 Linear rails	B08XXN9TVN		https://www.amazon.com/	1	$90.00			$90.00	
8	Uline	pelican case	H-6800		https://www.uline.com/Pro	1	$72.00			$72.00	
9	GO Photonics	spectrometer	USB4000-FL		https://www.gophotonics.c	1	$1,500.00			$1,500.00	
10	Ocean Insight	Fiber Cable	P200-1-VIS-NIR	for the spectrometer	https://www.oceaninsight.	1	$144.00			$144.00	
11	FTDI chip	UART → USB-A	TTL-232R-5V		https://ftdichip.com/produ	1	$23.40			$23.40	
12	Nilight	Toggle switch	B099S866XH	To toggle power of apparatus	https://www.amazon.com,	1	$12.38			$12.38	