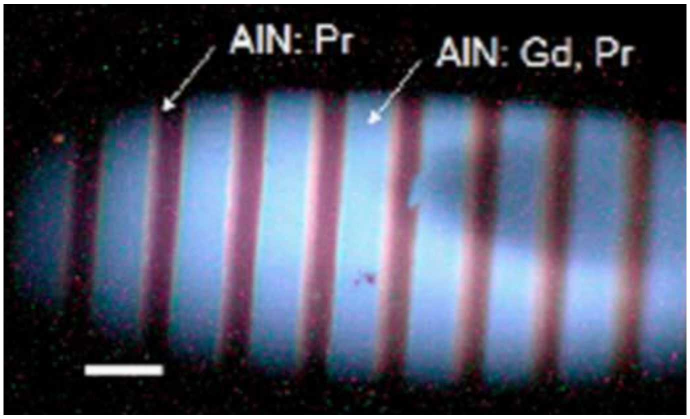
RESEARCH INTERESTS AND PLANS

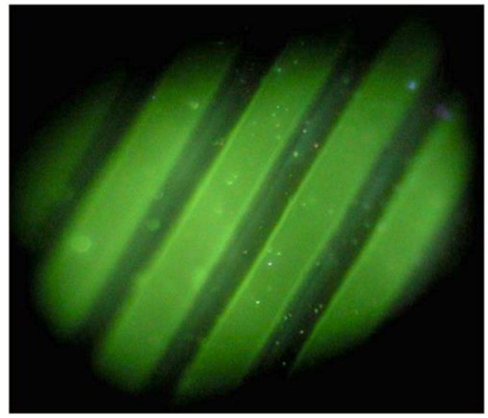
My area of research interests and goals are **Growth, Fabrication and Characterization of Thin film Optical & Nanomaterials for Energy Saving Optical Devices, Laser Cavities, Biomedical Applications, Superluminescent Materials and Thermoelectric Energy Materials.** The projects I plan to work on, engaging students, are given below.

1. Luminescence enhancement in rare-earth elements and transition metals based optical and nanomaterials for energy saving optical devices.

The objective of this proposed research is to investigate luminescence enhancement in nitride semiconductors doped with rare-earth phosphors and transition metals nanostructures. Due to the energy crisis around the world it is very important to construct energy saving devices that can provide better light emission with high efficiency and low input power. Rare-earth (RE) elements doped in nitride semiconductors have sparked interests due to their desirable luminescence, optical, electrical, acoustical and biomedical properties. Aluminum nitride (AlN) and Gallium nitride (GaN) are two semiconductors currently being studied as promising materials for light emitting diodes and electroluminescent devices because of their wide band gap, high melting point, and high luminescence intensity. Infrared (IR) emission from Tm^{+3} has been used in IR devices due to the high penetration ability of IR signal. Many of the rare-earth phosphors when incorporated in AlN or GaN have very strong visible emissions when excited by ultraviolet (UV) sources. For example praseodymium (Pr) and holmium (Ho) emit blue and green lights under UV excitation. This means we need a constant UV input power to get visible light out of such phosphors. Gadolinium ion (Gd^{+3}) is one of the strong UV emitter when doped in AlN. This strong UV emission from Gd^{+3} could act as an internal self exciting source for the emission of visible light from such rare-earth phosphors when codoped with Gd^{+3} in AlN host. When excited by an input power a rare-earth element (praseodymium, holmium, samarium, terbium, erbium and chromium etc.) will not only emit light by getting excited due to the input power but also the UV light emission from Gd^{+3} will cause further excitation and light emission from the doped rare-earth. This additional excitation and light emission due to the codoped Gd^{+3} with the rare-earth element could be many times higher than the light emission from the rare-earth element in the absence of the codoped Gd^{+3}. This mechanism could give us very strong and intense light emission from such rare-earth with the same input power consumption. Indirectly speaking, we can get the same light emission from a device made of AlN:Gd.RE with very low input power. Thus using such devices can save tremendous amount of energy. The goal of this proposal is to study such luminescence enhancement in rare-earth phosphors like Samarium (red light emission), Erbium (green light emission), Terbium (green light emission), Yterbium, Thulium (blue and IR light emission) and others and in a number of transition metals like Titanium, Chromium, and Tungsten.

In my previous work I have demonstrated visible light emission from rare earth and transition metal ions in wide bandgap nitride amorphous and crystalline hosts. I have also confirmed and reported that Gd^{+3} co-doped with Pr^{+3} and Ho^{+3} in AlN host separately, enhances the emission of blue and green light from these ions. The enhancement is more than 200% in both ions and clicking the door of a new exciting research in the area of energy saving light emitting devices. The figure below shows how the blue emission is enhanced in Pr^{+3} by the co-doped Gd^{+3}. It also shows how the green emission is enhanced in Ho^{+3} by the co-doped Gd^{+3}.



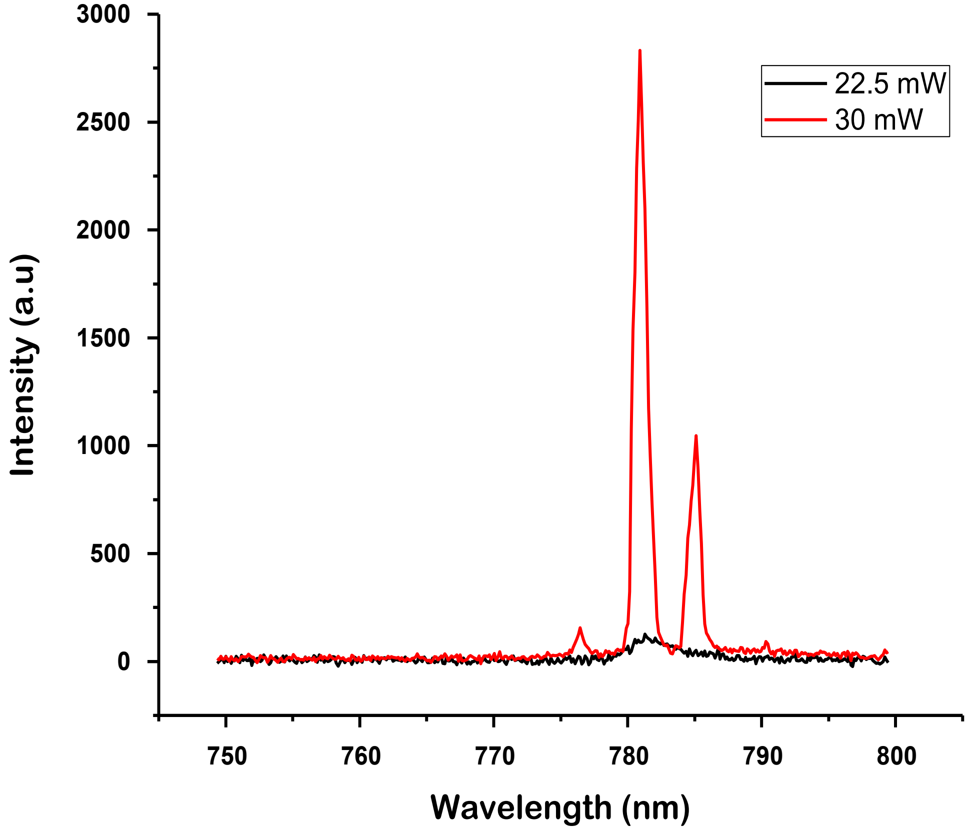


Thus my students will work on research projects in which we'll study and construct optical devices that will use a very low input power for the same light intensity, saving a tremendous amount of energy. NSF grant of $497000) is obtained for this purpose.

2. <u>Laser Cavities and Low Power Consuming Cylindrical and Ring Micro on Optical Fibers.</u>

The objective of this work is to make new micro lasers in optical fibers using rare-earth elements and transition metals doped in nitride semiconductors. It has already been reported that rare-earth elements and transition metals are amongst the most favorable candidates for making laser cavities and waveguides.

The laser has been used for a number of optical and biomedical applications since its birth in 1960. Different kinds and designs of laser cavities were developed to make lasers in UV, visible and IR regions of the electromagnetic spectrum. Microlasers are getting attention because of their smaller size and greater applicability. One such smaller cavity to achieve lasing uses optical fibers to make cylindrical and ring microlasers. We have observed lasing action in titanium doped aluminum nitride deposited around an optical fiber. Optical fibers of 12 microns diameter were coated with a sputter deposited layer (4 micron thick) of titanium (1 at. %) doped amorphous aluminum nitride. When optically pumped by a Nd:YAG green laser at 532 nm, laser action was observed in whispering gallery modes around the fiber (in a ring shape) at 780.5 nm with a quality factor $Q > 1500$. Other modes were also observed between 775 nm and 800 nm. The primary and secondary modes give a mode separation of 4.6 nm. Along with its applications in optics and photonics the AlN:Ti micro laser we produced is very important from a biomedical applications point of view. Researchers have already reported that near infrared light with a wavelength between 700 nm and 900 nm has minimum absorption and the greatest penetration in body tissues. The laser we have produced at 780.5 nm is in this range and hence, will have high penetration ability in the human body. Thus, this laser can be used for diagnosis of deep tissue abnormalities or tumors and for laser surgeries of deep body tissues. The figure shows the whispering gallery mode microlaser emission.

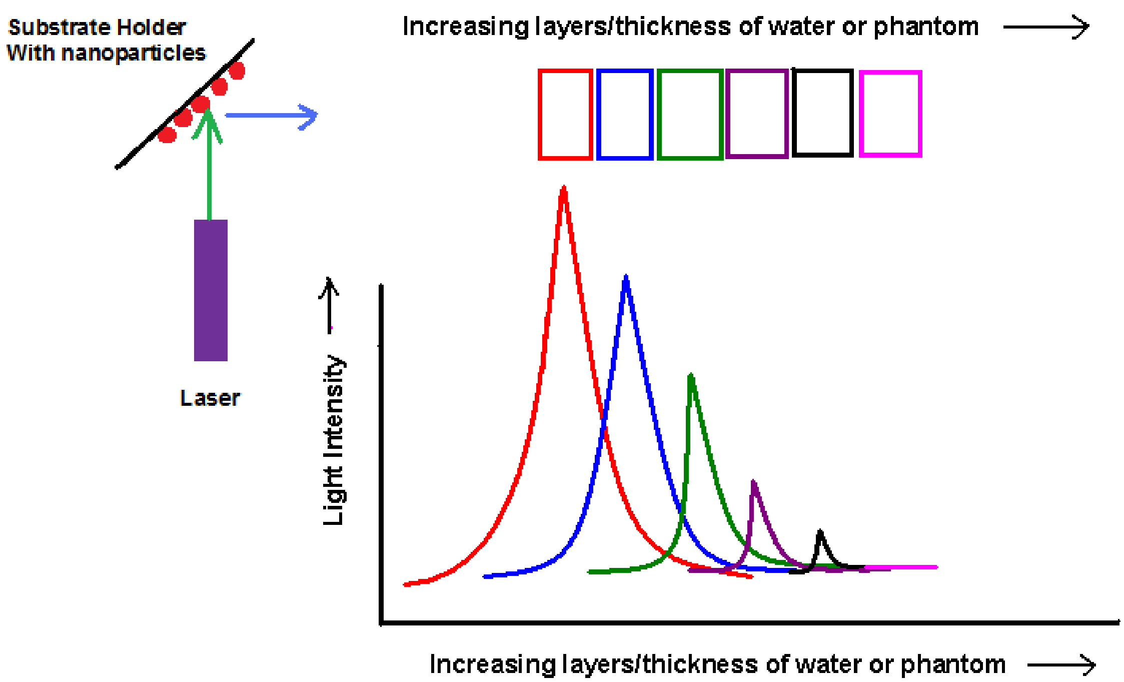


Like titanium, we'll dope other transition metals and rare-earth elements in AlN, BN, GaN and InN around optical fiber to produce microlaser in different wavelength range. Replacing optical fiber by a metallic fiber to pump the lasing material electrically, is also planned for future.

3. Light emission from Erbium Oxide and Neodymium Oxide Nanoparticles for Energy Saving nano-electronics and biomedical applications

Light emission and luminescence properties of materials play important role in the optical devices fabrication, display technologies, laser, cancer detection and biomedical physics applications. High thermal conductivity, stability, chemical inertness and better optical and luminescence properties of nitride semiconductors doped with rare-earth elements and transition metals make them very useful for its electrical, optical, photonic and thermal applications. I have investigated intense green and infrared emission from Erbium doped in amorphous aluminum nitride (AlN:Er) and its possible applications in 4-level lasing system. Our results show that Erbium is a potential candidate for a number of optical and biomedical applications based on its green and infrared emission.

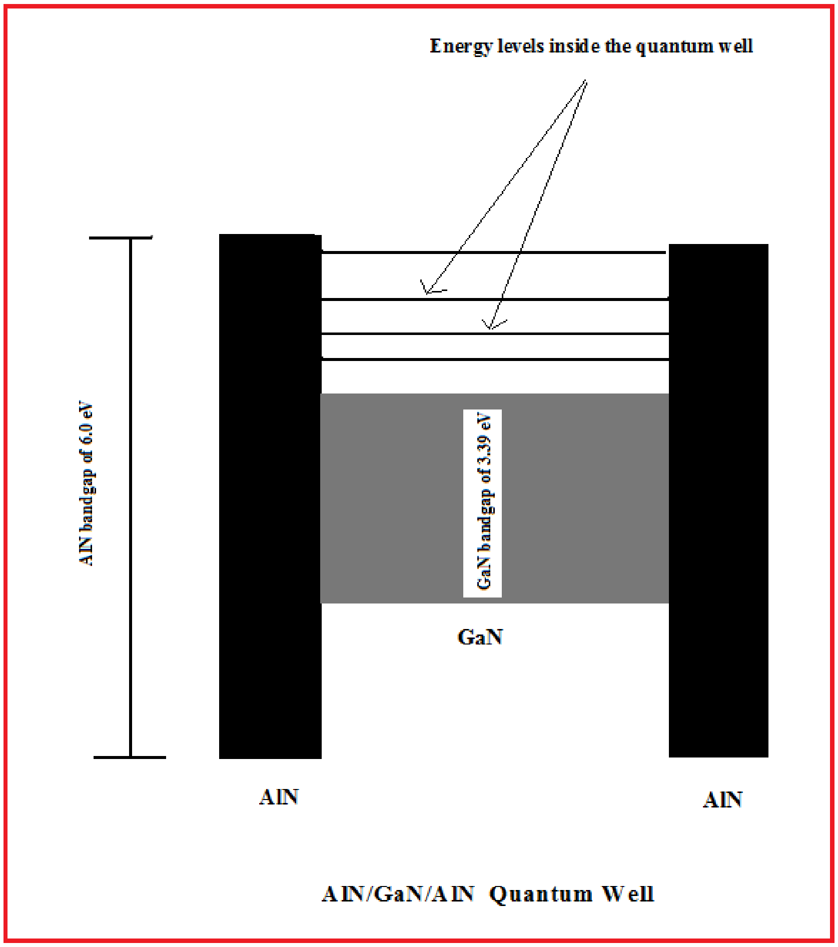
The purpose of this work is to study light emission from erbium oxide, neodymium oxide and other nanoparticles using NdYAG laser with emission wavelength of 532 nm and other laser sources for optical pumping. The nanoparticles will be purchased in the form of nanopowder, available commercially. Any emission from those nanoparticles will be detected by a photoluminescence (PL) system equipped with a CCD camera. Soft tissues of human body are water equivalent however tissue equivalent Phantoms are also available to study the penetration of light in human body. If we find the penetration ability of light emission from the mentioned nanoparticles in body equivalent phantom then it will give us an estimate of the body thickness that can be visible directly when these glowing nanoparticles are injected inside a specific soft tissue of a body. We'll work to find the penetration depth and light absorption and scattering properties of tissue equivalent phantom. In our work, after recording light emission from those nanoparticles, we will use various thick layers of phantom to attenuate the light before falling into our PL detector. The thickness of phantom layers will be increased gradually until the light from the nanoparticles is completely absorbed in the phantom layers. That maximum thickness of water layer that completely absorb the light will give us an estimate about how deep we can directly see inside the body through those glowing nanoparticles. The figure below shows an expected outcome of this project



Penetration depth of light from Erbium Oxide nanoparticles, in tissue equivalent phantom

4. Quantum Nano-Wells and Heterostructures.

Quantum well is an arrangement in which an electron / electrons are confined to a certain region called the well that is created by sandwiching a lower band gap material in a relatively higher band gap material. The thickness of the sandwiched material is usually in nanometer scale so that quantum phenomena could be observed. Once electrons are confined to the well, they are utilized to construct nan-photnics devices and improve the quality / efficiency of optical devices. For example the band gap of AlN is 6.0 eV while the band gap of GaN is 3.39 eV. Thus a quantum well can be constructed by standwiching GaN in between two AlN layer making AlN/GaN/AlN multilayer. Heterostructures composed of a number of multilayers quantum wells are formed to make devices from quantum wells. An AlN/GaN/AlN quantum well is shown in the figure. Since the energy levels of the quantum well depends upon the size of the well and hence varying sizes of quantum wells will be used to construct nano-photonic and optical devices in different wavelength. Students will make quantum wells of different materials for nano-photonic devices.



5. Identifications and limitations of UV emitting materials in cancer treatment use.

Different materials are frequently used in Radiation therapy and oncology, Radiology, Nuclear medicine and for other applications in medicine. To use materials for such purposes its important to know characteristics of materials from medicine point of view, their advantages and limitations in biomedical applications. In this area of research I study the optical and luminescence properties of materials specially rare-earth elements and other alloys and will test them for their suitability in biomedical applications. For example Gadolinium is widely used in MRI. Similarly a number of alloys are used as tissue compensators in Radiation Oncology. But in my recent research about the luminescence and optical properties of Gadolinium (Gd) provided results that Gd is a very strong ultraviolet emitter when exposed to X-rays, Gamma-rays, or electron beam.

Further, increasing temperature enhances the ultraviolet emission (UV) from Gd. Thus my recent research tells that Gd alloys are not suitable for biomedical applications if there is X-rays, Gamma-rays or electron beam exposure, otherwise it will start emission of UV radiation which is it self dangerous for human tissues. Further, if it is used for a long time then excessive irradiation will heat it up and hence UV emission will further increase. I have submitted paper on the Limitations of Gadolinium alloys in their use in radiation Oncology and radiation Shielding, to European Journal of Medical Physics (Physica Medica) in which I have also explained how we can overcome the problem of UV emission from Gd.

So in this research area I'll study optical and luminescence properties of different materials and will check their suitability for biomedical applications.

6. Improvement in Cancer Detection by enhancing the Infrared emission from Tm^{+3}.

Infrared fluorescence emission from Tm^{+3} ions is used in tumor imaging due to the high penetration power of IR radiation in tissues. However methods are needed to improve such images by increasing the amount of IR radiation emission from Tm^{+3}. We have found that such this IR emission can be enhanced by co-doping Ho^{+3} and other rare-earth ions with Tm^{+3} . My previous results show that if rather than growing AlN:Tm films, AlN:TmHo are grown then the relatively energetic emission from holmium ions enhances the IR emission from thulium ion.

7. Determination of the Build-Up factors and linear attenuation coefficient of various materials for radiation shielding and protection purposes.

Build-up factor is an important concept used in the radiation shielding and protection. It's a factor that determines the additional dose received by a worker or patient due to internal properties of an attenuator/absorber and must be taken care before using a material for Radiological and Health Physics applications.

In this work Build-up factors and linear attenuation coefficient of materials are determined for dose correction in radiation oncology and radiation protection, using 6 MV, 9 MV, 12 MV, 18 MV from a linear accelerator and Co_{60} gamma emitters. A narrow collimated beam of x-rays (or γ-rays) is passed through various thickness of a specific material (any material that is under investigation like MCP alloys or a similar kind of alloy for health physics applications) and the attenuation in the intensity of the beam is determined for every block of material under investigation. The thickness of the blocks varies from 0.5 cm up to 6 cm in a 4cm x 4cm or bigger shape and size. Plotting the thickness of the alloy and the corresponding intensity of the beam allowed us to determine its linear attenuation coefficient. The narrow beam geometry is then replaced by broad beam geometry by removing the collimator and the radiation beam is able to interact with the material at all possible positions facing the radiation source. Additional radiations obtained by the detector as a result from the scattering of radiation develops the build-up factor. The buildup factor is then calculated using the attenuated beam received by the detector in the broad beam geometry and in the narrow beam geometry. The buildup factor is found to be dependent on the thickness of the material, the solid angle and the source to attenuator distance. Buildup factor is plotted against the thickness of material, energy of the radiation beam and the solid angle of the geometry. These values provide ways for dose correction in radiation oncology and radiation protection when material is used as tissue compensator or for radiation protection purposes.

Mathematically, the build up factor B is given by the modified attenuation law given by,

$$N = BN_0.e^{-\mu x}$$

Experimentally it is given by

$$B = N'N_0/NN_0'$$

Where N and N' represent the number of radiation survived in a narrow beam geometry and in a broad beam geometry after the beam passes through an attenuator of thickness 'x' and linear attenuation coefficient 'μ'. Linear attenuation coefficient is determined from the slope of the graph between the ratio of beam intensities and thickness of attenuator.

8. Characterizations of Materials for their Stopping Power (penetration Depths) for Radiation Shielding and Protection.

In this project, the stopping power of materials used for radiation protection and safety purposes will be determined using a unique method of exploiting the blue and green light emission from Tm^{+3} and Ho^{+3} ions and electron beam in a Cathodoluminescence apparatus. Thin film bilayers of holmium doped in a material like aluminum nitride (AlN:Ho) [or any material whose stopping power is needed to be determined) will be deposited on flat Silicon substrates by RF Magnetron sputtering at liquid nitrogen temperatures. In our previous work we have successfully worked and found the stopping power of AlN. In that work 15.3 nm thick AlN:Ho film was deposited on a Si(111) substrate. On the top of this AlN:Ho film 37.8 nm thick AlN:Tm film is deposited to make it a bilayer. Electron beam of different energies, obtained from electron gun of the CL apparatus, was allowed to penetrate in the AlN:Tm/AlN:Ho bilayer film. The thickness of the film and the energies of electron beam were enough to get the stopping power of AlN. Energy of the beam just crossing 37.8 nm AlN:Tm film was used to obtain the stopping power experimentally. The linear stopping power for AlN was found to be 6.604×10^8 eV/cm Experimental results are compared to the theoretical value using the established mathematical equations for stopping power. A deviation of 2.6 % was found in the experimental and theoretical results.
This is a very simple and interesting technique of calculating the stopping power of any material used for radiation protection purposes.

9. Making Super-Luminescence materials using gadolinium ions.

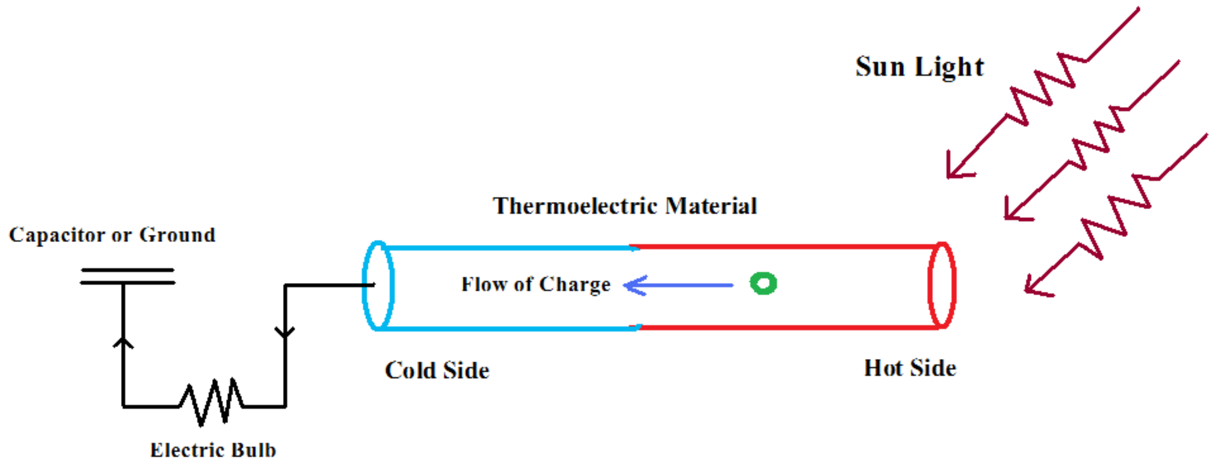
A SUPER-LUMINESCENT material is that material who's index of refraction is less than one and light travels faster than its vacuum speed inside a super-luminescent material. In one of my previous research projects Aluminum Nitride was made a super luminescent material by adding certain amount of gadolinium dopant to it. Amorphous Aluminum Nitride (AlN), a wide bandgap semiconductor, has index of refraction n = 1.95 in pure form and in the presence of 0.5% of holmium impurity. When 0.5 % of gadolinium (Gd) ions are added to AlN its index of refraction drops to 1.87 and with adding 1 % Gd dopant the refractive index of AlN drops to 1.72 and so on. In general we know that refractive index of a material should be more than one, making speed of light inside a material lower than the speed of light in vacuum. However, in our work when the concentration of Gd dopant reached 2.5 % in AlN, the index of refraction n dropped below 1. $n < 1$ clearly indicates that either additional energy levels are created in the dopant Gd or light is traveling faster than its vacuum speed. We investigated the energy levels of Gd after doping it in AlN and found no additional levels in Gd. Thus, it clearly indicates that light travels faster than its vacuum speed inside AlN when 2.5% or more Gd is added to it. This fact makes AlN a Super Luminescent material where light will travel faster than its usual speed if it is used for any devices application. We tested our results with an ellipsometer at Ohio University as well as an ellipsometer at Korean Advanced Institute of Science & Technology, and both were giving the same results, confirming that our results are correct and consistent. We are preparing our results to submit to NATURE PHOTONICS soon. Very advanced optical devices can be made out of such super luminescent materials.

10. Thermo-electric Energy Materials and Conversion of Solar Energy into Thermoelectricity.

Energy has been one of the most common and critical issues across the globe for the last few decades. Scholars and researchers are in search of alternative energy sources and energy saving devices to overcome this issue. Therefore, search for alternative sources of energy instead of the conventional sources and different types of energy conversion technology are initiated significantly. One of the relevant technologies is the thermoelectric energy conversion which is receiving remarkable attention. In this technology, heat is directly converted into electricity and vice versa. The materials used in such technology are called thermoelectric materials. Due to the high reliability and simple mechanism of converting heat into electricity thermoelectric materials are extensively used in space power generation. Broader use of thermoelectric materials is possible as these materials require only temperature gradient to operate and extract heat from waste heat energy stream.

In this project metallic materials like copper, iron, aluminum and other conductors will be used as thermoelectric materials. In the initial stage of the project one end of a long piece of each metal will be kept at high temperature while other end will be subjected to a cold temperature. Due to the high electrical conductivity of these materials charges will flow from one end to other end generating an electric current. To check the flow of electric current in each material an electric circuit will be established getting current from the thermoelectric material in use. The current will pass through a small electric bulb in the circuit going to the ground or a lower potential plate. The lightening of the bulb will show the flow of electric current generated as a result of the temperature gradient created in the thermoelectric material. The magnitude of the electric current will be measured with the help of a multimeter or ammeter. The effect of temperature difference on the magnitude of electric current will be investigated by varying the temperature of the hot end of the material in use keeping the cold end at the same temperature. In order to store this electrical energy generated in the form of electric current a capacitor will be devised and connected in the circuit.

Once the dependency of electric current is studied as a function of various parameters, sunlight will be used to heat up the material instead of a heater. The end of the thermoelectric material which is supposed to heat up will be designed in a way to receive as much light and heat from the sun as possible. Once successful, the method will be used to convert solar energy from the sun into electrical energy and store in a capacitor. This method will be a cheaper and easy way to obtain thermoelectric energy using heat obtained from the sun as a source of input energy and convert it into electrical energy and save it for its later use. The figure given below shows a schematic diagram of the thermoelectricity generation by sunlight or heat.



Schematic diagram of Thermoelectricity generation