

Introduction to Biophotonics

Photonics uses photons to probe and manipulate matter. Since the invention of lasers in the 1960s, which provide an intense source of coherent radiation, photonics techniques have revolutionized several areas such as high-bandwidth communication channels. The development of ultrafast lasers, which are capable of producing laser pulses with pulse widths as low as a few femto-seconds (fs, 1×10^{-15} s), enabled the use of non-linear optical processes for high-resolution imaging, providing novel information about biological systems. The high instantaneous power delivered by such ultrafast lasers while keeping very low radiation energy levels, enables the use of such lasers for micro-surgery or even laser-ablation of tissues. With the development of nanotechnology and plasmonics, we today have optically responsive nanoparticles that can be used as novel image contrast agents or selective removal of cancer tissues by the heat generated due to photoabsorption of the nanoparticles, which are selectively taken up by the tumor cells.

Biophotonics refers to the topics that lie at the intersection of Biology and Photonics. In recent times there has been significant development in the use of optical techniques to probe and manipulate biological systems. Optical microscopy using fluorescence emission has reached a point where structures even as small as 50 nm can be imaged using super resolution imaging techniques, breaking the diffraction barrier of optical resolution. Similarly, techniques such as optical tweezers, highly sensitive molecular sensors and so on allow one to probe bio-physical phenomena at the single molecular level. Biophotonics is a rapidly growing field with immense opportunities to researchers with pretty much any educational background. Biologists and Chemists can contribute in the development of molecules with engineered optical response for various applications such as image contrast agents, photosensitizers for photodynamic therapy and so on. Physicists can contribute in the development of novel imaging and sensing modalities that push the capabilities of tools to probe complex biological systems. Engineers can contribute in areas such as the fabrication and miniaturization of devices with automated process flow for high throughput bio-analytical studies. There is also requirement for applied mathematicians, computer scientists and

statisticians for developing computationally efficient techniques for analyzing massive volumes of data that modern bio-analytical and imaging systems produce.

This course is intended to provide a basic introduction to the field of Biophotonics to students from a wide range of academic background from pure science to Engineering. The attempt has been to communicate the essential ideas behind some of the current techniques being used in the field with appropriate background materials while avoiding most of the mathematical details for the sake of simplicity. The material presented here has been divided into 4 modules. The first module introduces basic notions in geometric, wave and electromagnetic description of light. The second module introduces the quantum picture of matter and the photon. The third module describes microscopy techniques and optical manipulation and the last module describes some optical biosensing techniques. The hope is that this material will provide a starting point for students desirous of advanced study in this field. A list of textbooks and online material suitable for advanced study is listed at the end of the last module.

I would like to thank Wikipedia Commons and several open access research journals for some of the images that have been used in the preparation of this material.