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Nanobiophotonics and its Role in Biomedical Sciences

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ABSTRACT: Nanobiophotonics is the journey of light from physics to biology. As biological matter can reflect light but can't emit light, we can use light for study the biological structures, diagnosis and therapies. Emerging as an interdisciplinary field of study, Nanobiophotonics encompasses all light-based technologies used in the biomedical sciences. Various light-based optical techniques can be utilized in diagnosis, therapy and treatment of various diseases. Localized Surface Plasmon Resonance, Raman Spectroscopy-Based System, Nanophotonics Bioimaging, and Magnetic Resonance Imaging techniques are used for diagnosis. Plasmonic Photothermal Therapy and Photodynamic Therapy are used for therapy purposes. Nanobiophotonics has been expanding quickly with extremely interesting applications in various fields, including biomaterials, solar cells, biosensors, photonics, optics, biomedicine and biophotonics. In this review, Nanobiophotonics and its applications are discussed along with its limitations and future aspects.

KEYWORDS: Nanobiophotonics, Biomaterial, Biosensors, Nanomedicine.

I. INTRODUCTION

The term itself consists of the Greek syllables "bios," which means "life," and "phos," which means "light." The technical word for all methods and technologies exploiting photonics is light interacting with any material across the full spectrum, which includes the ultraviolet, visible, infrared, and terahertz regions[1].The area of nano-biophotonics is gaining momentum as it integrates photonics and nanotechnology to investigate light-matter interactions at the nanoscale. This sector offers chances for new technologies while posing scientific and technological hurdles. The area of "Biophotonics," which studies the interaction of light with biological matter at the nanoscale, was formed by the union of photonics and biotechnology. Both artificial and natural structures such as photonic crystals, holey fibers, quantum dots, subwavelength structures, and plasmonics are explored. This field offers chances and difficulties for basic research as well as for technology advancements[2]. A fast-growing and potentially amazing approach to illness diagnosis, prevention, and therapy is photonic medicine. Light may be able to recover diagnostics, medications, and, surprisingly, the course of treatment in a single theranostics procedure mixture of therapeutics and diagnostics, which provides clinical screening and therapy tracking. This is due to the incredibly fast rate of light modulation and the remote nature of optical procedures. It is focused on the application of photonics in nanostructure media, namely in the compression of light through nanoscale volume and field enhancement effects arise leading to new optical marvels that can be applied to a wide range of topics including metamaterials, quantum dots, quantum nanophotonics, high resolution imaging, plasmonics, and functional photonic materials, to produce dominant superior photonic devices and counter current advanced cutoff points. It has recently gained widespread recognition as a field of study, and it will be crucial to the development of ground-breaking new technologies, such as specialized health monitoring devices that can identify the chemical makeup of molecules at extremely low concentrations. By adjusting them, these nanostructures' optical characteristics may be closely observed, enabling the convergence of many functions to achieve multifunctionality as well as the augmentation of one photonic function when displaying another photonic manifestation[3].There are scientific and technological obstacles in the field of studying light-matter interactions at the nanoscale. The study of photonics applied to nanostructured media, where light is compressed over the volume to nanoscale sizes, gives rise to field enhancement effects, is known as nanophotonics. This leads to novel optical phenomena that can be applied to pass through the present advanced cutoff points and produce dominantly superior photonic devices The The advancement of photonics and nanotechnology knowledge has become critical, pushing the boundaries of what is possible with sophisticated photonic experiments. [4].New possibilities in biomedical applications, power generation, and information technology are presented by Nanophotonics. It has potential applications in bioimaging, biosensing, optical diagnostics, and light-guided and light-activated therapeutics. The fusion of nanotechnology with biotechnology has resulted in the development of nanomedicine, which makes use of nanoprobes and nanostructures for targeted therapy, efficient drug delivery, multimodal imaging, and real-time drug activity monitoring[5]. This supports early-stage diagnosis and treatment by bringing together the three stages of therapy, diagnostic, and therapy guidance. The capacity of these processes is being enhanced by theranostics, which enables the simultaneous identification of gene-associated diseases and nanodevices employing light-guided and light-activated therapy. Additionally, this system can track drug action in real time. It is anticipated that theranostics techniques would address gaps in medical practice[6]. In actuality, nanophotonics has already influenced emerging technology. Using nanoscale optical processes are examples of devices like quantum cascade and well lasers. TiO2 nanoparticles are employed in sunscreen creams as efficient UV radiation blockers even at the consumer products level[7]. Biophotonics has revolutionized because of laser nano-surgery and monitoring devices, which allow for accurate nano-incisions in cells and modification of intracellular structures. Optical tweezers are a promising tool in the fight against cancer since they are a non-invasive biological instrument with sophisticated applications in biology, medicine, and nanotechnology. With the help of a single optical tool, these approaches may control bacteria, viruses, cells, and macromolecules to perform submicrometric and nanometer-precision analysis. The process of phagocytosis can be initiated by selectively manipulating cells to phagocytes using optical trapping techniques in a non-invasive manner. Moreover, tiny viruses like influenza may be tracked, captured, and worked with using optical tweezers[8].This review focuses on the application of Nanobiophotonics, highlighting new photon-based theranostics modalities for various disease confrontations. Additionally, there may be new opportunities for Nanobiophotonics in the field of Biomedical Science.

II. OVERVIEW OF NAINOBIOPHOTONICS

All light-based technologies used in the biological sciences and medical field are included in the growing field of biophotonics, a multidisciplinary research area. Regarding Biophotonics, one can categorize "conventional" light into two main fields: basic biomedical applications to all levels of biological structures, and monochromatic laser or laser-like non-ionizing radiation. In vivo and in vitro, at the cellular or molecular level, are the focus of the first set of applications; photon radiation therapy or surgery, such as bio stimulation, tissue removal surgery, photodynamic therapy, and cell micromanipulation, is the subject of the second. Contemporary non-invasive laser-based optical research methods are becoming more and more valuable in the biomedical area. They span a wide range of topics, from fundamental research in molecular and cellular biology to real-world, clinical applications[8]. In biomedical research and technology, nanophotonics has several applications. These include investigations of the principles of interactions and processes at the single cell/molecule level as well as applications in nanomedicine for light-guided and light-activated treatment. The field of nanomedicine is a young one, centered on the use of nanoparticles to develop new noninvasive diagnostics for early disease detection, as well as to support targeted medication delivery, treatment effectiveness, and real-time drug tracking. "Personalized" therapeutic treatments for disease control centered on molecular identification can be developed with a detailed understanding of drug–cell interactions, with a focus on molecular alterations at the single-cell level produced by the pre-onset condition of a disease. Nanophotonics provides an optical approach to tracking subsequent cytosolic interactions, elucidating the biological process, and mapping drug consumption. Biosensing, bioimaging, and single-cell biofunction studies with optical probes are therefore especially helpful. In the realm of molecular diagnosis based on nanomedicine, light-guided and light-activated treatments have achieved noteworthy advancements[9].

Biophotonics research focuses on improving sensing and optical imaging techniques to study the structure and function of cells or tissues at microscopic and nanoscopic levels. Spectroscopy studies the relationship between emitted energy and matter, using electromagnetic radiation such as fluorescence, infrared, ultraviolet, nuclear magnetic

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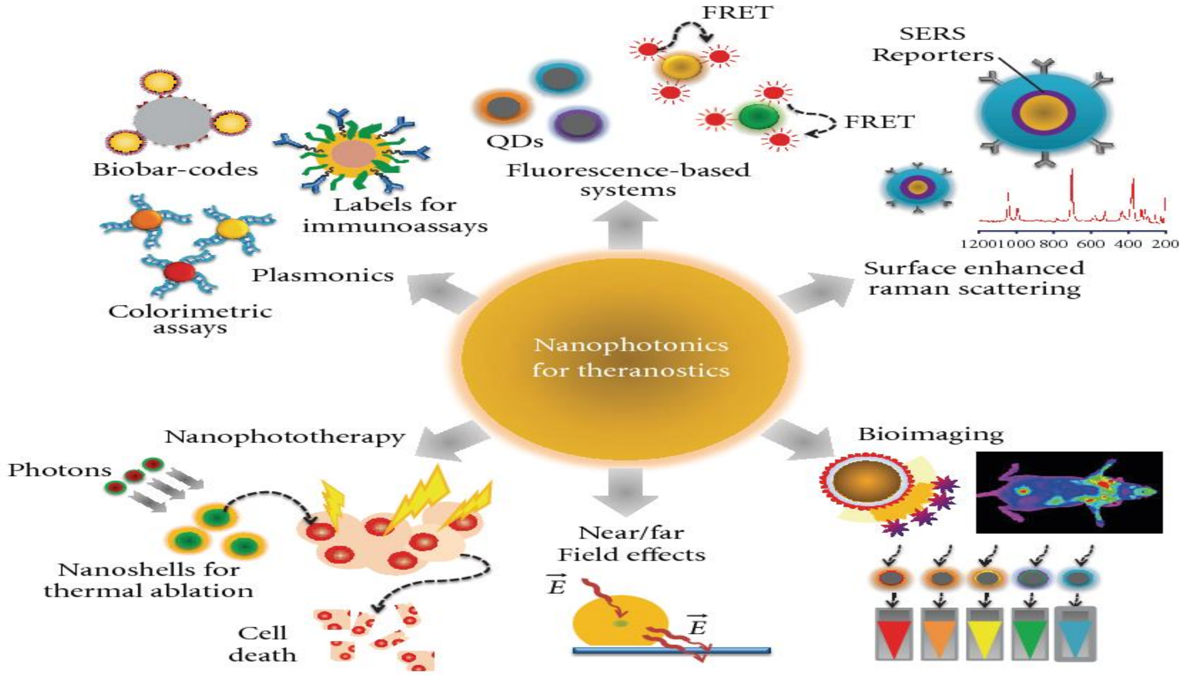

Fig1: Nanophotonics for theranostics. Nanoparticles-based strategies can be used for biosensing using plasmonic nano sensors, such as metal nanoparticles functionalized with nucleic acid strand for colorimetric assays and Biobar codes for protein detection or intense labels for immunoassays. Some nanoparticle systems can also be used for sensing by exploring a typical FRET system or can be surrounded with Raman reporters in order to provide in vivo detection and tumor targeting. In fact, NPs symbolize an important class of materials with unique features suitable for biomedical imaging applications such as increased sensitivity in detection and high quantum yields for fluorescence. Alternatively, NPs can survey near/far field enhancing qualities that hold promise for a bounty of novel applications in optics and photonics. Engineered NPs can also act as phototherapeutic agents that can be attached to specific targets for selective damage to cancer cells[6].

resonance, absorption, and mass spectroscopy. Raman spectroscopy is a scattering method based on the Raman effect, producing molecular vibrational excitation. Photomechanical analyses use optics to study gradient properties in biological materials and examine the relationship between mechanical stress and strain in root dentin structure. Fiber optic sensors are used for remote sensing of physical and chemical specifications, focusing light into the central part and directing it to a sample. These sensors are widely accepted for detecting clinical and biochemical analytes, such as metabolites, immunoproteins, enzymes, and serum electrolytes[10].

III. APPLICATION IN BIOMEDICAL SCIENCES

Nanobiophotonics is developing rapidly and have its application in various fields, including biomaterial, biosensors, nanomedicines as well as diagnostics purpose and therapy.

I. Biomaterials:

Scientists studying materials have found that biological structures offer a rich environment for the creation of innovative nanotechnologies with a broad range of potential uses. Nearly ideal nanostructures that are recyclable and effective at filtering, low-threshold lasing, high-density data storage, and optical switching can be produced via bioprocessing. Both active and passive nanophotonic devices find application in a wide range of photonic systems and biomaterial-based systems[2]. Bio-derived materials offer unparalleled molecular-level control over their properties, necessitating transdisciplinary approaches in their design and fabrication. Creating multifunctional organized materials and morphologies inspired by nature that may work as crystalline structures for light collection is the goal of the developing field of biomimicry. Artificial nanostructures are made by mimicking biological principles in the synthesis of natural biological materials. Bio-templates are nanostructures found in nature that have the right surface interactions and morphologies to be used as models for creating multiscale and multicomponent photonics materials. A variety of helical polymers with different optical properties can be produced by metabolically producing phototonic polymers inbioreactors based on bacteria or extending therapeutic applications beyond surface tissues and long-term sensing and imaging of difficult-to-reach regions like the brain.[4].Biological systems offer researchers a fertile ground for nanotechnologies, enabling new applications in various fields. Biodegradable, nearly flawless, and flexible, biomaterials are environmentally friendly due to their biodegradable nature. Compounds of biological origin can spontaneously self-assemble into complex nanostructures, forming systems with long-range and hierarchical nanoscale order. Chemical modification and genetic engineering can be used to enhance or engineer specific functionality. Nanophotonics applications can utilize various types of biomaterials for active and passive photonic functions. These include bioderived materials, bioinspired materials synthesized using biological systems' principles, biotemplates providing anchoring sites for self-assembling of photonic active structures, and bacteria bioreactors for producing photonic polymers through metabolic engineering. Bioderived materials include efficient solar energy harvesting, low-threshold lasing, high-density data storage, optical switching, and filtering. Native DNA is an example of bioderived material used as photonic media for optical waveguides and laser dyes, with its double-stranded helical structure providing nanoscale self-assembly of photonically active groups. Biocolloids consist of highly structured and complex biological particles that can be organized into close-packed arrays to form photonic crystals. Bioinspired materials are synthetic nanostructured materials produced by mimicking natural processes of synthesis of biological materials. Biotemplates are natural nanostructures with appropriate morphologies and surface interactions, serving as templates for creating multiscale and multicomponent photonic materials. Metabolically engineered materials, synthesized by naturally occurring bacterialbiosynthetic machinery, can be manipulated to produce helical polymers with a wide range of optical properties [4].

II. Biosensors:

A developing area of precision medicine called nanophotonic biosensors seeks to offer precise, robust, and trustworthy sensing technologies for the early diagnosis of illnesses and cancer. The contact causes a change in a transducer's measurable optical characteristic, and this change is directly related to the analyte concentration. Biosensors are self-integrating devices that use biorecognition components like enzymes, DNA strands, or antibodies to gather and detect the presence of a target molecule or analyte in a sample. A transducer's optical property changes as a result of this interaction, and this has a direct correlation with the analyte's concentration. Nanophotonic biosensors, which make use of the unique properties of light, can be used to create some of the most sensitive, dependable, and long-lasting sensing devices on the market today. Through the use of high optical sensitivity, the biosensing materials provide a low detection limit of analytes and have a variety of biomedical applications. The areas that are highly exposed speed up the immobilization of different types of bio-receptors. Transducers, interfaces, signal processors, and bio-receptors are the common components of biosensors. Optical transducers and bio-receptors are components of optical biosensors. Physical and chemical changes in the transducers cause the bio-receptors to exhibit a range of light characteristics, including fluorescence, reflection, refraction, absorption, phase, and frequency fluctuations. Controlling the characteristics of the optical events that comprise resonance properties include both the design features of nanostructures and the characteristics of the optical phenomena that give rise to resonances. Most nanophotonic biosensors use resonances that are sustained by metallic and dielectric nanostructures. Based on the evanescent-field theory, silicon photonics and Nanoplasmonics are commonly used in optical biosensors. Since evanescent-field biosensors can detect biomolecular interactions occurring at the sensor surface in real time and without labels or dyes, they offer a quick, simple, and non-invasive way for monitoring biochemical processes or quantifying analytes[11].

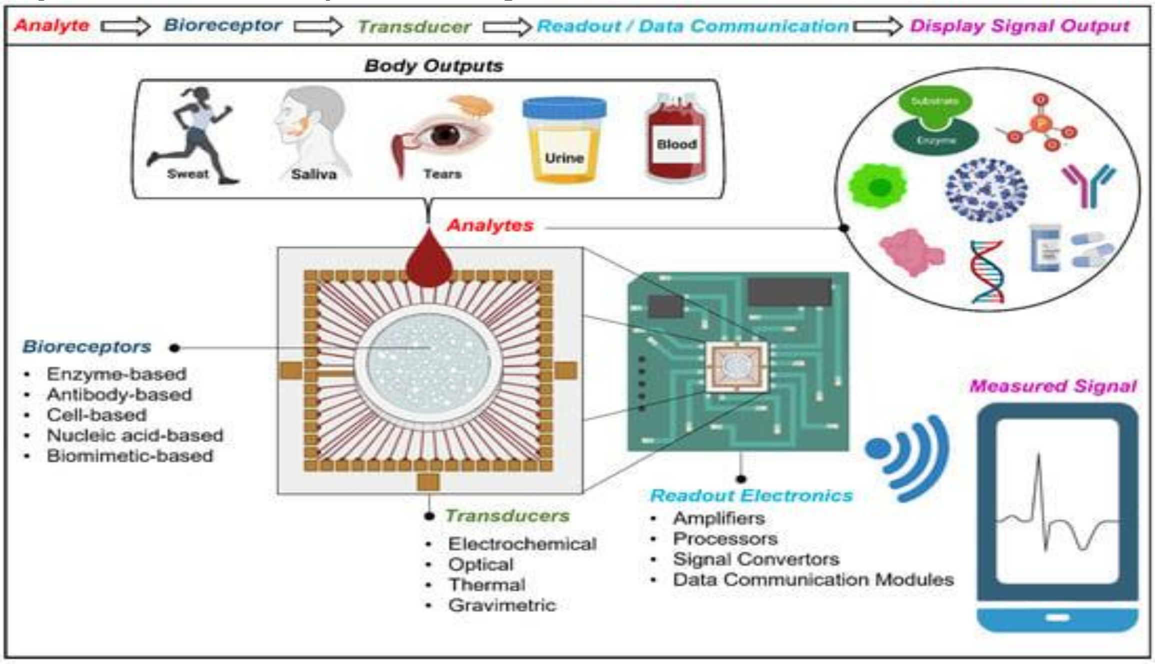

Fig 2: A biosensing design that allows the extracted signal to be viewed or recorded on any portable device to track health[4].

III. **Nanomedicine:**

Many biomedical studies and technology applications have made use of nanophotonics, such as the creation of noninvasive diagnostics for early disease detection, targeted medication delivery, treatment efficacy, and real-time drug monitoring. Molecular identification-based customized therapeutic management for illness control requires a thorough understanding of how medications interact with cells. The relevance of optical probe-based biosensing, bioimaging, and single-cell bio function research is increased by nanophotonics, which employs optical techniques to map drug ingestion, characterize cellular function, and monitor upcoming cytosolic interactions. In nanomedicine, the application of light-guided and light-activated therapies has significantly enhanced the identification of molecular diseases. Sophisticated carrier groups and optical variables must be taken into account when constructing biophotonic devices in order to process nanoparticles using modern technology. Fundamental ideas, developments, and new uses for nanophotonics probes, and light-activated therapies that have been researched to direct them to sick tissues or cells for targeted drug delivery in real-time drug efficiency monitoring. NPs alter the DNA structure of cancer cell lines or damage their walls, which results in apoptosis. A relatively new subject called "nanomedicine" studies the use of nanoparticles in the creation of innovative, minimally invasive diagnostic techniques for early therapeutic efficacy, and real-time drug activity monitoring. A significant improvement in the field of molecular recognition of diseases through nanomedicine is offered by light-guided and light-activated therapeutics. Targeted drug delivery is made possible by nanoparticles having optical probes, light-activated therapeutic chemicals, and certain carrier groups that can guide the nanoparticles to the diseased cells or tissues. This allows for real-time drug efficacy monitoring. Biological structures that are much smaller than the wavelength of light can be imaged using near-field microscopy. Such structures include different biomolecular subcellular structures, viruses, and chromosomes. High-resolution topographic pictures of individual DNA molecules and chromosomes have been obtained using Near-field Scanning Optical Microscopy (NSOM), showing heterogeneous intercalation[12].

IV. NANOBIOPHOTONICS FOR MOLECULAR DIAGNOSTICS AND THERAPY APPLICATIONS

Theranostics Procedure Overview:
• Combines therapeutics and diagnostics using light and optical methods.
• Connects diagnosis and treatment, addressing limitations in medical practice.
• Aids early-stage diagnosis and treatment, reducing sensitivity and specificity of medications.
• Nanophotonics-based sensors aid in simultaneous detection of gene-associated disorders.
• Nanodevices track real-time drug action using light-guided and light-activated therapy.[5]

One of the most useful applications of biophotonics in medicine is Photodynamic Therapy(PDT), or PDT. PDT involves three parts: a photosensitizer (a chemical compound that can be excited by a light of a particular wavelength), light, and tissue oxygen. The treatment is used for cancer, but can also be used on acne and psoriasis. In order for PDT to work, a photosensitizer must be administered to the patient. The surgeon will then shine a light of a particular wavelength (whichever energy level acts on the photosensitizer being utilized). There are a number of diseases which can be cured by PDT such as Non-Malignant Diseases like Ophthalmic Disease, Cardiovascular Disease, Dermatological Disease ,Urological Disease, Malignant Diseases like Brain Tumor, Head and Neck Cancer, Ophthalmic Tumor, Pulmonary and Pleural Mesothelial Cancer, Breast Cancer , Gastroenterological Cancer, Urological Cancer, Gynecological Cancer, Skin Premalignant and Malignant Diseases and Biophotonics in Dentistry [13].

A] Utilization of Nanobiophotonics for diagnostics purpose

Localized Surface Plasmon Resonance (LSPR).

• Surface plasmons occur at the interface between conductors and dielectrics.
• They can take various forms, including confined electron oscillations on metal nanoparticles (NPs) or freely propagating electron density waves along metal surfaces.
• The size, shape, composition, interparticle distance, and surroundings of nanoparticles affect the collective oscillation frequency of the conduction electrons.
• Plasmonic nanoparticles provide a limitless photon resource for observing molecular binding for extended periods.
• Gold nanoparticle colloids have been widely used in molecular diagnostics due to their strong surface plasmon resonance (SPR).
• Gold nanoparticles functionalized with ssDNA have been used for the detection of certain nucleic acid sequences in biological samples.
• Colloidal silver plasmon resonant particles (PRPs) coated with standard ligands can be used as target-specific labels for immunocytology and in situ hybridization studies.
• A nanoparticle-based Biobar code uses magnetic microparticle probes with antibodies that specifically bind a target of interest[6].

There is a strong correlation between specific HPV genotypes and cervical oncogenesis. E7 protein is the main immortalizing and transforming protein in high-risk HPVs, specifically HPV16. In differentiated keratinocytes, the E7 protein promotes S-phase reentry and deregulation of the cell cycle. Cervical cancer is currently diagnosed clinically based on phenotypic abnormalities seen in a screening Papanicolaou smear. While screening has been successful in lowering the incidence of cervical cancer, resources are squandered on the assessment of low-grade lesions that are unlikely to develop into cervical cancer because of the Pap smear's poor specificity. It is suggested that a non-invasive, low-cost method for identifying cervical pre-cancerous lesions would involve combining in-vivo optical imaging with molecular characterization of active HPV infections using molecularly specific contrast ants. Utilizing the peak absorbance and scattering shift of aggregated gold nanoparticles over solitary ones allows for contrast, and recognition moieties with strong affinity for E7 allow for molecular specificity. Using reflectance confocal microscopy, conjugates of gold nanoparticles and HPV16 anti-E7 antibodies are introduced into the nucleus of living cells. It has been demonstrated that these contrast agents efficiently boost contrast in HPV16+ cervical cancer cells compared to HPV- cells by a factor of 2.5. Further characterization and improvement of these contrast agents will pave the way for the creation of a dependable and reasonably priced screening tool for the detection of cervical precancerous lesions[19]

Raman-Spectroscopy-Based Systems

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Light can interact with materials in three different ways: it can be absorbed, transmitted, or scattered. Scattered radiation can come from an inelastic collision (Rayleigh scattering) or an elastic collision. The basis of Raman spectroscopy is a change in frequency that occurs when light is inelastically scattered by molecules or atoms, producing a molecular fingerprint that provides information on the molecular structure or intermolecular interaction of a particular process or molecule[6.].

Fluorescence based system

• Quantum dots (QDs) are semiconductor nanoparticles with narrow emission spectra and high quantum yields.
• Used for nucleic acid characterization, SNP identification, virus detection, and chromosome abnormality detection.
• Used as chemical sensors in Fluorescence Resonance Energy Transfer systems and fluorescence quenching of fluorophores near nanoparticles.
• Fluorophores like gold, silver, and quantum dots can be modulated to detect biologically relevant targets.
• Methods for DNA detection include fluorophore-labeled ssDNA electrostatically adsorbed onto gold nanoparticles, carbon nanotubes, and carbon nano clots.
• Nanoparticles have been used for detecting specific DNA strands, proteins, and specific ion sensing.
• Infrared fluorescent nanoparticles show enhanced fluorescence when interacting with proteins.
• Unique features for biomedical imaging applications include increased sensitivity in detection, high fluorescence quantum yields, properties that induce phagocytosis and selective uptake by macrophages, and physicochemical manipulations of energy.[6,15]

Fluorescence Microscopy:

A fluorescence microscope is a kind of light microscope that activates a fluorescent microorganism species in a sample of interest using a light source of greater intensity. Instead of the original light source, this species produces a magnified image by emitting a longer wavelength, lower intensity light. Fluorescent microscopy is frequently used to visualize and amplify small-scale 3D characteristics, as well as to image certain aspects of tiny objects, such microorganisms. This can be accomplished by filtering background fluorescence and reflected light, staining less specifically, or attaching fluorescent tags to anti-bodies. Confocal fluorescence microscopy makes use of strong light sources, including lasers, that are precisely focused to highlight the three-dimensional aspect of samples. An image reconstruction algorithm frequently combines multi-level image data to create a 3D reconstruction of the intended sample[16].

Two-photon luminescence (TPL):

Two-photon luminescence (TPL) spectroscopy is a technique that uses two photons to excited an electron from the conductance band to the valence band of metal nanoparticles. This process enhances optical properties and can be used for noninvasive imaging at the micron scale, allowing for the discrimination of cancerous and healthy tissue from endogenous fluorophores. Two-photon contrast agents have been developed to increase signal-to-noise ratio and target molecular signatures of interest.[17]

Quantum Dots For In vivo imaging:

• Quantum dots (QDs) have shown promise in imaging vascular networks of mammals, including lymphatic and cardiovascular systems.
• They have allowed major cancer surgeries in large animals under complete image guidance.
• QDs have been used to detect tumors in skin and adipose tissue.
• Fluorescent emission and multiplexing capabilities are being exploited for early tumor detection.
• ZnS-capped CdSe QDs coated with lung-targeting peptides used for targeted cancer imaging.
• Multifunctional nanoparticle probes based on QDs developed for cancer targeting and imaging in living animals.[15]

Biophotonics For Cancer Diagnostics and Treatment

Cancer is a leading cause of death worldwide, causing millions of deaths annually. Research has focused on developing new techniques to provide quick, relevant, and reliable information about tumor growth for timely intervention. Biophotonics, which uses photons to interrogate tumor microenvironments and eliminate cancer cells and tissues, has significantly improved diagnostic acumen by improving existing procedures and reducing side effects of anti-cancer treatments. Laser light can be focused onto diffraction-limited spots, delivering information on cellular and subcellular levels for early detection of cancers. Advanced laser technology with ultra-short laser bursts allows for clear-cutting and drilling in tissues, reducing time spent on surgery, bleeding, and patient pain. Artificial intelligence and machine learning have enhanced the efficiency and accuracy of image qualification and quantification, enabling differentiation between normal and malignant tissues and staging cancers.[10]

Molecular imaging:
The transmembrane protein known as the epidermal growth factor receptor (EGFR, or HER1) is overexpressed on the surface of certain malignancies. It promotes cell division, development, and proliferation in a variety of tissues. Anti-EGFR antibodies and the EGF protein are examples of ligands that target EGFR. Many malignancies and pre-cancerous conditions, such as those of the breast, lung, bladder, skin, mouth, brain, and neck, are characterized by an overproduction of EGFR1–10. Promising treatments have been identified that target this class of HER receptors. Treatment for breast tumors overexpressing the HER2 receptor now involves the use of a monoclonal antibody known by the commercial name Herceptin11-12. Nevertheless, there is a chance that the medication will cause harmful adverse effects, such as cardiac arrest13–14. To imaging EGFR overexpression17–18, antibodies for EGFR tagged with fluorescent probes15–16 and gold nanoparticles have been utilized as contrast agents, but at most a 10:1 intensity contrast. Previously created a nanoprobe that can offer an order of magnitude improvement, utilizing anti-EGFR antibodies. [18].

Optical Entrapment :
In many biological and biophysical applications, an optical trapping is a useful tool. It enables precise measurement and manipulation of different cellular structures in biophysics. Optical trapping has biological uses such as sorting and single-cell analysis. A laser beam that can be focused using an objective lens with a high numerical aperture can produce optical trapping. A dielectric particle close to the laser beam focus experiences force due to momentum transferred from the dispersed incident photons. This optical force is resolved into two components: the gradient force, which is a force in the direction of the spatial light gradient, and the scattering force, which is a force in the direction of light propagation. Using a concentrated laser, this technique can be utilized to move tiny cells and subcellular organelles[15].

B. Novel Materials related to Nanobiophotonics which can be used in biosciences and biomedicines.

Nanobiophotonics: A Multidisciplinary Field
• Combines nanotechnology, photonics, materials, and biomedicine.
• Soft and bio-nanomaterials offer high structural diversity and tunability.
• Unique optical, chemical, and electronic properties enhance their ability to absorb, reflect, and interact with light.
• Photonics techniques provide powerful tools for investigating Nanobiosciences and related materials.
• Recent advancements in biocompatibility, biosensing, photo-bio reactions, and photo-thermal effects are highlighted.
• Nanomedicine, with issues such as biocompatibility and biodegradability of novel nanomaterials, is a particular area of research.
• Plasmonic metasurface for the detection of deoxyribonucleic acid (DNA) fragments are used.
• Molecular model system for photo-crosslinking between nucleic acids and 10• The photothermal effect of 2D-nanoflakes at a single-cell level, mainly for anti-cancer application in theranostics has studied[10].

C. New tools for chemical Nano analytics[8]

Nano-Biophotonics: A Bridge Between Light and Electron Microscopes
• Aims to bridge the gap between light and electron microscopes by enabling optical imaging beyond the diffusion limit.
• Involves sensing and manipulation at the nanoscale, using nanostructures to probe biomaterials with higher sensitivity or specificity.
• Retains the noninvasive nature of light and permits live cell sensing with near molecular resolution and sensitivity.
• Overcomes the hurdles imposed by Abbe's diffraction limit by bringing a nanoscale light source in close proximity to the sample.
• Utilizes imaging, local probing, and manipulation of biological targets on the nanoscale to obtain higher spatial resolution or sensitivity.
• Recent developments have led to the development of tip-enhanced spectroscopies, novel probes, single-molecule fluorescence in biology, and

optical super-resolution microscopies.
• Fluorescent quantum dots as sensors have been explored as alternatives to fluorescent probes.
• Plasmon-resonant nanoparticles scatter light based on their surface plasmon resonance, with the potential for multiplexed detection and becoming active chemical sensors of their local environment

V. CHALLENGES AND LIMITATIONS

The rapidly developing subject of Nanobiophotonics integrates photonics, biotechnology, and nanotechnology to provide novel instruments and methods for biomedical applications. Among the difficulties and restrictions in this field are:

Complexity of Nanoparticle Design: Because of the intricate relationships that exist between nanoparticles and biological systems, creating nanoparticles with particular characteristics for use in biomedical applications can be difficult.

Biocompatibility: For Nanobiophotonics to be successfully applied in biomedicine, it is essential that the nanomaterials utilized in them are biocompatible and do not have harmful effects on living things.

Targeting and Delivery: One of the primary challenges in Nanobiophotonics is still delivering nanoparticles to the right cells or tissues in the body.

Regulatory Obstacles: Because of worries about safety and effectiveness, navigating the regulatory requirements for the use of nanomaterials in biomedical applications can be challenging.

Cost and Scalability: Developing Nanobiophotonics technologies that are cost-effective and scalable for widespread use in biomedical research and clinical settings is a challenge that needs to be addressed.

Despite these challenges, Nanobiophotonics plays a crucial role in advancing biomedical sciences by enabling high-resolution imaging, targeted therapy, and biosensing applications with the potential to revolutionize healthcare in the future[20].

VI. FUTURE DIRECTIONS

The rapidly developing discipline of Nanobiophotonics blends photonics, biotechnology, and nanotechnology to create novel instruments for medical use. Nanobiophotonics is predicted to transform medication delivery, therapy, imaging, and diagnostics in the medical field in the future. Future possibilities could include the following:

Better Imaging Methods: High-resolution imaging at the cellular and molecular levels is made possible by Nanobiophotonics, which makes it possible to identify diseases like cancer early on.

Targeted Drug Delivery: By delivering medications only to damaged cells, nanoparticles can minimize adverse effects and increase the effectiveness of treatment.

Theranostics: By combining therapy and diagnostics onto a single platform, Nanobiophotonics can enable personalized medical techniques that improve patient outcomes.

Regenerative Medicine: For tissue engineering and regenerative medicine applications, Nanobiophotonics can be used to track and manipulate cellular activities.

Point-of-Care Testing: By enabling quick and precise diagnostic testing at the point of care, portable and miniature Nanobiophotonics devices can increase accessibility to healthcare.

All things considered, Nanobiophotonics has enormous potential to further medical sciences by supplying new instruments and technologies for detecting, curing, and observing diverse illnesses. The field of nanomedicine is undergoing transdisciplinary development undertaking that presents both significant obstacles and chances for the development of nanomaterials. The regulation of these nanoparticles' surface characteristics is an essential component. Moreover, biodegradability and biocompatibility should be considered. The expanding strain of microorganisms and the growth of infectious diseases are driving up the requirement for sensor technology in health, structural, and environmental monitoring.. [11,20]. Diffraction-limited laser light is applied to localized areas in cancers. The analysis of light scattering and absorption provides information on malignancies at the cellular and subcellular levels. Ultra-short laser bursts prevent long surgical procedures, blood loss, and discomfort associated with surgery when incising tissues. Thanks to recent developments in the field of biophotonics, artificial intelligence and photonic technologies can now be used to distinguish between malignant and normal tissues as well as different stages of cancer. Numerous cutting-edge biophotonic cancer therapies are being researched, such as photo-disruption, photothermal ablation, photoablation, and plasma-induced laser ablation [13].It is now possible to conduct systematic studies in three-dimensional environments to examine the impact of mechanical scaffold stiffness and spatial ligand distributions on stem-cell differentiation and cell behavior. The goal of ongoing research in this field is to create live-cell imaging modes using light microscopy super-resolution techniques in order to explore biomolecular interactions in living systems at the highest possible spatial and temporal resolutions. Label-free single-molecule detection is the ultimate goal of basic research activity on biomolecular sensing techniques[16].

VII. CONCLUSION

Light is an adaptable medium that can transport a variety of messages and perform a number of tasks. In diagnostic and therapeutic applications, it can operate at the molecular and cellular levels via biological, chemical, mechanical, and thermal pathways. Nanodevices, which can be utilized to identify target candidates and validate their importance in disease states, are propelling nanotechnology-driven therapeutics into a new era. With personalized medicine, each patient's molecular profile is used to guide diagnosis and treatment decisions. Nanophotonics may open up new avenues for this kind of care. The confinement of photons and electrons as well as the dynamics of nanoscale interactions are the foundations of nanophotonics. Two sorts of foundations have been suggested for modeling nanophotonic structures and techniques used to challenges at the nanoscale regime, including light propagation, scattering, localization, and multiscale difficulties. Applications for nanophotonic structures are numerous and include biomaterials, optical diagnostics, nanomedicine, and biotechnology. Optical tweezers are one such biophotonic technology that has shown promise in the field of cancer theranostics. It has also been shown to be an effective tool for treating cancer and for studying the cellular and subcellular mechanisms behind the disease. High sensitivity and selectivity optical tweezers-based integrated systems are capable of manipulating cells, biomolecules, and nanocarriers while tracking their interactions and yielding data on their biomechanical, biochemical, and biophysical characteristics. The proliferation of new microbial strains and infectious diseases like COVID-19 has increased the need for sensor technology to monitor environmental and health issues more effectively. Further research in Nanobiophotonics, can bring revolution in biomedical science.

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