A Study of Biophotonics:

Market Segments, Size and Growth

Introduction

Biophotonics is the study of the interaction of light with biological material, where "light" includes all forms of radiant energy whose quantum unit is the photon. A more recent development of photonics, much of biophotonics is focused on translating discoveries in the sciences around lasers, light and imaging into useful medical tools. Medical imaging and in vitro diagnostics are just two of the many applications of biophotonics that already had an enormous positive impact on our lives. Besides advancing the frontiers of medical technology, biophotonics is also being applied to non-medical applications. As the experts in the field attest, the promise of future developments in biophotonics is nothing short of extraordinary.

Light and other forms of radiant energy can be used to image, analyze and manipulate living tissue at cellular and molecular level, in a noninvasive or minimally invasive manner. The region of the electromagnetic spectrum of interest comprises of wavelengths shorter than 10^{-3} m.

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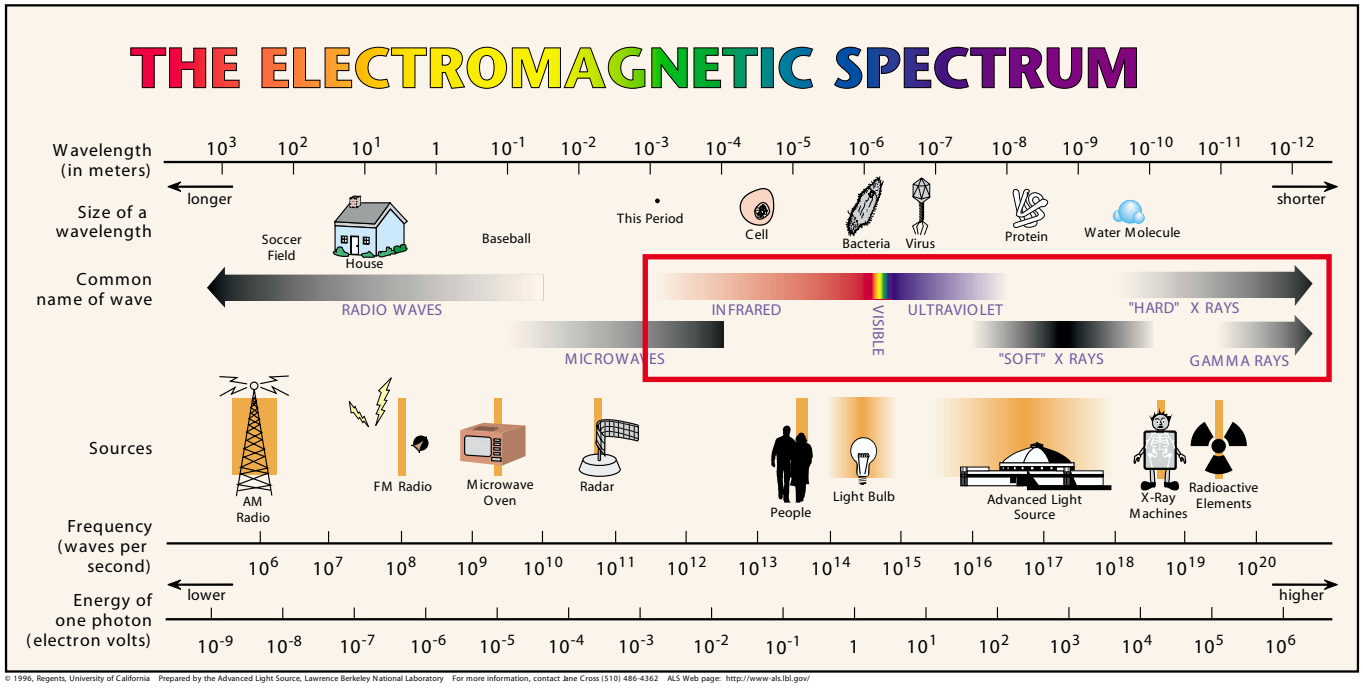

FIGURE 1: **Biophotonics is the application of light and other forms of radiant energy (as indicated by the red box) to the life sciences and medicine.**

Highlights

- Based on a bottom-up approach (relevant company revenues), the size of the biophotonics market was estimated at over $63 billion.
- Based on a top-down approach (industry-specific market reports), the size of the market was estimated at well over $53 billion, with the caveat that not all biophotonics-related industry segments are covered in readily available market reports.
- The biophotonics market can be divided into 4 segments: tests and components, medical diagnostics, medical therapeutics, and non-medical applications.

Scope

The scope of this project was to investigate the size and composition of the international biophotonics market. The project was commissioned in March 2006 by the Center for Biophotonics, Science and Technology (CBST) to a team of MBA students from the MBA Consulting Center at the Graduate School of Management, University of California at Davis, working under the direction of Dr. Richard Dorf, Consulting Center Director, and Dr. Dennis Matthews, CBST Director. Valuable guidance was also provided by John Walter, Deg. Eng., MBA, Managing Partner of The MarkeTech Group consulting firm. To our knowledge, this is the first study of the international biophotonics market.

Methodology

This study is based on data from a variety of sources, such as company, industry, government, trade journals and organizations, and market studies of related products. It includes information from literature reviews and discussions with biophotonics experts and medical technology marketing consultants.

Briefly, we used the following methods to estimate the biophotonics market size:

1. Determined the segmentation of the biophotonics market by dividing the market into distinct subsets, which exhibit minimum overlap. For the newly defined, highly interdisciplinary industry of biophotonics, which comprises all the applications built upon the interaction of light with biological matter, we defined segments based on applications, as listed in Table 1. Biophotonics technologies applications are found throughout many industries (as they are currently defined by the Standard Industrial Classification SIC), next to many other technologies. For example, many in vitro diagnostics assays and instruments are based on biophotonics, with the remainder using different technologies. Only a part of the In Vitro Diagnostics industry belongs to the biophotonics industry.
2. Identified companies serving the market, performed specific company research and extracted data on relevant revenue streams. In the bottom-up approach, we estimated the market size

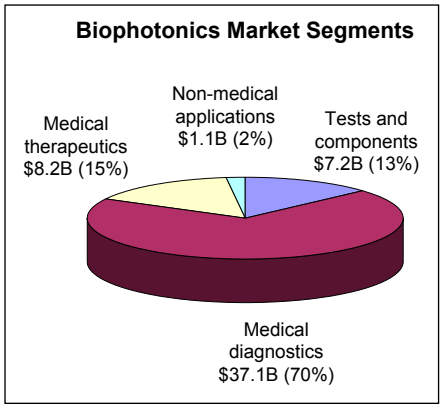

FIGURE 2: **The biophotonics market segments and their sizes, in 2005 US $, and percentage of total market.**

TABLE 1: BIOPHOTONICS INDUSTRY SEGMENTS

1. **Tests and components**
   - a. Optical instruments, parts and accessories
     - i. Microscopes
     - ii. Spectrometers (Visible, UV, IR & FTIR, X-ray, Fluorescence, Raman, NMR, etc.)
     - iii. Laser illumination sources
     - iv. Light sources (including lamps and LEDs, excluding lasers) for biophotonics instrumentation
     - v. Detectors marketed specifically for bioscience applications (CCD, Intensified CCD, Optical diodes, Photomultiplier tubes)
     - vi. Cameras and displays marketed specifically for bioscience applications (IR cameras, Streak and gated cameras)
   - b. Molecular biology assays and instruments
     - i. Gene sequencers
     - ii. Microarrays (gene, protein, cell, and tissue arrays)
     - iii. Optical assays (ELISA)
     - iv. Real time PCR, etc
   - c. Probes: fluorescent dyes, nanoparticles, nanobiosensors, quantum dots
   - d. X-ray diffractometers for protein crystallography
   - e. Fiber-optic based enzymatic sensors
2. **Medical diagnostics**
   - a. In vitro diagnostics assays and instruments
     - i. Clinical biochemistry
     - ii. Immunodiagnostics
     - iii. Blood testing
     - iv. Nucleic acid diagnostics
     - v. Flow cytometers
   - b. Patient monitoring systems
     - i. Pulsed oxymetry
     - ii. IR body temperature sensors
     - iii. Blood glucose monitoring systems
     - iv. Cardiac and multi-parameter monitoring systems with fiber optic sensors
     - v. Optical metabolomics instruments (IR-based body fat monitors, Raman analysis of β-carotene in humans, etc)
   - c. Imaging instrumentation and accessories
     - i. Computed tomography (CT) scanners
     - ii. Single photon emission computed tomography (SPECT)
     - iii. Positron emission tomography (PET)
     - iv. Fluoroscopes
     - v. Contrast agents for radiology
   - d. Advanced biophotonics imaging
     - i. Bioluminescence imaging
     - ii. Elastic scattering imaging
     - iii. Fluorescence and fluorescence lifetime imaging
     - iv. Time gated imaging
     - v. Optical coherence tomography (OCT imaging devices for ophthalmic, vascular and cancer detection)
     - vi. Diffuse optical tomography (DOT)
     - vii. Molecular imaging with X-ray lasers
     - viii. In vivo Coherent Anti-Stokes Raman Scattering (CARS)
   - e. Endoscopes using optics (conventional illumination, fluorescence) and endoscopic capsule
   - f. Optical biopsy technology
3. **Medical therapeutics**
   - a. Surgical equipment and accessories
     - i. Surgical lasers (includes laser keratotomy/refractometry/vision correction and lasers for benign prostatic hyperplasia)
     - ii. Dermatology lasers
     - iii. Cosmetic lasers (hair and wrinkle removal, spider vein removal, treatment of psoriasis, acne, cellulite, tattoo removal)
     - iv. Dental lasers (cleaning, UV teeth whitening)
     - v. Surgical microscopes
     - vi. Surgical positioning devices (optical or IR registration of the patient)
   - b. Photodynamic therapy (PDT) instrumentation and therapeutic agents
   - c. UV illuminators to treat psoriasis and hyperbilirubinemia
   - d. Wound care devices (tissue welding, light therapy)
   - e. Low-level laser therapy
   - f. Radiation-based therapy
4. **Non-medical applications**
   - a. Biometric devices
   - b. Biosensing devices (pathogen detection) for homeland security
   - c. UV sterilization equipment for medical instrumentation and food

based on company revenues (2005 fiscal year).

3. Analyzed industry-specific market reports that include biophotonics products. In the top-down approach, we based our market size estimation on the analysis of industry-specific market reports.

This project focused on medical application products and biometric devices. Future iterations should address other non-medical application products, as well as emerging technologies.

Biophotonics Market Size Based on the Bottom-Up Approach

In the bottom-up approach, we estimated the market size based on company revenues (2005 fiscal year) from biophotonics applications. We analyzed the annual reports of over 145 companies, but many more serve the market. As such, we acknowledge that this study provides a conservative estimate of the size of the biophotonics market. Moreover, we do not contend that our estimates are very accurate, as company revenues are not broken up by technology class.

Biophotonics is a highly interdisciplinary science, broadly applicable throughout many existing industries. 25 different SIC codes were identified among the companies researched.

Companies of all sizes and from many industries offer biophotonics products and technologies, from large multinational corporations to small specialized manufacturers. Based on each company's product and service offerings, we made rough estimates of the percentage of income due to biophotonic products and technologies. Approximately 40% of the companies analyzed are private, which indicates that the market is very young, with explosive growth potential. 84% of the companies we researched are headquartered in the U.S.

For a more detailed analysis, we divided the market in 3 tiers, based on revenues:

- Tier 1 – companies with revenues over $1 billion
- Tier 2 – those with revenues between $500,000 and $1 billion
- Tier 3 – those with revenues under $500,000

Among the companies analyzed, 17% were in Tier 1, 6% in Tier 2, and 77% in Tier 3. As mentioned, there are many more companies active in the area of biophotonics, and most of them are likely in Tier 3, which changes the relative ratios above. For many private companies, revenue information was not easily available. If we suspect their contribution to the total market size to be relatively modest, with a great majority of private companies

Industry Segments Relevant to Biophotonics	**Components within Segment**	**Estimated Market Size** (in Millions of USD)	
		US	**World**
Microscopes and accessories [1]	Microscopes		1,650 in 2004
Medical lasers [2]	Laser illumination, Lasers for OCT, Surgical lasers, Dermatology lasers, Cosmetic lasers, Dental lasers, Would care lasers, Lasers for low-level laser, therapy, Lasers for benign prostatic, hyperplasia	1,554 in 2004	2,390 in 2004
DNA sequencing [3]	DNA sequencing		7,800 in 2004
In Vitro Diagnostics [4]	Clinic biochemistry, Immunoassays, Blood testing, Nucleic acid diagnostics, Flow cytometers	13,170 in 2004	29,400 in 2004 [5]
Endoscopes [6]	Endoscopes, (excludes visualization equipment)	442 in 2004	110 in 2000 [7]
Medical imaging equipment [8]	X-ray, PET, CT, MRI, ultrasound	6,600 in 2003 1,500 X-ray 1,400 MRI 1,300 ultrasound 2,400 PET+CT+ nuclear medicine etc	14,000 in 2001 [9]
Patient monitoring systems [10]	Pulsed oximetry, IR body temperature sensors, Blood glucose monitors, Cardiac and multi-parameter, monitoring systems with fiber optic sensors, Bili light, Slit lamps, Borescopes, fiberscopes, videoscopes	6,000 in 2003	
Radiation-based therapy and therapeutic imaging [11]	X-ray and laser therapeutic radiation	4,000 ib 2004	
Adjunctive therapies: photodynamic, electromagnetic, radioimmunotherapy, and angiogenesis inhibitors [12]	PDT instrumentation and therapeutic agents	1,700 in 2004	
Biometric devices [13], [14], [15]	Face, Iris, Live Scan, FIngerprint Chips, Large-Scale AFIS Systems, Hand and Finger Geometry, Retinal, Vein, Multimodal, Gait Recognition, Ear, Olfactory, Lip, Nail, Skin	270 in 2004	1,539 in 2005 [15]
ESTIMATED TOTAL BIOPHOTONICS* (in Millions of USD, based on products above)	**$ 53,720**		

TABLE 2: **Market size of various industry segments relevant to biophotonics.**

***Assumptions:**

- For segments where worldwide market data was not available, we estimated it to be two times the US market.
- We used 2004 as reference year. We used the growth rates available to estimate the market size in 2004, where it not available for that year. If the worldwide growth rate was not available, we approximated it with the US growth rate.

Compound annual growth rate = r

$E = B(1 + r)^T$

where E denotes ending value, B denotes beginning value and T denotes the time passed in years.

belonging to Tier 3, we are certain that these companies bring significant contributions in terms of innovation.

Based on the bottom-up approach, we estimated the international biophotonics market today at over $63 billion. Again, this is a conservative estimate, for at least 3 reasons: the limited number of companies analyzed within the project's time constraints, the difficulty of finding information on private companies and companies headquartered outside U.S., and the fact that most companies do not provide revenue figures by technology.

Biophotonics Market Size Based on the Top-Down Approach

In the top-down approach, we analyzed existing industry-specific market reports and estimated the percentage due to biophotonics-based products and technologies. We projected the international biophotonics market at over $53 billion, with the caveat that not all biophotonics-related industry segments are covered in readily available market reports. Therefore, this is a very conservative estimate. The segments that were not included in the market studies analyzed could easily make up the $10 billion difference between the two approaches to market assessment.

We collected data on US and world markets for various product classes that include biophotonics-based products and technologies (Table 2), as well as market size forecasts and annual growth rates, where available (Table 3). The market reports studied did not focus on biophotonics; therefore, the industry segments below don't always have a one-to-one correlation with the biophotonics industry segments as classified in Table 1 above.

Discussion and Outlook

Photonics as a field really began in 1960, with the invention of the laser, followed in the 1970s by the development of optical fibers as a medium for transmitting information using light beams. Until recently, biophotonics was included under the "basic research" segment of photonics science.

In their 1998 report, "Harnessing Light – Optical Science and Engineering for the 21st Century", the National Research Council (NRC) discussed the (then) current utilization of laser technology for basic medical diagnostic and therapeutic applications, and pointed to the relative lack of translation of laboratory bench top research into technology to improve or enable noninvasive clinical diagnostic measurements. The Center for Biophotonics, Science and Technology (who commissioned this report) was conceived in response to the NRC recommendations, and also to a perceived need among leading academic and research institutions for a consolidated and more concerted effort to address a host of emerging grand challenges.

The broad field of biophotonics has ramnifications in many existing industry segments; however, it is but one of many technologies employed, which makes it difficult to extract information specific to biophotonics without access to detailed financial information. Most companies do not break down their revenues based on the science behind their products. Similarly, few market reports give market information for specific technologies. When estimating the biophotonics market size by the above-mentioned approaches, we therefore had to make rough estimates of the percentage of company revenues and industry segment market size respectively that is due to biophotonics-based products and technologies. At times, industry segment data was available only for the US. In such cases, we used the conservative assumption that the worldwide market is twice the size of the US market.

Industry Segments Relevant to Biophotonics	Components within Segment	Forecast (in Millions of USD)		Annual Growth Rate (A=average, C=compound)	
		US	World	US	World
Microscopes and accessories	Microscopes		2,770 in 2009		11% AAGR
Medical lasers	Laser illumination, Lasers for OCT, Surgical lasers, Dermatology lasers, Cosmetic lasers, Dental lasers, Would care lasers, Lasers for low-level laser, therapy, Lasers for benign prostatic, hyperplasia	2,086 in 2006	3,209 in 2006	12% CAGR 2003 - 2006	12% CAGR 2003 - 2006
DNA sequencing	DNA sequencing		17,500 in 2009		17.6% AAGR
In Vitro Diagnostics	Clinic biochemistry, Immunoassays, Blood testing, Nucleic acid diagnostics, Flow cytometers	17,700 in 2009		6.1% in 2004	5% in 2005
Endoscopes	Endoscopes (excludes visualization equipment)	513.5 in 2012		1.9% CAGR 2005 - 2012	
Medical imaging equipment	X-ray, PET, CT, MRI, ultrasound	9,500 in 2008 1,900 X-ray 1,775 MRI 1,775 ultrasound 4,050 other		7.6% 2003 - 2008 4.6% X-ray 5.3% MRI 6.2% ultrasound 11.2% other (PET more than 3X)	7% through 2007
Patient monitoring systems	Pulsed oximetry, IR body temperature sensors, Blood glucose monitors, Cardiac and multi-parameter, monitoring systems with fiber optic sensors, Bili light, Slit lamps, Borescopes, fiberscopes, videoscopes	8,200 in 2008		6.7%	
Radiation-based therapy and therapeutic imaging	X-ray and laser therapeutic radiation	5,700 in 2009		7.6% AAGR	
Adjunctive therapies: photodynamic, electromagnetic, radioimmunotherapy, and angiogenesis inhibitors	PDT instrumentation and therapeutic agents	8,800 in 2009		39.2%	

TABLE 3: **Market size forecasts and annual growth rates of various industry segments relevant to biophotonics.**

INTERVIEW: BIOPHOTONICS ON THE RISE

Research on Biophotonics is making fast progress. Andreas Thoss spoke with Dennis Matthews, Director of the NSF Center for Biophotonics, Science and Technology (CBST), about the impact that Biophotonics could achieve.

O&P : How do you define Biophotonics and where do you see the difference to Biomedical imaging?

MATTHEWS: We define biophotonics as the development and application of photon-based technology to the life sciences and medicine. Biomedical imaging fits within our definition of biophotonics, but certainly only represents one topic within the field of biophotonics. We categorize biophotonics into four broad topics, biophotonics for: 1) bioimaging, 2) biosensors, 3) bioassays and 4) medical devices for monitoring, diagnosis or therapy.

O&P : How do you see the funding situation for Biophotonics research in the US at the moment and in the future?

MATTHEWS: Currently, my research program in the USA is funded by NSF, NIH, Department of Homeland Security and private industry. Other researchers in the field also obtain funding from DARPA and AFOSR. Especially in the topical area of biosensors, bioassays and medical devices we expect significant increase in funding from both government and industry.

O&P : What major findings would you see in the field of biophotonics? How has this research already changed our life?

MATTHEWS: Looking at our own research interests, we hope to vastly improve the resolution of photon-based microscopy to the point where it rivals electron imaging, but, of course, photon-based imaging can be applied to living organisms. We also are developing spectroscopic imaging systems that can real-time identify biological systems from the subcellular level to the whole organism.
I see a great need also for so-called point of care testing devices which need to be field portable and can be used to quickly identify pathogens and disease by assaying biomaterials from humans or animals. I believe biophotonics in the form of real-time PCR, sandwich assays and Raman cytometry will play a big role in providing this type of information. Medical applications of biophotonics are numerous but already have included the development of photodynamic therapy, rapid testing for influenza viruses and so on.
Biophotonics has already led to some very important medical devices and monitoring systems, not to mention the whole field of molecular imaging. Biophotonics medical devices include pulsed oxymeters, laser surgery tools etc. Some examples for new methods in this field are corneal sculpting for vision improvement, optical coherence tomography for retinal imaging to check for macular degeneration and other eye diseases. Furthermore there are lasers for cosmetic surgery, laser-activated catheter tools and many more.

O&P : Looking at the near future, where do you expect great influence of Biophotonics research on health care (or industrial applications)?

MATTHEWS: In my view some of the greatest challenges in medicine can be addressed using biophotonics. One of my favorites is the development of precision surgical tools based on the short pulse laser ablation which use hyperspectral imaging for guidance. This will eventually enable surgeons to remove tissue at the single cell level of precision, i.e., identify normal from abnormal cell in tumor margins, e.g., and real-time photoablate the unwanted cells without damaging the good ones. Another favorite is the development of low-cost point of care biomarker assays that help physicians check for recurrence of cancer or test ER patients for the presence of infectious disease prior to admitting them into and thereby exposing the entire hospital. I am also extremely intrigued by the possibility of using light for pain therapy. The field of low level laser therapy has been around for a while, but not much is understood about some of the positive results that are being observed with patients. Can light be used to treat pain and inflammation or are the results so far just examples of the placebo effect? Automated pathology using biophotonics is also a major quest that is addressable relatively soon with biophotonics being used to characterize either live or freshly-excised tissue. One last example is the development of personal health monitoring systems. I know several companies and research labs which are exploring the ability to miniaturize biophotonics-based devices that transdermally monitor body metabolites and even look for proteins that are expressed when certain diseases are affecting the person being monitored.
There are clearly many other areas in medicine where biophotonics can be used, everything from better surgical illumination systems to non-invasive glucose monitoring. I have many colleagues out there in the world of biophotonics researchers who can certainly add many of their own ideas and speculations.

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CBST was commissioned in 2002 with a $40M commitment by NSF to focus research efforts in the broad field of biophotonics. The Center's goal is to advance biomedicine and photonics engineering through rapid and directed development of novel biophotonics technologies. CBST is headquartered at the UC Davis Medical Center in Sacramento, but coordinates activities within its core group of eight university campuses and one national laboratory.

Dennis Matthews is Director of the CBST and Program Leader for the Medical Technology Program at Lawrence Livermore National Laboratory. He holds a professors position within the UC Davis Department of Applied Science and the School of Medicine.

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The forecasts and annual growth rates did not have the same base years for all industry segments analyzed, but they do give individual snapshots, at different moments in time. Most interesting to note is that many segments of the biophotonics market are forecasted to exhibit healthy, double-digit growth rates. For example, the demand for PET scanners is projected to grow more than threefold in the US through 2008; real-time PCR: 12.2%; nanotechnology used in the Life Sciences: 30.3%; adjunctive therapies: 39.2%; biometric devices: 31.1%.

Overall, biophotonics has tremendous growth potential as it goes from cutting edge to standard practice. Increased adoption will lead to decreases in costs, further fueling growth. Its use is expanding into novel research areas and is producing disruptive technologies that will fundamentally change current practices. Other reasons for growth include the technology's potential to change basic research paradigms, the need for high throughput in both research and industry and increased vigilance with respect to both human and environmental threats.

More difficult to estimate, the effects of emerging technologies on people's lives and market potential cannot be overstated. Examples such as genetics based diagnosis of individual risks for cancer or Alzheimers desease give aglimpse of what to expect within the next decade.

Conclusion

The highly interdisciplinary field of biophotonics is already pervasive in our lives, for example through in vitro diagnostics and medical imaging, while it also has the potential to expand the frontiers of medicine. We estimated the biophotonics market today at $63 billion based on company revenues (bottom-up approach) and $53 billion based on existing industry reports (top-down approach), with the caveat that not all biophotonics-related industry segments are covered in readily available market reports. Medical diagnostics (see Table 1) makes up 70% of the biophotonics industry, with In Vitro Diagnostics having the largest share at 55% of the total biophotonics market.

The collaboration of scientists from diverse fields of physical sciences, engineering, biology and medicine will continue to be the prime mover of advances in biophotonics. Their ability to image, analyze, and manipulate living tissue with light, at molecular level, in a minimally or noninvasive manner, is truly revolutionizing biomedicine and photonics engineering. As anticipated, the biophotonics field is not only vast and expanding, but it may well exceed the most optimistic growth forecasts for almost any other scientific field. In short, the future of biophotonics is both exciting and assured.

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