

LASERS IN HEALTHCARE:

How light is revolutionising medicine

A laser array in the lab.

Photo: Supplied

Once confined to science fiction movies and high-tech laboratories, lasers are now playing an increasingly important role in healthcare. From precise surgeries to advanced diagnostic tools, laser technology is reshaping how we diagnose, treat and even prevent diseases.

What is a laser?

The word laser stands for "Light Amplification by Stimulated Emission of Radiation". Lasers are devices that concentrate beams of light by forcing their waveforms and frequencies to align. A laser works by exciting a material (called the gain medium) with an energy source, such as a diode, which amplifies light at certain wavelengths through a process called stimulated emission. This creates a powerful beam of light that is focused, uniform and precise.

In simple terms, a laser produces a narrow, controlled beam of light that can be directed with high accuracy. In essence, lasers are engineered to produce light with specific, controlled properties that make them ideal for applications requiring precision, high intensity and focused beams. Other light sources like light bulbs are designed for general illumination (scattered light) and have broader applications (Figure 1).

How do lasers work?

To achieve application-specific characteristics, the laser beam is manipulated using a series of optical

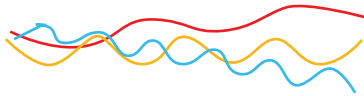
components including mirrors, beam splitters, lenses and optical windows, which enable control over focus, direction and beam shape. The resulting high-intensity beam can be concentrated into a micron-scale spot or expanded for wide-field illumination, depending on the specific applications in fields such as medicine, manufacturing and research.

The Photonics Centre at the CSIR is home to expertise driving the development of cutting-edge laser technologies that provide solutions for industries such as manufacturing, mining, defence, energy and healthcare. These laser technologies help businesses lower costs, boost performance, unlock new design possibilities and extend the lifespan of critical equipment, strengthening South Africa's industrial competitiveness. Different types of lasers are chosen based on their wavelength and pulse duration. Some common lasers and their application in health care include:

- **CO₂ lasers (10.6 μm):** These are strongly absorbed by water, making them effective for cutting, vaporising and sealing soft tissues, especially in fields like dermatology, surgery procedures and gynaecology.

Light source

Wave properties



Many frequencies
Non-coherent (randomly distributed)
Low intensity
Omnidirectional



One frequency
Non-coherent (randomly distributed)
Low intensity
Omnidirectional



One frequency
Coherent (synchronised)
High intensity
Unidirectional

Figure 1: The wave properties of different light sources

- **Nd:YAG lasers (1064 nm):** Known for their deeper tissue penetration, they are used in treatments such as tumour removal, eye surgeries (like posterior capsulotomy) and vascular operations.
- **Er:YAG lasers (2.94 µm):** Offering precise tissue removal with minimal heat damage, they are widely used in dental and skin-related procedures.
- **Femtosecond and picosecond lasers:** These ultra-short pulse lasers are ideal for microsurgery and cell-level tasks, thanks to their ability to deliver high peak power with limited surrounding tissue damage.
- **Diode lasers:** Compact and energy-efficient, they are commonly used in soft tissue treatments, Low-Level Laser Therapy (LLLT) and photodynamic therapy (PDT).

To ensure these systems work safely and effectively in clinical or research settings, proper maintenance, skilled operation and strict safety measures are essential. This includes eye protection, regular calibration and adequate ventilation.

Lasers for diagnosis and monitoring

Diagnosis is the first and most important step in addressing any health problem. It is the foundation upon which all subsequent medical interventions are built. Lasers are not just about cutting or treating; they are also powerful tools for looking inside the body (Figure 2). Laser-based imaging techniques, such as Optical Coherence Tomography (OCT), are used in ophthalmology to detect diseases like glaucoma and macular degeneration at very early stages.

In research, the CSIR biophotonics laboratory team recently reported using laser-based technologies to

develop biosensors that can detect disease pathogens such as TB, HIV and diabetes. Raman microscopy, another laser-based method in the biophotonics lab, is helping scientists identify the chemical fingerprints of diseases at the molecular level. This could lead to faster and more accurate diagnoses, even from simple blood or saliva samples.

Fighting infections and drug-resistant bacteria

Lasers are also coming up as powerful tools in the fight against infections, offering innovative, non-invasive and highly targeted solutions for managing and treating diseases. Their role spans across medical, dental and research applications.

1. Photothermal Therapy (PTT)

Lasers heat up nanoparticles or tissues to destroy microbial cells.

Applications: Used to kill antibiotic-resistant bacteria by generating localised heat that disrupts their cell membranes without harming surrounding healthy tissue.

2. Photodynamic Therapy (PDT)

A photosensitising agent is activated by laser light to produce reactive oxygen species (ROS) that kill pathogens.

Applications: Effective against bacteria, fungi and viruses, including drug-resistant strains. Common in wound care, dental infections and dermatology.

3. Low-level Laser Therapy (LLLT)

A low-power laser interacts with light-sensitive molecules within cells, triggering a series of

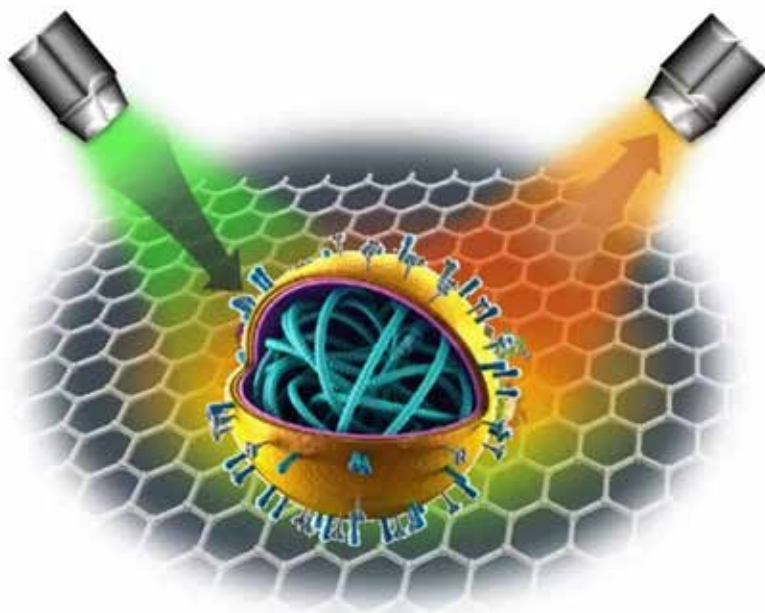


Figure 2: A visualisation of laser monitoring of pathogens or abnormalities in human patients.

biochemical reactions that can accelerate healing, reduce pain and boost cell function.

Applications: Helps treat conditions like carpal tunnel syndrome, fibromyalgia and arthritis. Also, under research for use in jaw joint problems, wound healing, quitting smoking and tuberculosis.

4. Laser-enhanced drug delivery

Lasers temporarily increase the permeability of tissues or bacterial biofilms to enhance the penetration of antimicrobial drugs.

Applications: Improves the effectiveness of antibiotics in hard-to-reach or resistant infections, such as chronic wounds or abscesses.

5. Antimicrobial surface sterilisation

High-intensity lasers can decontaminate surfaces by destroying microbes directly or through plasma generation.

Applications: Used in sterilising surgical tools, hospital surfaces and even implants.

With the rise of antibiotic-resistant bacteria, lasers offer new hope. Some researchers are exploring photothermal therapy, where laser light is used to heat and destroy harmful microbes without harming human cells. This approach could be a game-changer in fighting infections that no longer respond to traditional antibiotics.

Precision tools in the operating room

One of the earliest and most famous medical uses of lasers is in surgery. Laser surgery is often less invasive than

traditional methods. It allows doctors to make cleaner incisions, seal blood vessels more efficiently, and reduce damage to surrounding tissue. Eye surgeries like "LASIK" have become almost routine thanks to lasers, restoring vision with minimal pain and quick recovery.

In cancer treatments, lasers can be used to shrink or destroy tumours. In some cases, they help remove or reduce abnormal tissue growth with high precision and less impact on healthy cells. Laser treatments are also popular in dermatology for removing unwanted hair, scars or wrinkles. Dentists also use lasers for procedures like cavity removal, teeth whitening and gum reshaping, offering more comfort and less bleeding than conventional tools.

The future of lasers in health

The possibilities are endless. The future of laser technology in healthcare is moving towards integration with fields such as artificial intelligence (AI), nanotechnology and robotics to enable highly precise, minimally invasive and personalised treatments. Breakthroughs such as femtosecond lasers bring a new level of precision, while wearable laser devices could one day make continuous monitoring and home-based care a reality. Collectively, these developments are aimed at improving patient outcomes and providing faster recovery, better results and a healthcare system that focuses more on prevention than reaction.

These innovations are especially promising for cancer treatment, medical diagnostics and the management of chronic diseases. For instance, the biophotonics lab is currently developing smart, laser-based biosensors designed to detect early signs of diseases like HIV and TB. With the integration of nanotechnology and AI, these devices can even be controlled via mobile apps, enabling real-time monitoring and adjustments.

Lasers have become far more than beams of light; they are powerful instruments of healing, discovery and hope. As technology advances, we are only beginning to unlock the full potential of lasers in healthcare. Whether it is saving sight, treating tumours or helping diagnose disease in seconds, the future of medicine is looking brighter, literally. The evolution of medical laser systems is not just shaping the future of medicine; it is redefining it.

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