

New Materials for Diode Pumped Solid State Lasers and Its Applications to Medical Photonics

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In the history of lasers, 1980 is a remarkable year. In this year an efficient, powerful room temperature AlGaAs semiconductor laser revolutionized the field of solid-state laser. Replacement of conventional flash lamps paved a path for diode pumped solid-state lasers. Many Nd³⁺ ions doped laser crystals such as Nd:LiYF₄ and Nd:YVO₄ has emerged. As you know, erbium doped fiber amplifier (EDFA) needed 980 nm laser to make a revolution in amplifying optical signals. Luckily, InGaAs laser diode with 980 nm was developed. This laser was used as diode pumped laser for Yb: YAG laser, which was discarded as inefficient laser during 1960s. Hence, Ytterbium (Yb³⁺) doped solid-state laser (Yb:YAG) pumped with InGaAs laser diodes has been intensively and successfully developed. A search is in progress for novel Yb doped crystals possessing properties superior to known Yb laser with new capabilities. Several such materials have been identified and characterised recently. This talk concerns with such new laser materials for diode pumped solid-state lasers and its potential use in cosmetic, medical and veterinary photonics.

Key Words: Photonics, Solid state lasers.

INTRODUCTION

Lasers have gained popularity in cosmetics because they enable cost-effective skin treatments that are not easily achieved with other technologies. The wider new applications reduce equipment cost and products. This enables lasers to play an even broader role in cosmetics in the future. In recent years, a number of important advances, including the development of versatile solid-state materials and non-linear crystals offered a major impact on cosmetic and medical laser technology. This opened the door to a wide range of new instrumentation and treatment capabilities. Cosmetic lasers are used in skin resurfacing and in plastic surgery. Laser skin resurfacing *viz.*, laser peel of the face is a popular type of plastic surgery. Dermatologists began performing laser resurfacing as an alternative to dermabrasion. Most commonly a CO₂ laser is used to vaporize the top five cell thick layer of epidermis. To speed healing, some doctors use an Er:YAG laser that does not penetrate very deeply. With CO₂ laser, the initial redness may take up to three months to fade away while with erbium lasers it is generally less than two weeks.

In our modern world huge amounts of money are spent to make skin look younger, more beautiful and healthier. Recently, a doctor from Hollywood recommended the combination of full face CO₂ laser skin resurfacing with surgical face lift to obtain younger looking skin. Thus a 60 year old woman can now appear to be physically young using laser skin resurfacing. A few years ago, doctors used dye lasers to treat varicose veins. Now their attention has shifted to frequency doubled Nd:YAG to perform this treatment. The common cosmetic/dermatology lasers available at present are as follows:

Laser type	Wavelength	Applications
Alexandrite	755 nm	Hair removal
CO ₂	10.06 μ m	Skin resurfacing
Diode	800-1000 nm	Hair removal and teeth whitening
Er:YAG	2.94 μ m	Skin resurfacing
Flash lamp pumped dye	585-600 nm	Vascular and pigmented conditions
Nd:YAG	1.064 μ m	Hair removal
Nd:YAG/Freq. doubled	532 nm	Vascular and pigmented conditions
Rubby	694 nm	Hair removal

Lasers have also been used to remove unwanted decorative tattoos and benign pigmented skin marks and lesions. The pulsed dye lasers are widely used for this purpose. Traumatic discolouring caused by accidents, gunshots or explosives, with various materials becoming embedded in the skin, can be extremely difficult to correct. Recently, Dr. Agneta Troilius, a Swedish doctor has achieved good results in the removal of such marks with Q switched Nd:YAG laser treatment.

Hair removal is one of the largest potential markets for laser applications and treatment. This is going to be of great help not only to doctors but also to men and women who spend a vast amount of money on razor blades, electrolysis and hair removal creams. On the other hand, hair transplants are also possible with lasers. In laser assisted hair transplantation laser creates skin pockets that can accept hair follicle transplants.

Nowadays people are interested in having white teeth. They don't want discoloured teeth. Argon and CO₂ lasers (low intensities) are widely used by dentists for teeth whitening.

Since injections cause pain and possibility of infection, there has been interest in delivering drugs without injection. Now the 694.3 nm Q switched ruby laser delivers drugs without injection. This new approach could be useful in application for drugs such as insulin for diabetic patients. In short, lasers will provide better cosmetic care at a lower cost in the years to come.

LASER SKIN RESURFACING

Traditional cosmetic procedures which included chemical peels and dermabrasion helped to remove the dead surface layers of skin to expose the still living dermis. Chemical peels literally burned away the top layer of the skin with little control over the chemical's penetration while dermabrasion uses abrasive compounds to clear off dead skin cells. Both techniques are often ineffective, carry risks and are very expensive.

Due to the limitations of these methods, laser skin resurfacing is becoming a popular choice for skin rejuvenation. This technique has produced dramatic results.

In laser resurfacing, a physician typically uses a pulsed laser to deliver hundreds of milliwatts of energy in less than the thermal relaxation time of skin that is estimated at 700 μm . This energy ablates the surface layers of skin and shrinks collagen strands embedded in skin by about one-third. The result is smoother skin with fewer fine lines, wrinkles and age spots. This technique produces consistent and predictable improvements in facial skin quality. This can also be used to remove irregular scar contours.

A coherent CO₂ laser was used to vaporise areas of elevated skin around the scars to induce a local inflammatory reaction that causes epithelial cells to multiply and to smoothen out skin in the long term. Individual wrinkles were treated in a single pass of laser light with energies from 300 to 400 mJ per pulse. When the entire face needed resurfacing, the best results were obtained using up to two passes of 300 mJ per pulse of light. For the thinner skin around the eyes, a single sweep of 200 mJ per pulse was used. No special skin care was applied before surgery and water compresses were used to sooth the skin after surgery. The full-face laser resurfacing with face-lift surgery is another milestone in the cosmetic laser research. This approach is adopted to correct sagging skin and to improve the quality of the skin.

To start with, α -hydroxy acids are applied as a light chemical peel to remove dead tissue and expose new skin. Then deep moisturizer is applied and followed by resurfacing with a coherent laser. The best results were achieved using light doses of 300 mJ per pulse

delivered in a single pass for areas around the eyes. The obvious advantage in this method is the considerable decrease in healing time.

CO₂ LASER VANQUISHES SKIN WRINKLES

The anatomy of a wrinkle is as follows: The skin dermis layer, a mere millimeter or less in thickness on the face, consists of large tough fibers of collagen protein and stretchy fibers of elastin protein. With age, particularly in a person who has spent considerable time in the sun, the epidermis dries and thins. Excessive sun exposure leads to abnormal, disoriented elastin fibers, robbing the skin of its support and elasticity. The epidermis folds and wrinkles are born. In early days skin resurfacing was done using a CO₂ laser system.

The laser heats the skin, peeling off the outermost layers and at the same time it heats the collagen in the dermis. The heated collagen shrinks and newly synthesized collagen protein gradually replaces it. The new collagen tightens the skin and wrinkling caused by sun damage or aging is removed. Larger, deeper wrinkles like brow furrows may tend to recur to some degree.

The procedure is usually not painful but produces a red and raw look that may last up to four months.

The continuing redness indicates the construction of new collagen and reflects the formation of a new blood supply to the new collagen.

COSMETIC LASERS ARE AT THE THRESHOLD OF A NEW ERA

In the past, doctors used dye lasers to treat varicose veins. Now they can choose the frequency-doubled Nd:YAG to perform the treatment. The pulsed dye laser was used for many years to treat port wine stains. Although results are acceptable, they are far from perfect. Multiple procedures are often required and port wine stains become darker before they fade away.

These lasers can selectively damage larger, abnormal veins while leaving smaller veins intact. This means that port wine stains and spider and varicose veins can be treated successfully.

In the past, medical lasers required manual adjustments but today they represent a sophisticated hardware and interactive databases. The system allows physicians to command a preprogrammed treatment modality at the push of the button. Laser manufacturers also have become more attuned to the needs of their customers. In the past, laser systems were designed for a single application. Today many laser systems let you start with just the capability you need and upgrade when necessary. Combination of a KTP, Nd:YAG and an alexandrite is a versatile dermatology laser used for tattoo removal and scar minimization. This is

because no single laser can match the absorption wavelengths of all tattoo pigments and skin colors. Combination of CO₂ and Er:YAGs in a single system is targeted for dermatologists. More recently, KTP lasers have met with great success because the 532 nm wavelength ablates tissue instead of coagulating them.

Fibers can be either side firing or end-firing; side-firing configurations are used to reach areas that are not in the line of sight of the fiber. These configurations find use in urology for the treatment of ureteral strictures, bladder tumours and enlarged prostates.

Matching the pulse length of a frequency doubled Nd:YAG to thermal relaxation time of enlarged varicose veins improves the outcome of treatment.

Light also can be delivered *via* scanners to surface tissues. Scanners expand and shape the laser beam so that it delivers a precise amount of energy in a fairly large spot size.

Scanners eliminate the accumulation of thermal energy in any given area and minimize the discomfort that it would cause. They find application in hair removal and skin resurfacing where large areas have to be reproducibly covered in a short time.

Lasers in biotech research are becoming indispensable. New spectroscopic methods coupled with an increased knowledge base are making the early diagnosis of disease a reality. Medical practice has not yet caught up with this capability. But with continued improvements in lasing materials and delivery methods – plus accumulated experience in their use and suitable selection of surgical parameters this imbalance surely will be corrected with time.

Q-SWITCHED Nd:YAGs REMOVE TRAUMATIC TATTOOS

Lasers have long been used to remove unwanted decorative tattoos and benign pigmented skin marks. Removal of accidents, gunshots or explosives marks with Q-switched Nd:YAG laser is possible.

Scientists suggest the use of 1064 nm Nd:YAG laser, emitting 10 ns pulses at 10 Hz for the removal 3 mm tattoo spot. The fluence can be varied between 5 and 7 J/cm². The ideal laser for treatment of these conditions would be a laser with a cooling system, so that one could use a higher fluence and at the same time the epidermis could be saved from scarring and pigment changes. The possibility to vary wavelength and pulse duration also would be very valuable.

LASERS IN DERMATOLOGY

Pulsed dye lasers operating at the range of 577-585 nm have proved useful for treating patients with red to pale pink portwine stains on the face, head and neck. The portwine stains that involve small capillary tube vessels can easily be treated with dye lasers. Longer wavelengths in 590-600 nm range generally are used to treat older patients with older lesions caused by larger and deeper vessels. Other lasers that treat portwine and other small vessel vascular lesion include long pulse 582 nm cw, 532 nm cw argon-dye and copper vapour (which emit at 511 or 578 nm) lasers.

Large veins such as varicose veins commonly seen on the legs require a different approach. Doctors use longer laser wavelength pulses to penetrate more deeply to heat larger areas to shrink blood veins in the leg without scarring. They also employ dye alexandrite and frequency-doubled Nd:YAG lasers with long pulses, as well as pulsed and cw near infrared diode lasers.

HAIR REMOVAL

Hair removal is one of the largest potential markets for aesthetic laser equipment and treatments. Long-pulse ruby lasers, long pulse alexandrite lasers, quasi-CW pulsed diode laser systems and Q-switched ND: YAG lasers are employed for this purpose.

Laser hair removal methods rely on selective photothermolysis interaction with the hair follicles. Although the underlying mechanisms are not completely understood, they probably depend upon the type of laser and specific methods employed. In one method a carbon-based ointment is rubbed into hair follicles with the carbon particles serving as primary absorbers of laser energy. In other ointment free methods, melanin particles resting the hair follicles are thought to absorb the laser energy.

HAIR TRANSPLANTATION

In laser-assisted hair transplantation, a laser creates skin pockets that can accept hair follicles transplants. A char free laser vaporizes a slit type pocket only several millimeters deep. Char free lasers, usually CO₂ laser, cause minimal thermal necrosis and charring at edges of pockets as is required for the transplanted hair follicle to grow successfully.

Another application in clinical trials is the use of lasers for tissue welding to improve cosmetic skin closure results after breast cancer surgery.

LASERS DELIVER DRUGS WITHOUT INJECTION

The drugs administered with needles may cause infection and pain. Hence there has long been interest in delivering drugs without injection. The stratum carneum, outermost skin layer (10 to 100 μm) protects the interior of our body from the outside elements and organisms in the atmosphere. With the aid of a 694.3 nm Q-switched ruby laser it is possible to open a microcrack in this wall temporarily. A small reservoir of the drug is placed on the skin's surface and covered by a black plastic pouch. The absorbed laser energy creates a stress wave that opens a temporary pass in the stratum carneum and allows molecules as large as 40 kilodaltons to diffuse passively through it. The laser beam itself does not penetrate the skin. After the procedure, the stratum carneum remained permeable for as long as 15 min before returning to normal. This may also be extended to as much as an hour with the help of surfactants. This new approach is a great boon to diabetic patients who take insulin (which is only 6 K dalton in size) periodically.

WHITER TEETH FOR BRIGHTER SMILES

Humans wish to keep their teeth whiter for cosmetic beauty. Lasers are used for this purpose. Toothpaste like whitening agents is applied on teeth and low intensity argon or CO_2 lasers are then used to activate them. The teeth and gums are not exposed directly to the two lasers. The low intensity of lasers does not cause any problems on gums. This new method for teeth whitening using lasers has been widely accepted by dentists and the common man. More than 300 dental centers have already been established in the State of Utah, USA.

Conclusions

Lasers which started at laboratory level has extended its wings to industry, medical, entertainment, cosmetic, food, military, biology, veterinary science and to several other areas. The emerging new laser technologies help us in developing new mechanisms that control the delivery of laser energy. Manufacturers attempt to develop smaller, faster and more accurate delivery systems to keep up with the demands of the cosmetic market. Future scanners will have improved performance and will fit into smaller hand pieces that are more comfortable and easier for beauticians to use.