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Application Note

Thermoelectric Modules & Assemblies for Medical Laser Applications

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Thermoelectrics are easy-to-service, cost-effective systems that encompass high cooling efficiency in small sizes. With a wide range of heat pumping capacities, Thermoelectric Modules (TEMs) and Thermoelectric Assemblies (TEAs) afford precise temperature control, making them the only effective thermal management solution for many medical laser applications.

Many medical laser applications have tight space constraints and low weight requirements, making thermoelectrics a better choice than compressor-based systems. In addition, the solid-state assemblies have higher reliability with fewer moving parts and require less maintenance, resulting in less downtime over the extended product life cycle.

Thermoelectrics offer the ability to cool down to well below room temperature, DC operation with reverse polarity to accommodate heating and cooling in one system, and are easily optimized to minimize vibration and noise.

The units can also be customized to accommodate medical regulation standards put in place to minimize bacteria infections, surgical complications, and recovery time. All of these factors, as well as being environmentally friendly and with a low-cost of ownership, make thermoelectrics an excellent choice for medical laser applications.

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Thermoelectric Modules & Assemblies for Medical Laser Applications

Thermoelectric Assemblies (TEAs) are cooling and heating systems utilizing Thermoelectric Modules (TEMs) to transfer heat by air, liquid or conduction methods that include integrated temperature controls. TEAs remove the passive heat load generated by the ambient environment in order to stabilize the temperature of sensitive components used in medical lasers.

Thermoelectric Operation

TEAs use TEMs to dissipate heat. TEMs are solid-state heat pumps that require a heat exchanger to dissipate heat utilizing the Peltier Effect. During operation, DC current flows through the TEM to create heat transfer and a temperature differential across the ceramic surfaces, causing one side of the TEM to be cold, while the other side is hot. A single-stage TEM can achieve temperature differentials of up to 70°C and transfer heat at a rate of up to 150 watts. In order to increase the amount of heat pumping capacity, the TEM's modular design allows for the use of multiple TEMs mounted side-by-side, which is called a TE Array.

TEMs are composed of two ceramic substrates that serve as electrically insulating materials and house P-type and N-type semiconductor elements. Heat is absorbed at the cold junction by electrons as they pass from a low-energy level in the P-type element onto a higher energy level in the N-type element. At the hot junction, energy is expelled to a thermal sink as electrons move from a high-energy element to a lower-energy element.

Reversing the polarity changes the direction of heat transfer. TEMs are rated at maximum parameters (ΔT_{max}, I_{max}, V_{max}, and Q_{max}) under no load conditions, with temperature control accuracy achieving ±0.01°C under steady-state conditions. TEMs can be used as power generators and create from 1 to 2 watts of energy per TEM. They can cool to -100°C (6-stage) and pump up to 150 watts of heat, with higher heat pumping capacities achieved by wiring TEMs into an array. Their geometry can vary from 2x2 mm to 62x62 mm and are much more efficient in heating mode than resistant heaters. They also fit into tight geometric space constraints that cannot accommodate a much larger compressor-based system.

Thermoelectric Modules

Different TEMs are used to meet the thermal demands for specific applications.

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- **Standard Modules** offer reliable cooling capacity in the range from 10 to 100 watts. They have a wide product breadth that is available in numerous heat pumping capacities, geometric shapes, and input power ranges. These modules are designed for higher current and larger heat pumping applications with a maximum operating temperature of 80°C.
- **Miniature Modules** have a geometric footprint less than 13x13 mm and are used in applications that have lower cooling requirements of less than 10 watts. These modules offer several surface finishing options, such as metallization or pre-tinning to allow for soldering between TEM and mating conduction surfaces.
- **Multistage (Cascade) Modules** offer the highest temperature differential, (ΔT). Each stage is stacked one on top of another, creating a multistage module. Available in numerous temperature differentials and geometric shapes, these modules are designed for higher current and lower heat pumping applications.
- **Thermal Cycling Modules** are designed to operate in thermal cycling conditions that require reliable performance in both heating and cooling mode (reverse polarity). Thermal stresses generated in these applications will cause standard modules to fatigue over time. These modules are designed for higher current and higher heat pumping applications with a maximum operating temperature of 175°C.
- **High Power Density Modules** offer the highest heat pumping capacity within a surface area. Heat pumping densities of up to 14 W/cm^2, or twice as high as standard modules, can be achieved. The cooling capacity can range from 100 to 300 watts. TEMs are also ideal for applications that require low temperature differentials and high coefficient of performance (COP).

Thermoelectric Assembly Transfer Systems

Different TEAs are used to meet the thermal demands for specific applications.

- **Air-Air Assemblies** offer dependable, compact performance by cooling objects via convection. Heat is absorbed and dissipated by heat exchangers equipped with fans. Specifications apply to the ambient temperature and nominal voltage with tolerances ±10%.
- **Direct-Air Assemblies** offer dependable, compact performance by cooling objects via conduction. Heat is transferred through a plate, pumping the heat through the TEM and dissipating it into the air through a heat sink. Specifications apply to an ambient temperature of 32°C and nominal voltage with tolerances ±10%.

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- **Liquid-Air Assemblies** cool or heat liquids that flow through a heat exchanger. The liquid heat exchanger is designed for a recirculating system, absorbs heat and pumps it through the TEM, where it dissipates into the outside environment through an air heat sink. Specifications apply to an ambient temperature of 32°C and nominal voltage with tolerances ±10%.
- **Direct-Liquid Assemblies** cool or heat objects attached directly to the plate. Heat is dissipated into a liquid heat exchanger on the hot side. The liquid circuit is normally a recirculating type that requires a pump and additional liquid heat exchanger that dissipates heat into the ambient environment or into water. Specifications apply to the warm side liquid temperature of 32°C and nominal voltage with tolerances ±10%.
- **Liquid-Liquid Assemblies** cool or heat liquids as they pass through a heat exchanger. Heat is then transferred onto another heat exchanger on the hot side. The liquid circuit is normally a re-circulating type that requires a pump and additional liquid heat exchanger that dissipates heat into the ambient environment. Specifications apply to warm side liquid temperature of 32°C and nominal voltage with tolerances ±10%.
- **Recirculating Chillers** cool a wide range of liquid circuits and work in “closed loop” systems that contain a liquid-air assembly, pump, temperature controller, power supply and reservoir. Outlet temperature can be controlled from 2°C to 40°C to within ± 0.02°C under steady-state conditions using distilled H_2O as coolant.

Medical Laser Applications

Medical lasers are designed for use in hospitals, outpatient surgical centers, and physician offices. They combine excellent cutting, ablation, and coagulation properties for precise, virtually bloodless procedures; minimizing thermal damage to the surrounding tissue and increasing recovery time. They also sanitize the area through the heat of the laser, destroying any microbiological bodies that could lead to infection.

Although medical lasers are very proficient in many medical treatment applications, they do generate waste heat that affects the sensitive laser diodes when in operation. They also have size constraints, power consumption requirements, or noise restrictions that make thermal management difficult.

Thermoelectrics are an ideal thermal management solution used to remove excess waste heat in medical lasers by offering highly reliable cooling or heating below or above ambient through solid-state operation, low maintenance, and long service life. They keep the laser optics stable at peak performance by controlling the operating temperature of the medical laser to within

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defined parameters. Thermoelectrics also make an excellent thermal management solution due to a low cost of ownership, compact size, and can be installed in any orientation. This cannot be accomplished by any other means without a complex heating and cooling system. TEAs are utilized in the most popular medical laser applications.

One class of medical lasers using thermoelectric technology is CO^2 lasers. CO^2 lasers are the highest-power gas lasers used for cosmetic surgery, foot surgery, dermatology, and soft tissue surgery and tumor removal. They can generate up to 200 watts of waste heat that must be dissipated. Thermoelectric chillers provide precise temperature control to the laser system, keeping it at a stable temperature to within ±0.5°C for peak performance, while the ambient temperature may fluctuate by more than 10°C in a room temperature environment. This reduces the heat load on the intricate laser components, thereby improving performance by reducing system wear and expanding the lifespan of the laser.

Likewise, TEAs provide precise temperature control of YAG lasers, keeping the temperature stable to within ±0.5°C for optimal performance, while the room temperature environment may fluctuate by more than 10°C. YAG lasers use a crystal as a medium, and can generate up to 50 watts of waste heat that must be dissipated. As with other advantages, cooling the laser system results in a more precise laser beam, thereby providing tighter control of the wavelength and eliminating excess thermal damage to the surrounding tissue. YAG lasers are used in ophthalmology for correcting vision and removing cataracts, in oncology for removing skin cancers, and in cosmetic surgery for hair removal and minor vascular procedures.

At the same time, thermoelectric technology is also utilized in dye lasers in order to keep them operating at temperatures from -15°C to 45°C in an ambient temperature from -10°C to 50°C. Dye lasers use an organic dye as a medium and are tunable in the visible light spectrum. They are used in cardiology surgery by minimizing damage to the surrounding tissue, in cancer diagnosis and treatment by diagnosing and removing the cancer cells. In angioplasty, dye lasers are used to remove built up plaque on the artery wall without damaging the artery wall itself, and is also used in cosmetic surgery for minor vascular procedures. Up to 50 watts of waste heat can be generated that must be dissipated so the laser can operate at peak performance. TEAs dissipate the excess waste heat that damages the components of the laser system, especially the diodes, which reduce the operational lifespan of the laser. A reduced lifespan results in additional costs such as repairs of the components, or actually replacing the entire laser system itself.

Furthermore, excimer lasers are another medical laser application that depends on thermoelectric chillers to keep their operating temperature stable in a room temperature environment. These lasers can generate up to 100 watts in a waste heat load that must be dissipated so the laser can operate at optimal performance. This results in many factors, such as

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calibrating the laser to the specific tissue being operated on. The concentrated beam does not harm the surrounding tissue; therefore reducing the number of treatments the patient goes through. Excimer lasers use xenon chloride as a medium, and use a high powered beam in the treatment of several dermatology applications and in eye surgery.

Additionally, TEMs are used in conjunction with free electron lasers in order to keep the operating temperature of the system stable, thus enabling optimal performance. These lasers generate up to 30 watts of waste heat that must be dissipated in a room temperature environment, and dissipating the heat load properly reduces the total amount of thermal stress that is placed on the critical operating components of the laser. Proper thermal management reduces overall operational and repair costs. Free electron lasers use a relativistic electron beam as the medium and can cut soft tissues like skin, the eye cornea, and brain tissue while minimizing damage to the surrounding tissue. The laser can also melt fats without harming the overlying skin, resulting in a method of treatment for acne, as well as cellulite, body fat and fatty plaques that form in arteries.

Similarly, diode lasers incorporate TEMs for precise temperature control. These lasers use a semiconductor as a lasing medium for the treatment of cancer by using Photodynamic Therapy (PDT), a process that combines a drug with a light beam, which targets and destroys cancer cells. They also are used in the early detection of cancer cells. The lasers can also be used in ophthalmology for the treatment of macular degeneration (AMD) and diabetic retinopathy by using the laser light to coagulate the tissue and seal the blood vessels. Dental procedures incorporate diode lasers in order to reduce the amount of bacteria in the mouth, treating and / or reducing the risk of infection. Diode lasers operate in a room temperature environment and generate up to 15 watts of waste heat that must be dissipated. TEAs keep the operating temperature of these lasers to within ±0.5°C, dissipating the heat load of the system, and increasing the optimal performance of its sensitive components. This results in greater system efficiency and better laser beam control, which reduces thermal damage to the tissue surrounding the surgical area.

A final medical laser application that uses thermoelectric technology is fiber lasers. Fiber lasers use TEMs to cool the operating system of the laser, keeping its sensitive components at a stable temperature for peak performance in a room temperature environment. Fiber lasers consist of an optical fiber (fiber optic) combined with a rare-earth element to create the lasing medium. They are used in cosmetic surgery for skin rejuvenation, wrinkle smoothing, and hair removal and also in cancer treatment by targeting and destroying cancer cells, thus minimizing damage to the surrounding tissue.

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Summary

Thermal management of medical laser components and systems is now more challenging. Power densities continue to increase while product form factors continue to shrink. Simple thermal management solutions, such as adding a fan or heat sink, are no longer typically viable to meet required performance and reliability specifications. In today's complex medical operating environment, TEMs, TEAs and chillers are necessary to provide precision cooling and heating in a variety of modular platforms.

Thermoelectrics combine special benefits that make them the only effective solution for many medical laser thermal management applications by offering greater performance, higher reliability, and longer life. Their advanced capabilities are aided by new materials technology, thinner profile modules, and automated assembly.

About Laird Technologies, Inc.

Laird Technologies designs and manufactures customized, performance-critical products for wireless and other advanced electronics applications.

The company is a global market leader in the design and supply of electromagnetic interference (EMI) shielding, thermal management products, specialty metal products, signal integrity components, and antenna solutions, as well as radio frequency (RF) modules and wireless remote controls and systems.

Custom products are supplied to all sectors of the electronics industry including the handset, telecommunications, data transfer and information technology, automotive, aerospace, defense, consumer, medical, mining, railroad and industrial markets.

Laird Technologies, a unit of Laird PLC, employs over 12,000 employees in more than 49 facilities located in 16 countries.

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