Non corrosive micro coolers with matched CTE

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ABSTRACT

At Photonics West 2005 a new technology was described for building a new, non corrosive micro cooling heat sink for diode lasers made of stainless steel with the procedure of three dimensional laser melting.
Due to the thermal conductivity, which is 20 times worse than the conductivity of copper, first test leads to the result, that it is not possible to compensate the worst thermal conductivity by an optimized inner structure, regarding wall thicknesses and flow rate. So the solution was searching a different material, with a better thermal conductivity to achieve a thermal over all resistance that is usable for the cooling of high power laser diodes.
Searching that material leads to a special nickel alloy in the field of nuclear industry. The new generation of micro coolers are named TEX series. All TEX Series coolers were made out of a special nickel alloy, specially developed as a corrosion protection material. Therefore, the TEX coolers have excellent corrosion resistance. In addition, due to the manner and way of using three dimensional laser melting, the surface of the inner structure was hardened. The hardening HV1 is 380, so that there is no danger regarding erosion or a combination of erosion and corrosion.
Metallization and soldering the semi conductor also had been tested. The commonly used structure with Nickel and Gold is possible as well as the metallization only with gold. With both variations the semi conductor can be soldered and the connection to the cooler surface is very strong.

Keywords: Micro cooler, non corrosive, matched CTE, diode laser, micro channel, heat sinks, micro cooling systems, MKWS, hard solder.

1. INTRODUCTION

Micro channel heat sinks of copper material for cooling high power diode laser are state of the art. But the past showed, that there are many problems regarding leakage and decreasing cooling performance over the time. That leads very often to a breakdown of the whole laser after a few thousand hours. The reason is a combination of corrosion and erosion, due to the usage of deionised water as cooling lubricant.
The objective of the described work was to find a way, building micro channel heat sinks with lifetime over 10.000 hours. Therefore the two main problems had to be solved: corrosion and erosion.
To avoid these, the material has to be changed. But only changing the material is not successful, the manner and way of building the micro coolers has to be changed as well, to compensate the bad thermal conductivity by a more effective micro cooler design.
The first trials with alternative material to copper and the new manufacturing procedure of three dimensional laser melting were done with stainless steel, as pointed out last year at photonics west 2005. Further testing showed, that these micro channel heat sinks have not the cooling performance which is needed for cooling high power diode lasers.
So an alternative material has to be found. Searching that material leads to a special nickel alloy in the field of nuclear industry, which is used as a corrosion protecting coating for transport boxes of nuclear material.
For the testing and calculation a micro channel heat sink type was chosen with a thickness of 1,2 mm, but all the common used micro cooler types can be made as well. The micro cooler type is named TEX 12.

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2. THERMAL PROPERTIES OF TEX 12 SERIES

Due to the fact, that the metal powder properties after being laser melted were unknown, some tests regarding CTE and thermal conductivity were necessary.
The thermal conductivity was measured with the “laser-flash-method”. For this measurement a special test-part was built, a round plate with a diameter of 12,7 mm and a thickness of 2 mm. In an Argon-atmosphere the test plate is heated by a laser pulse, the temperature is measured by an infrared detector on the back side. In the range of 20°C to 100°C the thermal conductivity is nearly constant on 30W/mK. With that value the nickel alloy material is two times better regarding thermal conductivity than stainless steel, but still 13 times worse than the usually used copper.

To find out the coefficient of thermal expansion, CTE, a push rod dilatometer was used. With this method the expansion is measured mechanical during a slowly and constant heating with 3K/min. In the range of 20°C to 100°C the CTE is constant at a value of $10*10^{-6}$/K.

To find out, if it is worth to build some real micro coolers including finding new parameters for all the manufacturing steps like laser melting and the mechanical finish, some simulations regarding the cooling performance were done.

2.1 SIMULATION WITH THREE DIMENSIONAL TEX 12 MODEL

With the above measured properties first three dimensional calculations could be done. The diode laser is simulated by a planar heat source of 1,5 mm, the heat input is 90 Watt, see figure 1:

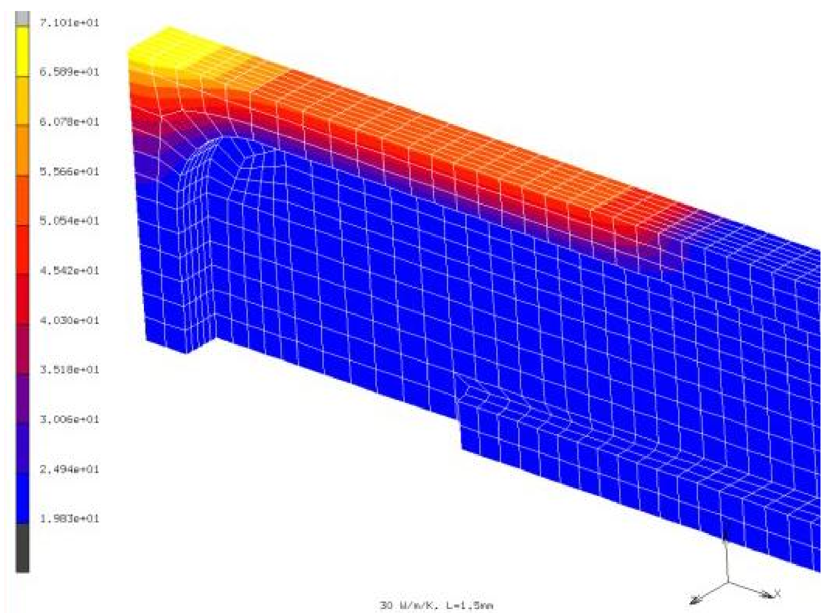

Figure 1: Calculation model for TEX 12 micro cooler with thermal load 90 Watt

Based on an inlet water temperature of 20°C the rising of temperature on the surface were the heat source is located is 45,6°C. With the thermal load of 90 Watt the thermal resistance is 0,51 K/W.
This thermal resistance is as good as the thermal resistance of common copper heat sinks, so that work could go on.

3. CONSTRUCTION OF TEX 12 MICRO COOLER

The TEX 12 series, a type of second generation micro cooling systems, is a cooler system for stack applications with a thickness of 1,2 mm.
At the beginning there was the final, due to the manufacturing process of selected laser melting, optimized inner structure. Optimized inner structure in the meaning of low pressure drop in the in- and outlet zone and a very turbulent flow in the area of micro cooling structure for a very high cooling performance, see figure 2:

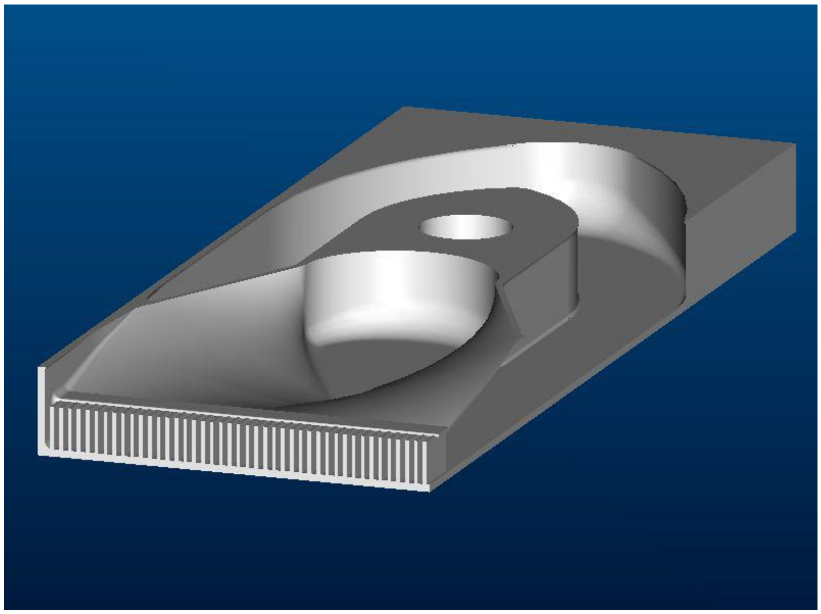

Figure 2: TEX 12 micro cooler with optimized in- and outlet structure as well as turbulent cooling structure

The new material, a special nickel alloy in the field of nuclear industry, was very difficult to process. Due to the affinity of getting porous, the building of three dimensional, sealed structures were very different to the experiences one get with the first attempts with stainless steel[1]. Using the same parameters as with stainless steel, the building process of the coolers leads to a serious problems regarding the inner structure: The flow rate of the new cooler was much to low. Investigating the reasons for that, some of the new coolers were opened and the inner structure was analysed. The result was without any doubt: the thicknesses of the micro structures are too big and the space between the structures is much to small, the flow was blocked with melted material, see figure 3:

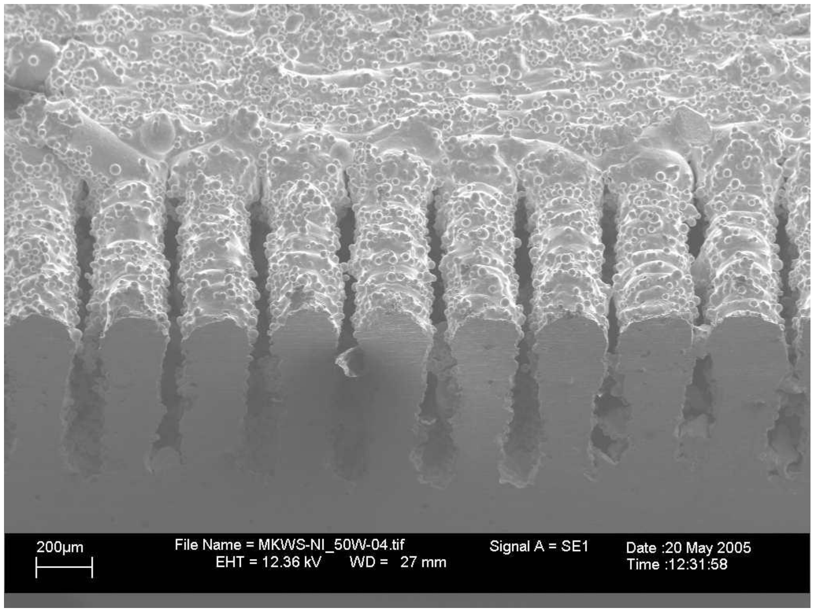

Figure 3: Micro cooling structures made with “old” parameters

The space between the cooling structures was to small due to the laser parameters, fitted to the material of stainless steel. The new material requires at completely different set of parameters. Adjusting the whole machine again, take in account the different material properties, leads to a set of better parameters. With these new, fitted to material parameters, some new micro cooler were build and the success is obvious: the cooling structures are not blocked at the inside, see figure 4:

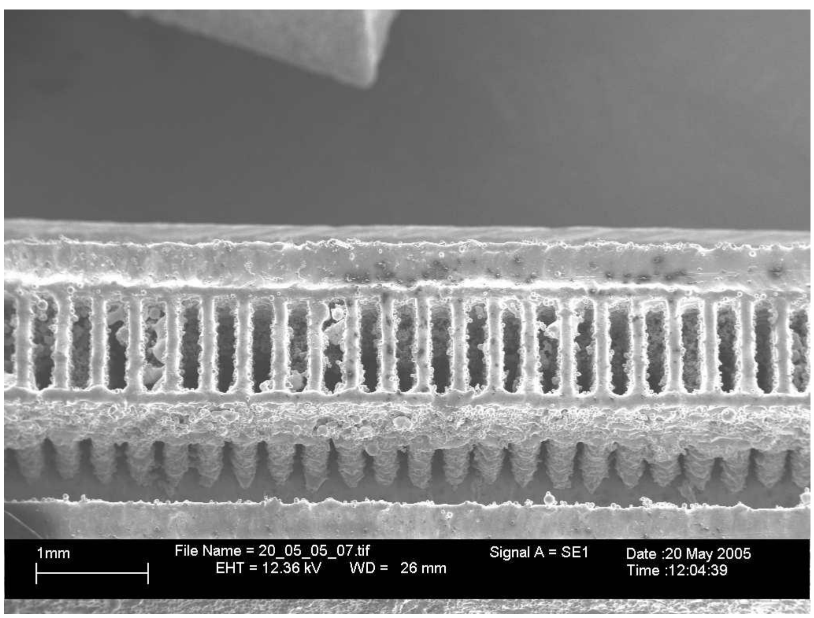

Figure 4: Micro cooling structures made with “fitted to material” parameters

Due to the new parameters of manufacturing the second generation of micro channel heat sinks, the flow rate is now on the level which was expected for a successful cooling performance.
The flow rate of the coolers were measured using differential pressure drop of 1,5 bar, having a flow rate of 1.000 ml/min with a very small deviation from cooler to cooler, figure 5:

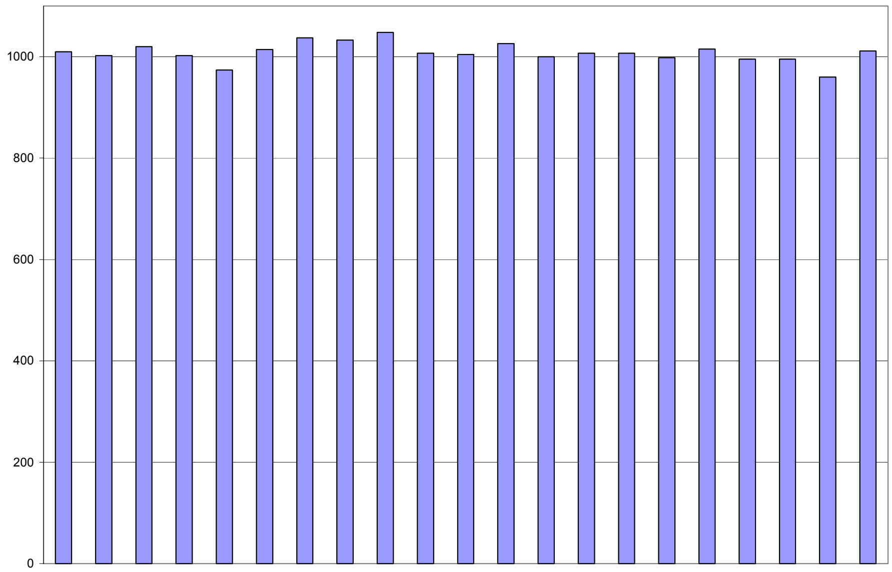

Figure 5: Flow rate in ml/min of 20 micro coolers Type TEX 12 at a pressure drop of 1,5 bar

MEASURING

After finishing the surface the coolers will be metallized. Due to the nickel alloy material a coating with nickel is not necessary. A couple of soldering tests showed, that the metallization with gold can be made directly on the coolers surface with very good results. So the laser bar was mounted on a cooler only coated with a thin gold layer.
The following test were made with a diode bar with a footprint of 1,5 mm by 10 mm. The water temperature on the inlet side is 20°C. The short pulse wavelength of the diode bar at 20°C is 928,10 nm, the rising of wavelength is 0,270 nm per K. Figure 6 shows the rising of wavelength with increasing thermal load:

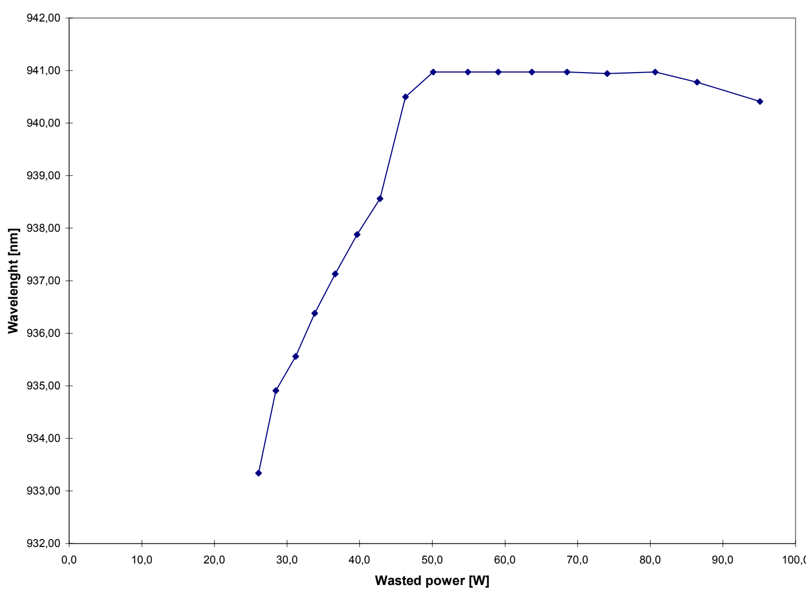

Figure 6: Measured drift of wavelength

The difference between the shortpulse wavelength and wavelength at maximum power is 12,31 nm. With the known drift of 0,27 nm / K the rise in temperature is 45,6°C. That leads to a thermal resistance of 0,48 K/W.
This result is a little bit better than the calculated one, that means the parameters of the three dimensional model, specially the coefficient of heat transfer from material to water, was not totally correct. For the next calculations this parameter was fitted to the measurement.

CTE MATCHING

The coefficient of thermal expansion of the nickel alloy is $10*10^{-6}$/K. This value is much better than the CTE of copper, $17*10^{-6}$/K, but it is still far away from the CTE of GaAs, which is $6,5*10^{-6}$/K. For using hard solder the CTE of the cooler and diode laser has to be matched. For that, in the area where the semi conductor chip will be mounted, a material will be used with a CTE much lower than GaAs. Due to the very small thickness of this layer, the CTEs of layer and cooler material will be mixed to a matched CTE of GaAs. This method was already shown successful in the past with copper heatsinks during the authors thesis for his PhD[2], see figure 7:

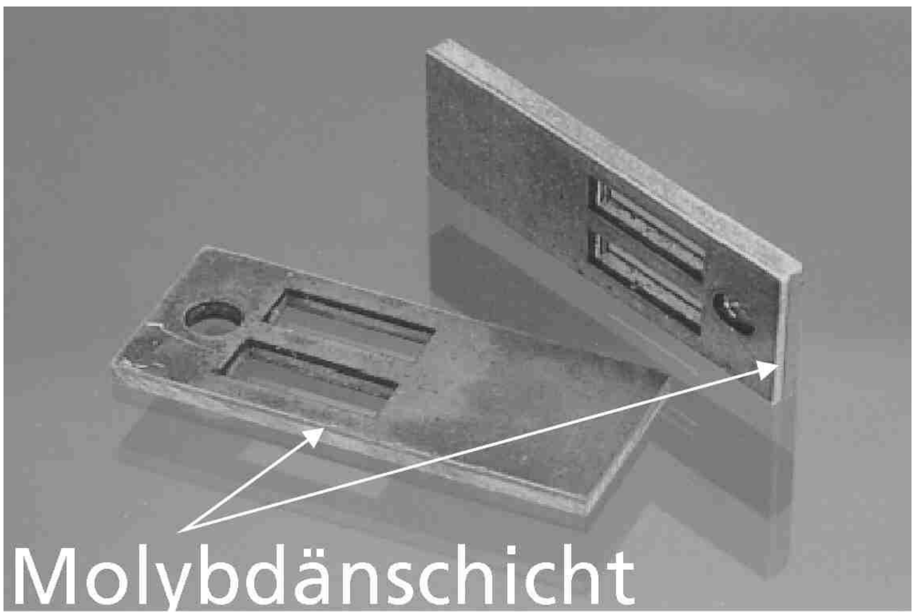

Figure 7: Copper heat sinks with matched CTE

The additional materials thermal conductivity is worse than the conductivity of the nickel alloy. Although the thickness of the additional material is in the range of a few microns, this layer will block the flow of heat on its way to the cooling structures. Therefore a higher thermal resistance is expected. Due to the fact, that the measured thermal resistance of the nickel alloy cooler is already on the bottom end of the range which leads to a good cooling performance, at first the cooling performance has to be improved. To achieve this point, the alloy was changed, with the result of a much better thermal conductivity, see figure 8:

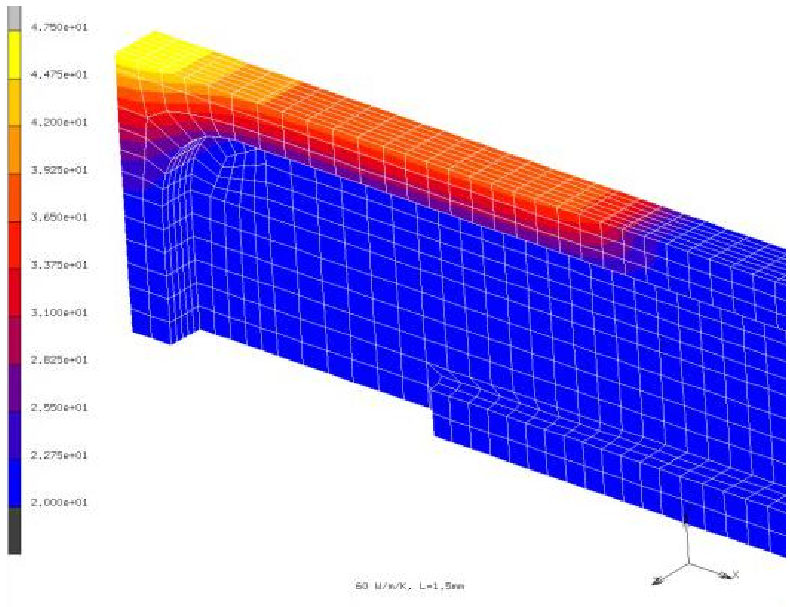

Figure 8: Calculation model for TEX 12 micro cooler with thermal load 80 Watt

This time for the calculation the coefficient of heat transfer was used like it was measured as described before. The length of the diode bar is 1,5 mm again, but the thermal load was reduced to 80 Watt. The rising in temperature was reduced to 27,5°C, that leads to a thermal resistance of 0,34 K/W.
Adding now the material with the lower CTE and worse conductivity leads to a thermal resistance of 0,46 K/W again, but the CTE which was calculated is $6{,}9 \cdot 10^{-6}$/K.

CONCLUSION

The presented work showed, that it is possible to create micro channel heat sinks by using a non corrosive material. Optimizing the coolers structure leads to thermal resistance of 0,34 K/W. Due to the special manufacturing procedure the inner structure is hardened, so there is no danger regarding erosion by the high flow rate of about 1000ml/min.
With the three dimensional laser melting it is possible to add thin layers of additional material in the area were the semiconductor will be mounted, to achieve a matched CTE to GaAs for using hard solder.
The results, achieved with the cooler type TEX 12, must be transferred in the near future to the cooler design which is already used by the customers. There is still some work to do regarding the CTE matching, but the problems with the corrosion of micro channel heatsinks is solved.

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