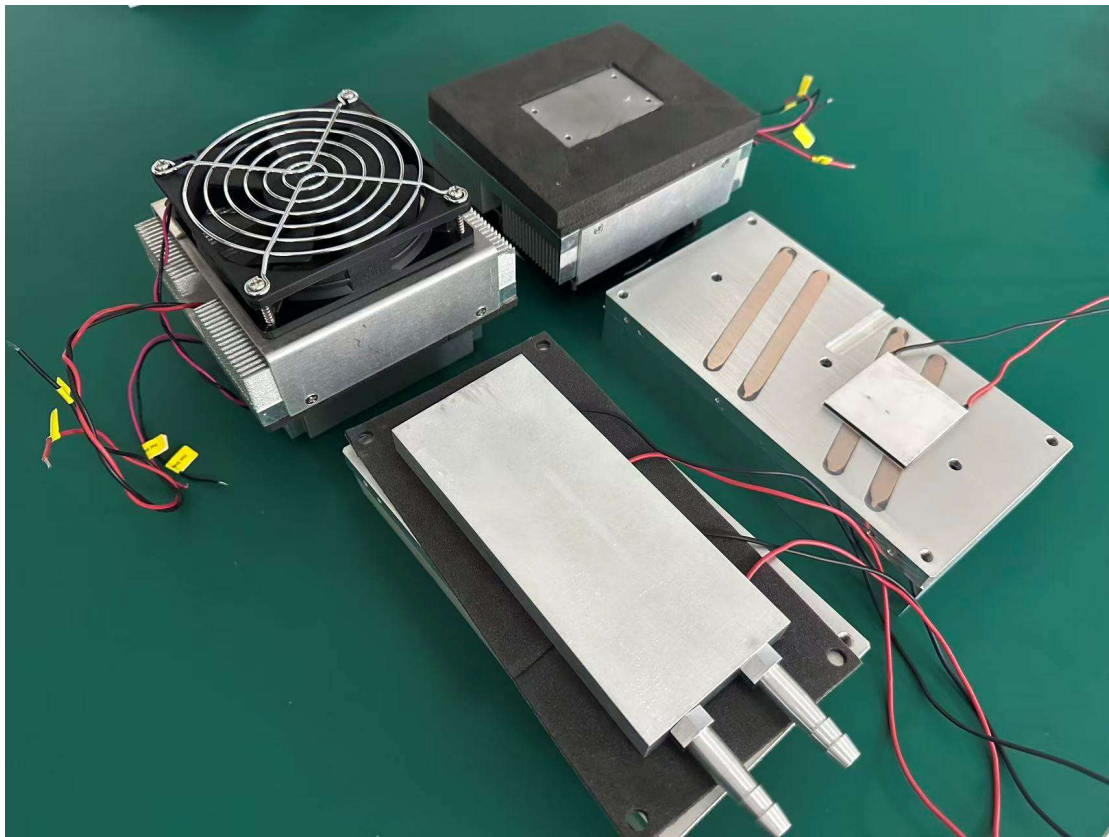


Guide to Thermal Grease in TEC Refrigeration: Coating Thickness and Thermal Conductivity Optimization



1. Abstract

In thermoelectric cooler (TEC) semiconductor refrigeration systems, the interfacial thermal resistance between the chip and the heat dissipation structure is a core hidden factor restricting overall cooling efficiency. Most equipment failures such as insufficient cooling temperature difference and excessive steady-state attenuation stem from mismatched thermal media and improper construction processes, rather than defects in chips or heat dissipation hardware. This paper focuses on the practical application value of thermal grease in TEC systems, deeply analyzing the influence of thermal conductivity parameters, coating thickness and material quality on interfacial thermal resistance, cold and hot end temperature difference, and long-

term temperature control stability. Combined with ZICOTEC's batch test data and field engineering experience, this paper verifies the thermal resistance variation law of different coating thicknesses through controlled variable experiments, summarizes the cooling power loss mechanism caused by inferior thermal materials, puts forward targeted material selection standards for high and low-temperature working conditions, and forms a fully implementable standardized coating process. It provides a complete practical reference for mass production assembly, after-sales commissioning and performance optimization of TEC equipment.

Keywords: thermal grease for TEC, TEC thermal conductivity optimization

Meta Description: Master ZICOTEC TEC thermal grease coating thickness and parameters to reduce thermal resistance and boost cooling efficiency.

2. Thermal Conduction Principle and Core Parameters of Thermal Grease

The contact surfaces between TEC ceramic substrates, heat sinks, water cooling plates and heat pipe modules appear smooth visually but contain numerous micro uneven gaps at the microscopic level. These gaps are filled with air, which has extremely low thermal conductivity and causes high interfacial contact thermal resistance, seriously hindering heat transfer from the TEC hot end. As a flexible thermal medium filled between two solid contact surfaces, thermal grease replaces air to fill microscopic gaps, eliminates contact thermal resistance, and builds a continuous and stable heat transfer channel. It serves as a key auxiliary material connecting TEC chips and heat dissipation structures to maximize the refrigeration performance of the entire system.

Unlike ordinary electronic thermal grease, products optimized for TEC refrigeration conditions determine the upper operating limit of refrigeration systems, with two core parameters prioritized in practical industrial applications. The first is thermal conductivity, measured in $W/(m \cdot K)$. A higher thermal conductivity value means faster heat transfer and lower interfacial heat loss. Civil-grade thermal grease usually ranges from 1.5 to 3.0 $W/(m \cdot K)$, while industrial high-conductivity grease reaches 4.0 to 8.0 $W/(m \cdot K)$, suitable for high-load and high-power TEC operating scenarios. The second is thixotropy and consistency, which directly affect coating uniformity and thickness. Overly thin grease tends to flow and accumulate, while overly thick grease easily causes uneven coating and air bubbles, both leading to excessive local thermal resistance.

In addition, temperature resistance, insulation performance and non-oil-precipitation characteristics are essential indicators. TEC equipment features frequent cold and hot alternation and drastic temperature changes. Ordinary inferior grease is prone to drying, oil precipitation and pulverization after long-term operation, resulting in a sharp rise in interfacial thermal resistance. According to ZICOTEC's long-term thermal management project statistics, most TEC cooling attenuation failures after six months of operation are caused by thermal medium aging rather than heat dissipation structure degradation, proving the necessity of adopting TEC-specific

high-quality thermal grease.

3. Experiment on the Influence of Coating Thickness on Thermal Resistance

A common industry misconception is that thicker thermal grease delivers better heat dissipation. In fact, the relationship between grease thickness and interfacial thermal resistance is non-linear. An insufficiently thin coating fails to fill micro gaps, while an excessively thick coating forms a thermal insulation layer and aggravates heat accumulation. To determine the optimal coating thickness for TEC equipment, ZICOTEC built a unified experimental platform with identical TEC12706 chips, standard micro-channel water cooling systems, 12V regulated power supply and a constant ambient temperature of 25°C. Only the thermal grease coating thickness was adjusted to test steady-state interfacial thermal resistance and cooling temperature difference changes.

Four experimental groups were set up: no grease coating, ultra-thin coating of 0.03mm, standard coating of 0.1mm, and thick coating of 0.3mm. The test results show that the uncoated group suffered severe heat accumulation, with interfacial thermal resistance reaching 1.87°C/W and a steady-state cooling temperature difference of only 28°C. The 0.03mm ultra-thin coating failed to fully fill micro gaps and retained partial air interlayers, with thermal resistance of 0.92°C/W and a temperature difference of 34°C, showing limited performance improvement. The uniform 0.1mm coating completely filled gaps without redundant accumulation, reducing thermal resistance to 0.35°C/W and achieving a maximum steady-state temperature difference of 42°C with full release of cooling performance. When the thickness increased to 0.3mm, the inherent thermal resistance of the grease became prominent, raising the overall thermal resistance to 0.78°C/W and reducing the temperature difference to 36°C with obvious performance attenuation.

Repeated variable tests verify a clear conclusion: TEC thermal grease has an optimal thickness range. **0.08~0.12mm** is the golden coating thickness applicable to most TEC chips. Thinner coatings cause incomplete gap filling and high contact thermal resistance, while thicker coatings form a thermal barrier that offsets the advantages of high-performance heat dissipation structures. This explains why many TEC devices with high-end heat dissipation hardware fail to achieve expected cooling effects.

4. Refrigeration Losses Caused by Inferior Thermal Media

Low-cost universal thermal grease on the market adopts simplified formulas and mixed fillers without targeted optimization for TEC's frequent cold-hot alternation, high-frequency start-stop and long-term constant-temperature operating characteristics. Although performance differences are negligible in short-term use, inferior media cause continuous refrigeration losses in long-term operation, seriously

undermining equipment stability and service life, and becoming a easily overlooked hidden failure source.

First, inferior media lead to continuously rising dynamic thermal resistance. With low thermal conductivity and uneven filler particles, such grease cannot form a uniform heat conduction layer. During TEC operation, the thermal expansion and contraction caused by frequent temperature changes crack and delaminate the grease layer, forming internal voids. The interfacial thermal resistance increases gradually over time, resulting in normal initial cooling performance but continuous temperature difference attenuation after 1 to 3 months of operation.

Second, oil precipitation and drying cause complete medium failure. Ordinary grease with unstable silicone oil content tends to seep and flow under high temperatures, leading to thinning and peeling of the coating layer. It also pulverizes and hardens in low-temperature environments, completely losing its gap-filling function. According to ZICOTEC after-sales fault statistics, nearly 30% of TEC cooling attenuation and chip overheating failures are caused by thermal grease aging, drying and peeling, rather than chip or heat dissipation structure faults.

Third, uneven coating and local voids cause hotspot overheating and permanent chip damage. Localized high-temperature hotspots generate severe thermal stress on the TEC chip. Long-term repeated cold and hot shocks induce fatigue of internal thermoelectric grains and micro-cracks on ceramic substrates, which not only reduce cooling efficiency but also shorten chip service life, and may even cause breakdown and burnout in severe cases.

5. Selection of Special Thermal Materials for High and Low Temperatures

TEC equipment covers a wide range of application scenarios. Normal-temperature civilian, high-temperature industrial and low-temperature cold chain environments impose completely different requirements on the temperature resistance and stability of thermal grease. A single universal grease cannot meet all working conditions. Targeted material selection matched with ZICOTEC heat dissipation modules can maximize the overall system performance.

For conventional normal-temperature working conditions (0°C~45°C), mid-to-high-end universal thermal grease with a thermal conductivity of 3.0~4.0 W/(m·K) is recommended. This material features high cost performance and anti-drying performance, suitable for civilian refrigeration boxes, small temperature control modules and ordinary embedded refrigeration equipment. It meets the heat dissipation demands of intermittent and conventional-load operation and is ideal for mass production.

For high-temperature industrial scenarios (long-term operation above 50°C and full-load continuous working), high-temperature and non-precipitation specialized thermal grease is mandatory. Industrial-grade media with thermal conductivity ≥ 6.0 W/(m·K) and a temperature resistance range of -20°C~180°C are preferred. Adopting stable

inorganic fillers, this grease avoids oil precipitation, flowing and aging under high temperatures, maintaining low interfacial thermal resistance for a long time. It perfectly matches ZICOTEC micro-channel water cooling plates and heat pipe heat dissipation modules, supporting 24-hour full-load stable operation of high-power TEC chips.

For low-temperature cold chain and ultra-low-temperature temperature control scenarios (below 0°C), low-temperature anti-hardening thermal grease is required. Ordinary grease hardens and embrittles at low temperatures, losing fitting performance and causing a sharp increase in contact thermal resistance. In contrast, low-temperature specialized grease maintains excellent low-temperature flexibility and stable interface fitting, ensuring reliable temperature control accuracy and stability for TEC equipment in low-temperature environments.

6. Conclusion: Standardized Thermal Grease Coating Process

Based on principle analysis, measured data and rich field engineering experience, ZICOTEC has summarized a set of standardized thermal grease coating processes suitable for mass production assembly and after-sales commissioning to eliminate TEC cooling attenuation and poor heat dissipation caused by improper thermal medium application. Full-process specifications covering material selection, surface pretreatment, coating operation and re-inspection minimize interfacial thermal resistance and maximize cooling performance.

First, standardized material selection. Match thermal grease according to actual working conditions: 3.0~4.0 W/(m·K) grease for normal-temperature conventional scenarios, ≥ 6.0 W/(m·K) high-temperature resistant grease for 24-hour continuous industrial operation, and anti-hardening grease for low-temperature scenarios. Inferior universal grease is prohibited for formal assembly.

Second, standardized substrate pretreatment. Wipe TEC ceramic substrates and heat dissipation contact surfaces with dust-free cloths before coating to completely remove dust, oil stains and residual old grease, ensuring flat and clean contact surfaces to avoid excessive local thermal resistance caused by impurities.

Third, standardized coating thickness control. Strictly control the coating thickness within the golden range of 0.08~0.12mm. Adopt a combined dot coating and scraping method to form a thin, uniform and full coating without accumulation, air bubbles or missing areas, avoiding thermal insulation caused by over-coating and incomplete filling caused by under-coating.

Fourth, standardized assembly and pressure application. Fit the chip and heat dissipation structure smoothly after coating, and tighten fixing screws evenly to ensure uniform stress on the contact surface. Avoid grease offset and uneven thickness caused by unilateral stress, and do not displace or pry the assembled structure to prevent air interlayer generation.

In summary, thermal grease is the most easily overlooked yet performance-critical

medium in TEC refrigeration systems. Reasonable thermal conductivity selection and standardized coating processes, combined with ZICOTEC's professional thermal management solutions, can effectively reduce interfacial thermal resistance, eliminate common problems such as cooling drift, temperature difference attenuation and local heat accumulation, and comprehensively improve the temperature control accuracy and long-term operational stability of TEC equipment.

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