INTERNATIONAL MOLYBDENUM ASSOCIATION
THE VOICE OF THE MOLYBDENUM INDUSTRY

Keeping it cool

Molybdenum heat sinks are essential to power semiconductor devices that manage the flow of electricity in electronic equipment because they prevent overheating. Molybdenum's good thermal and electrical conductivity, combined with its low coefficient of thermal expansion, make it the ideal material for this application.

A modern, well-functioning infrastructure requires a reliable electric power supply. This is extremely important because of the high cost of downtime and unexpected shutdowns. At every step along the way, from generating electricity at huge electric power plants, to controlling power distribution, and operating machines and appliances, molybdenum heat sinks assure the reliability of all electrical systems.

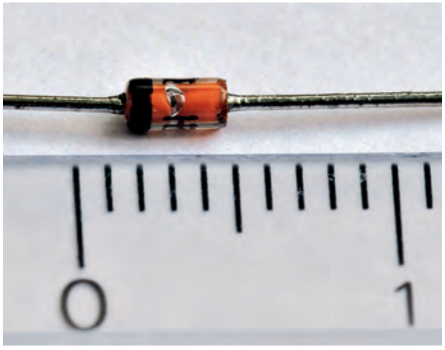
Semiconductors and power

The electric power flowing through any electrical device, large or small, needs to be controlled, modulated, and dispensed within the system. A simple low-power example is the tiny silicon diode. There are four in each rectifier bridge found in many small home appliances. Such a bridge might handle currents of less than an amp. The diodes and heat sinks in these bridges are very small, perhaps only a few tenths of a millimeter in diameter and thickness. At the other end of the power spectrum are devices that allow the precise operation of large industrial motors and power distribution systems. They can be built using either traditional monolithic silicon-based semiconductors or sophisticated integrated circuits created on specialty ceramic substrates. They must deal with electrical currents in the order of hundreds of amps. The heat sinks for monolithic devices can be up to 100 mm in diameter and 2–3 mm thick, which in the power semiconductor world is quite large.

No matter what the design, all devices are fragile. Silicon and ceramic materials are brittle and can easily fracture and fail if they are subjected to high stresses or impact. Electrical current passing through a device creates heat that can be catastrophic to semiconductors. Heat must, therefore, be dissipated so that the devices do not lose their electrical properties during service and so that thermal stresses, which can lead to mechanical failure of the device, are minimized. Regardless of the semiconductor's size, molybdenum heat sinks help to remove heat from the system.

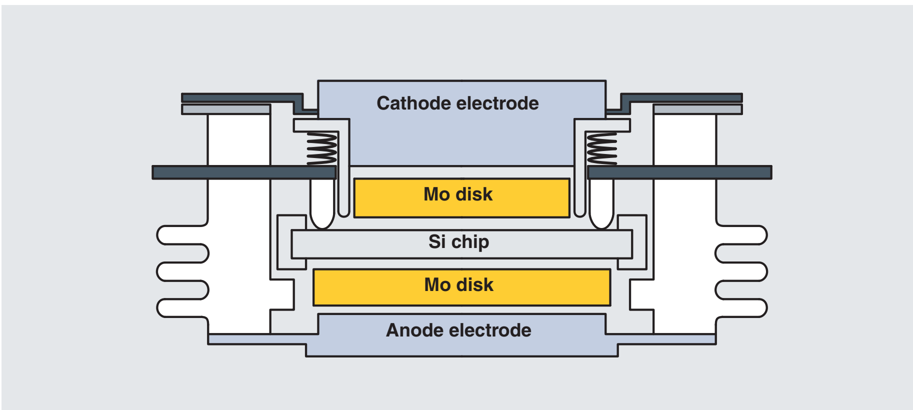
Molybdenum is the material of choice

A good heat sink material for these applications needs more than just a high coefficient of thermal conductivity. It must also be a good electrical conductor because electricity to and from the device has to pass through it. Because the heat sink is brazed to the device in order to provide the best possible electrical and thermal contact, it must expand and contract on heating and cooling at a rate similar to that of the device. A large disparity may cause the device to crack and fail. Meeting these criteria – high thermal conductivity, high electrical conductivity, low coefficient of thermal expansion (CTE), and reasonable cost – requires a balance to obtain the most reliable overall component design.



A typical Zener diode containing a tiny silicon semiconductor sandwiched between two molybdenum metal heat sinks. © Medvedev/CC-BY-SA-3.0 (http://creativecommons.org/licences/by-s/3.0/deed.en)

Molybdenum provides the optimal combination of physical properties at an acceptable cost. For this reason, it was the material of choice in the first power semiconductor designs of the early 1950s, and remains so today. Despite their good electrical and thermal conductivity, copper and aluminum are not suitable alternatives. ›



Schematic drawing of a gate-communicated thyristor (GCT) power semiconductor, showing molybdenum metal heat sinks. Source: Powerex

They expand at much higher rates than silicon and would pull the device apart during operation causing premature failure. (see table)

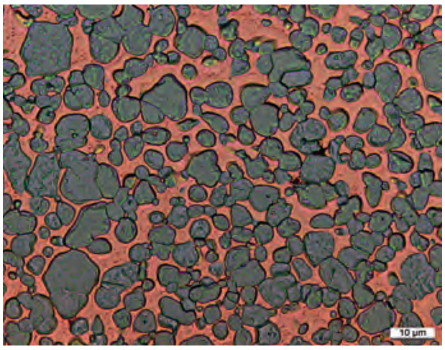
An added benefit of molybdenum is an elastic modulus nearly twice that of steel, which enables it to provide a rigid support for the semiconductor, limiting the possibility of damage due to physical abuse. This unique set of properties has made molybdenum indispensable to the power semiconductor industry.

Railway locomotives have reliable and long-lasting power control and distribution. © Shutterstock.com/mdgn

Molybdenum and copper: an even more powerful combination

Semiconductor designs evolve rapidly, and power devices now use sophisticated integrated circuits built on specialty ceramic substrates. These devices produce more highly concentrated regions of heat, causing greater challenges for the package designer. Furthermore, ceramic substrates expand more than silicon. Pure molybdenum metal has some disadvantage in these designs because its CTE is lower than that of the ceramic substrates.

Overcoming this disadvantage requires an engineered composite: By creating a molybdenum skeleton whose voids are filled with copper (see photo), materials engineers have produced a heat sink with higher thermal and electrical conductivity than pure molybdenum, along with the higher CTE required.



Composite molybdenum-copper materials further enhance the already excellent properties of molybdenum metal heat sinks. © Plansee SE

Comparing physical properties of semiconductor and heat sink materials at 20°C.

Material	CTE (ppm/°C)	Thermal conductivity (W/mK)
Selected semiconductors (S) and ceramic (C) substrates		
Si (S)	2.8 [a]	150
Al_2O_3 (C)	6.7	21
BeO (C)	8.0	275
AlN (C)	4.5	250
Selected potential heat sink materials		
Mo	5.0	140
Cu	16.9	398
Al	23.0	240
Kovar® (Fe30 Ni)	5.3	17
Mo-30 Cu [b]	7.1	205
Mo-40 Cu [b]	8.7	215

Source: NIST, except **a** (C. A. Swenson) and **b** (Plansee SE)

A world of applications

Power semiconductors are everywhere. Electric power generation, whether from fossil fuel, nuclear, solar or wind energy, requires high-power semiconductor devices to manage and distribute the power they create. These devices rely on molybdenum heat sinks, as do all kinds of industrial motors, electric trains and buses, and diesel-electric locomotives. Hybrid vehicles use molybdenum-copper composites in their power management and distribution systems. Even the lowly electric hair dryer needs tiny molybdenum heat sinks to operate reliably. Molybdenum helps to ensure dependable, affordable electrical power wherever it is used. (John Shields)