Thermal Conductivity

A while ago I was talking about a new heatsink concept I was toying with. The basic design called for a solid copper construction of base and fins. I was asked why copper, and not say, aluminum? Explaining that while aluminum was the standard in heatsinks, copper just had a better thermal conductivity. The eternal "why" popped up, and I managed to avoid a full explanation with a passing 'it transfers more heat'. That 'why' got me to thinking however.

With all the effort that goes into keeping processors cool, how many of us really know why copper suddenly improves the cooling ability (not to mention the marketability) of a heatsink?

Before moving into a full explanation, it might be useful to see a range of thermal conductivities for a variety of materials.

	conductivity	density
Material	**W/m*K**	**g/cm(3)**
Aluminum	247	2.71
Aluminum (6061)	171	2.6-2.9
Aluminum (6063)	193	2.6-2.9
Aluminum (7075-T6)	130	2.6-2.9
Brass (70Cu-30Zn)	115	n/a
Copper	398	8.94
Gold	315	19.32
Magnesium	170	1.74
Magnesium alloy ZK60A	117	1.74-1.87
Silver	428	10.49
Tungsten	178	19.3
Zinc	113	7.13
Diamond	2500	3.51
Graphite	25-470	1.3-1.95
Silicon	141	2.33
Epoxy	0.19	1.11-1.4
Anodize coating	7	n/a
Air (not moving)	0.026	n/a
Mica	0.7	n/a
Berquist sil-pad 2000	3.5	n/a
Berquist sil-pad k-10	1.3	n/a
Berquist sil-pad 400	0.9	n/a
Grey thermal compound (AOS52031)	2.51	n/a
White thermal compound (AOS52022)	0.7	n/a
Solder (63Sn-37Pb)	50	n/a

Next to silver, copper is king. Silver would be the ideal material for ultra efficient heatsinks, but is cost prohibitive. Copper offers the next best solution, at a fraction of the cost. Aluminum is a far third as far as thermal conductivity goes (not including gold), but makes up for those downsides with less cost, and lighter weights. From a manufacturing perspective, aluminum is also much easier to work with.

Thermal conductivity explained.

Thermal conductivity itself deals with the transportation of heat from higher to lower temperature regions. How that transportation occurs is via a mechanism of internal atomic vibrations. In fact, the total thermal conductivity of a material is the summation of these phonons (vibrational waves within the materials' lattice) and by the movement of free electrons. Each effect contributes to the rate at which heat energy moves. Generally either free electrons or phonons predominate in the system.

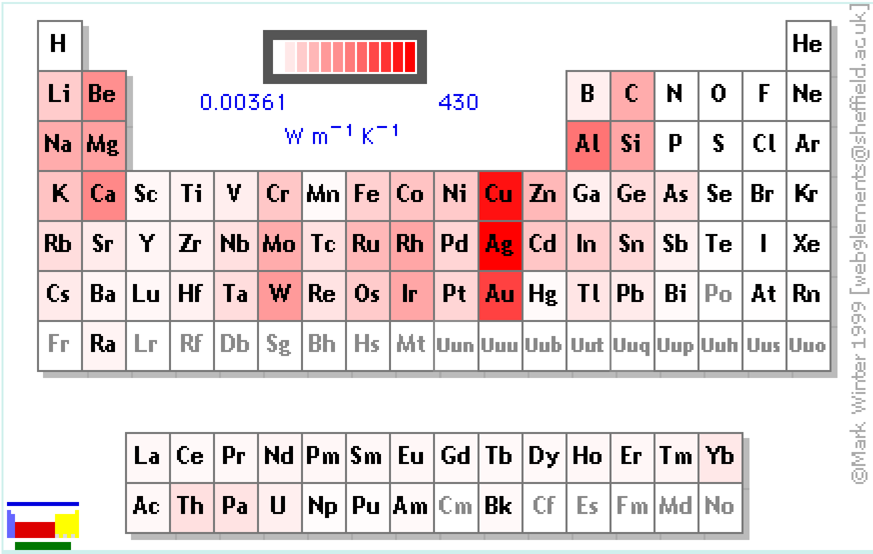
Phonons:

By virtue of the crystalline structures which form the basis for all solid materials, atoms excited into higher vibrational frequency impart vibrations into adjacent atoms via atomic bonds. This coupling creates waves which travel through the lattice structure of a material. A good example would be waves traveling through the ocean. In solid materials these lattice waves, or phonons, travel at the velocity of sound. During thermal conduction it is these waves which aid in the transport of energy.

Free electrons residing in the hot area of the material pick up heat energy, which is in the form of kinetic energy. Migration of the free electrons to cooler areas results in some of this kinetic energy being imparted on the surrounding lattice, or individual free electrons. Transference of this kinetic energy (in the form of vibrations) comes about by collision with other electrons, or the lattice structure in general.

For the metals most often used for heatsinks, it is the migration of heat across a thermal gradient via the movement of free electrons which is most prevalent. Considering highly electrically conductivity metals, a correlation becomes quite obvious that there is a larger number of free electrons to take part in thermal conduction. Therefore those types of metals are typically more thermally conductive, then say ceramics, where less efficient phonon conduction would be prevalent.

While this does stray from our point somewhat, it is interesting to note that there is a correlation between high thermal conductivity and the electrical conductivity of a metal.



This image from www.webelements.com shows the elements with the highest thermal conductivity, indicated by the intensity of red colouring.

So what does all this mean? It means that heat energy from a processor die causes a variety of reactions on the atomic level within a heatsinks' material. Depending on what that heatsink is made of, it will have more or less resistance to moving that heat away to the surrounding air mass. Understanding why metals are thermally conductive will hopefully explain a little bit about why copper is better then aluminum in this regard.

Sources: M*aterials Science and Engineering 4th Ed*, William D. Callister, Wiley Publishing 1997.