Advanced Topic: Filament Material

As is evident from Fig. 1, is desirable that the filament (blackbody) temperature be as hot as possible for two reasons. First, the amount of visible light emitted per unit of energy consumed is higher; in other words, the light is cheaper. Second, the color of the light is nearer to that of the sun, which is approximately a 6100 K blackbody, shown as the daylight curve in Fig. 2. The choice of materials that can operate at very high temperatures is limited: electric lamp filaments have been made from the following materials.

Filament Material	Melting Point (C)
Platinum	1773
Osmium	2700
Tantalum	2900
Tungsten	3380
Carbon	3600

Edison used platinum as the filament in his early lamp experiments. (Actually, he used a zirconium oxide coated platinum wire, with the zirconium oxide coating preventing the oxidation of the platinum.) However, he switched to carbon filaments due to the high cost, short lifetime and low light output of the platinum filament. In 1879, he produced a carbon filament lamp that remained lit for over 40 hours.

It is not practical to operate any filament at temperatures approaching its melting point, due to the high rate of evaporation at these temperatures. When evaporation occurs as a result of operating at high temperature, not only does the filament become thinner, resulting eventually in failure, but the evaporated material settles on the inside of the lamp causing it to darken. This deposit absorbs some of the light and, as it increases in thickness, the efficiency of the lamp decreases. Although the melting point of the carbon filament is very high, the rate of evaporation is so great that it cannot be operated at temperatures in excess of about 1850 C, where its efficiency is fairly low. The useful life of this type of lamp was more often terminated by excessive darkening of the bulb than by filament failure.

Tungsten increasingly was recognized as an ideal metal for a filament, but it was difficult to fabricate into fine wires. In 1910, Dr. William Coolidge announced that he had developed a commercial process for producing fine wires of tungsten. The Coolidge process is still used to produce today's tungsten wire filaments for incandescent lamps. These filaments operate at temperatures of about 2700 C. If the lamp operated at higher temperatures, it would give off more light and produce light more efficiently, but it would burn out sooner due to the higher evaporation rate of the tungsten at the higher temperature. Thus, filament design is a tradeoff between bulb lifetime and light output.

The filament wire must be very uniform in diameter. Since the same amount of current passes along its entire length, any thin spot will be hotter because of its higher resistance, as can be seen from equation 4. At such a hot spot increased evaporation will occur, leading to further thinning and hence higher resistance and still higher temperature. This effect leads to rapid failure of the filament: if the filament diameter at any point is only 1% less than specified, the lamp life may be reduced by 25 %.

The lamp designer must be aware that the resistance of metals generally increases with increasing temperature. Indeed, the filament resistance at the operating temperature is typically 15 times greater than its room temperature value. For a 100 W lamp filament, the typical resistance is about 9.6 ohms when at room temperature (so I=12.5 Amps) and 144 ohms at the operating temperature (where I=0.83 Amps). This leads to a large "inrush" current when the lamp is turned on, which must be accounted for by the designer.

As noted above, as the lamp operates, filament material evaporates and deposits on the inside of the bulb, darkening it and reducing its light output. Since the filament material is evaporating, the diameter of the filament decreases, increasing the filament resistance. It is interesting to point out that if the filament operates on constant current instead of constant voltage, the power dissipated in the lamp will increase ($P=I^2R$), so that the light output will increase over the lifetime of the lamp. This light output increase roughly counteracts the decrease in light output due to bulb blackening due to evaporation of filament material on the inside wall of the bulb, leading to a relatively constant light output over the life of the bulb. Many street lights operate on constant current.