Solution: Exercise 2

You have to produce the electron beam of 1 mA and having the energy of 1 keV. For this alone the power of 1 W is required (1 kV x 1 mA = 1 W). Consequently, there is only a minimum amount of power available in order to emit the electrons from the material. Possible emission concepts are: 1) thermionic emission, 2) field emission, 3) photon-induced emission and 4) secondary electron emission. Lets consider these methods:

1) Thermal emission: In order to have thermal emission the filament needs to be heated. As was mentioned above the beam production alone needs the power of 1 W – consequently less than 0.5 W is available for the heating (remember also that the efficiency of power supply is not 100 %!). With the aid of Richardson-Dushman equation the emission density as a function of temperature can be estimated for different materials (please see lectures: Part 1). Lets choose first Ta filament having the surface area of 1 cm^2. In other words the current density of 1 mA/cm2 is needed. Using the afore-mentioned equation the temperature of 1835 K is required. The heat radiation losses at this temperature are $P_{\text{heat losses}}$= 5.67 x 10-8 AεT4 where A is the area of hot surface, ε its emissivity and T temperature. At 2000 K the emissivity of Ta is about 0.2. This gives the radiation power of about 13 W for our filament. This means that the power of at least 13 W + 1W is needed in the case of Ta filament. Using other filament material, Ba on W, the heat radiation losses of about 0.8 W can be expected (by assuming the emissivity of 0.2). In this case the total power would be 1.8 W if 100 % efficiency is expected. We may conclude that using the thermal electron emission we cannot meet the requirement of 1.5 W.
2) Field emission: This method is so called cold cathode method, which means that no heating is needed. In this case the electrons are emitted with the aid of strong electric field (see lectures: Part 1). In this case the voltage of 1 kV can be used to generate the adequate electric field between the cathode and anode. By assuming the efficiency of 100 % the beam can be produced by 1 W.
3) Photon-induced method: In this case the electron is emitted from the material by giving the required energy to electron by photon (see lectures: Part 1). The quantum efficiency is fairly low at the photon energy just exceeding the work function of material (efficiency of the order of 1/1000). The efficiency may be of the order of 10-20 % using the photon energies of the order of 20 eV. Using this method we should first produce photons. Lest assume the photon energy of 20 eV and efficiency of 10 %. In order to produce 1 mA of photon induced emission we need the total photon beam power of 10 x 20 eV x 1 mA = 0.2 W. At this point we need 1 W + 0.2 W…but first we need to produce those photons! By electron beam? And for this we would need power! Poor efficiency?

4) Secondary electron emission: Some materials can have very high yield of secondary electrons (see Lectures: Part 1). For example MgO surface has the yield of about 20 at the electron energy of 1.5 keV. In this case we should first produce the electron beam of 0.05 mA and accelerate it to 1.5 keV. The acceleration of this beam would need about 0.08 W. So, We still have some power available for producing the emission of 0.05 mA (if we expect the efficiency of 100 %). This might be possible but fairly complex!

Conclusion: the field emission is the most efficient concept for producing the electron gun. The emission and the beam acceleration/formation can be realized at same time!