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EMISSION DRIFT - LaB_6 AND GUN STABILITY

1. Introduction

Operators of various electron microscopes report drift in specimen current measurements when they have been using LaB_6 cathodes. The type of drift reported is not usually seen when they operate the gun with a tungsten cathode. The following comments are directed at the general problem of current drift in triode electron guns and address specifically what is believed to be the cause of anomalous drift in the case of LaB_6 sources.

The most critical parameters in the setting up of a triode gun by the operators of TEM's and SEM's are the filament height setting and the axial alignment of the filament tip within the Wehnelt aperture. On the assumption that the axial alignment is accurate (unfortunately this is often not the case), the parameter that most affects the operation of the gun at a specific accelerating voltage is the height setting, that is the distance of the tip of the cathode from the front surface of the Wehnelt aperture, as shown in Figure 1.

The recommended height for normal operation of the microscope is generally given by the Manufacturer for a specific range of operating voltage. This height is set during the set up of the cathode in a new or clean Wehnelt aperture or assembly. This setting of h should be referred to as the cold height setting h_{cold}.

When the cathode is heated to operating temperature it immediately expands forward with respect to the Wehnelt aperture due to thermal expansion of the cathode heater. The magnitude of this expansion is typically about 50 μm for tungsten hair-pin cathodes and wire mounted LaB_6 cathodes, but is closer to 30 μm for the Kimball Physics carbon heater ES-423E LaB_6 cathode. On some bases with long mounting posts, the total expansion can be as much as 80 μm. Stabilization of the heater thermal expansion is sufficiently rapid (seconds) that specimen current changes associated with this expansion are not likely to be observed.

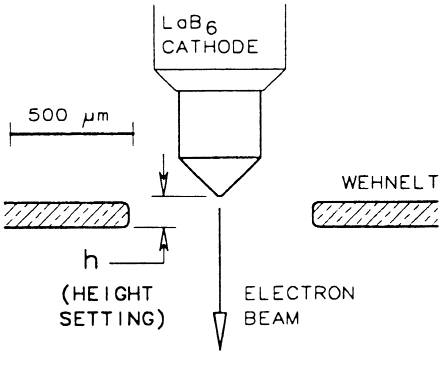

Figure 1. Lanthanum hexaboride cathode in position with height setting, h, behind a Wehnelt aperture. Proper height setting, and accurate centering, are essential for stable long-term operation.

However, during the warm-up of the remaining gun structure, there are further slow thermal changes in the height setting due to thermal expansions in the cathode support structure and the Wehnelt support structure, as shown in Figure 2. The rates of these changes are determined by the cathode power dissipation and the thermal properties of the gun assembly. Due to the massive nature of most TEM and SEM gun structures, the stabilization can take many hours. The stabilization is readily observed by watching changes in the "cut-off" voltage in an independently biased triode gun. Alternatively, in an automatically biased gun, where the true accelerating potential is the applied high voltage less the auto-bias voltage, the drift can be accurately observed in a TEM using a magnetic sector energy filter. The

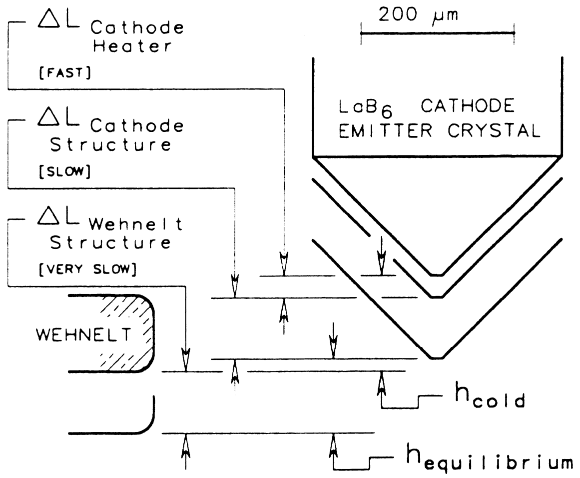

Figure 2. Thermal expansion length changes in various structural parts of the gun assembly cause significant changes in the originally set (operator adjusted) height setting, h_{cold}. Eventually a new stable value, $h_{equilibrium}$, is reached, but only after hours of drifting in both decreasing and increasing directions. The final height setting may be either larger or smaller than the original value. These changes may be observed electronically, by watching small cut-off bias voltage changes in a fixed bias gun, or by following shifts in the electron kinetic-energy spectra in an auto-biased gun.

energy of the direct beam is observed to drift as the change of the auto-bias (due to height changes) alters the accelerating potential. Such a drift can be readily observed with about 0.1 V resolution. Stabilization of a Philips EM-430 gun, observed with this method, takes up to 6 hours after initial turn-on.

As the cathode height changes, both total emission current and axial brightness also change, thus changes in the specimen current will be observed. Careful measurements which require stable specimen currents, should not normally be done until the thermal stabilization of the gun is complete. Each system should be evaluated to determine the period required for stabilization.

Tungsten Cathodes

In the case of tungsten guns, good emission current stability is generally found after the final thermal stabilization of the gun. Exceptions may occur if the filament mounting is of faulty design such that local thermal stresses cause long term motions at the tip of the cathode. Fortunately this is rarely the case in good quality commercial cathodes.

LaB_6 Cathodes

In the case of LaB_6 cathodes, longer term drift of specimen current is often reported. The frequency of the effect and its general magnitude are not as well documented, but the existence is well established from the experience of many microscope and probe operators. It is the opinion of the author that this effect is generally associated with the accumulation of the evaporation/oxidation products of LaB_6 on the inner surfaces of the Wehnelt aperture.

In ultra-high vacuum, as in Auger instruments, this effect is not observed. However, even in such instruments, a gun drift effect can be found when Auger measurements are done in conjunction with SIM's studies where oxygen is used as the exciting ion. More generally in electron microscopes the gun pressure is not sufficiently low to prevent considerable oxidation of the cathode to occur at the operating temperature. At gun pressures of 10^{-7} torr, about half of the Wehnelt deposit is still oxide, even with the cathode temperature up at around 1850 K. The amount of oxide in the deposit increases at higher pressures, since the operating pressure is usually limited by the presence of water vapor in the system, and the diffusion of gases through and around the elastomer seals of the conventional microscopes.

Wehnelt Aperture Contamination

The implications of the presence of this insulating contamination film are rarely appreciated. If the deposit is a good insulator, then it accumulates positive charge from the ion beam being directed at the cathode, opposite to the trajectory of the electrons. This effect is well known. The number of ions will vary as the pressure and the total emission vary. The charge accumulating on the inner surface of the Wehnelt will depend on the ion flux and the conductivity of the film.

In an independently biased gun, without total emission stabilization, the immediate effect may be for run-away emission to develop as the positive charge reduces the effective negative bias, thus increasing the total emission. This in turn increases the ion flux to the surface of the contamination.[1]

In an auto-biased gun the effect on the total emission is less noticeable, as any trend to an increase in total emission causes the applied bias to increase, thus limiting the rise in emission, and thereby controlling the ion flux to the contamination. Slow total emission drift is often observed, with pulses of emission as the voltage on the insulator periodically discharges. The magnitude of the effect is clearly dependent on the amount of insulating contamination on the Wehnelt.

In an independently biased gun, with total emission current compensation, the effect can only be predicted; a detailed examination of this situation has not been conducted by the author. In such a gun, as positive voltage accumulates on the Wehnelt contamination, and as the total emission tends to increase, the feed back control will apply an additional bias to the Wehnelt assembly. While this may serve to force stabilization of the total emission, the specimen current will not necessarily remain stable. The presence of positive charge on the insulator is equivalent to having another Power supply, $V_{contamination}$, in series with the bias voltage, as shown in Figure 3. While this situation has not yet been analyzed in detail, it is suspected that the divergence of the beam will alter in the presence of this additional potential. If the divergence of the beam from the gun changes, then, for a fixed total emission current the axial brightness must change. Since the probe or specimen current is proportional to the axial brightness and not the total emission current, a slow change in specimen current might be due to slow changes in the axial brightness at fixed emission current, as the beam divergence changes. A detailed electron optical analysis of the simulated contaminated gun is needed.

This type of situation may lead to slow drift in both the auto-biased and the emission-stabilized independently biased gun, over a period of many hours to weeks. The situations reported to the author seem to be worse in guns with massive Wehnelt structures which tend to conduct heat away from the Wehnelt aperture. Since the conductivity of the insulating film is known to be a function of temperature,[1] then it seems that the hotter the Wehnelt aperture, the less trouble that is likely to be caused by this effect.

Very little trouble has been observed with the Philips EM-430 gun and this is assumed to be due to the poor thermal conductivity of the aperture structure, as shown in Figure 4.

At very low beam energies, around 1000 eV, the gun in the Nano-Quest 3006 gives some trouble with image drift after only some 500 hours of operation of LaB_6 at 1850 K in a pressure of 10^{-7} torr. This drift can be eliminated by increasing the filament temperature (of a KPI ES-423E cathode) to about 2100 K where congruent evaporation of LaB_6 occurs at a sufficient rate to coat the contamination with a conductive film of LaB_6. This is now an accepted routine in this microscope.

Generally, less trouble is found in guns with thin Wehnelt structures such as the 100 micron thick top-hat aperture used in numerous commercial instruments. However in guns with massive Wehnelts such as the conical Wehnelts used on JEOL instruments, drift problems have been reported.

Comments

While this phenomenon has not yet been evaluated in detail, it would seem to be good practice to design the Wehnelt aperture so that it operates at as high a temperature as is possible. Design changes should include the use of thin films aperture structures constructed from materials of poor thermal conductivity. In addition, the replaceable aperture should be supported in the main assembly in such a manner that thermal conductivity from the aperture to the main support structure is restricted. None of these features would appear to be difficult to achieve; however, no serious effort in this direction seems to have been taken thus far, by any manufacturer of commercial electron microscopes.

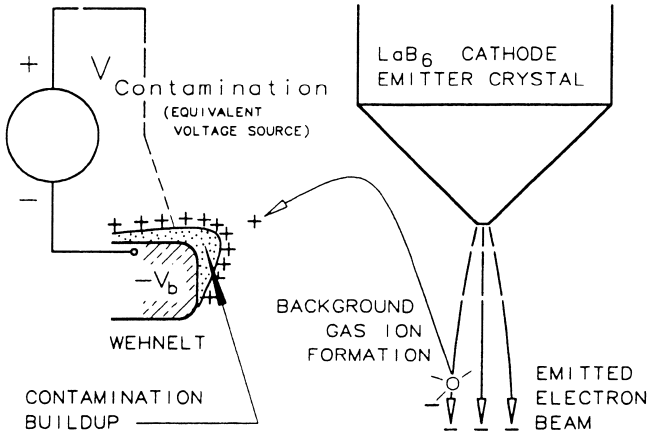

Figure 3. *Contamination charge-up, on the inner rim of the Wehnelt aperture, effectively adds an additional uncontrolled voltage in series with the bias voltage applied to the Wehnelt aperture. The result of the charge-up is to reduce the magnitude of the applied voltage. Further difficulties ensue when the contamination is not deposited symmetrically, or when sections flake due to differential thermal expansions with respect to the aperture disk.*

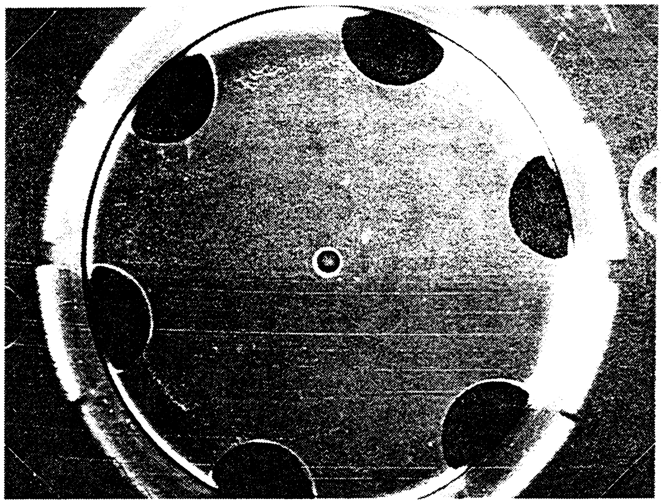

Figure 4. *Wehnelt aperture insert for Philips TEM. Heat conduction from region of 500 μm diameter aperture to the main Wehnelt assembly is restricted by (1) the large diameter (1.5 cm), (2) the thin metal (0.1 mm thick), and (3) the six holes near the outer diameter of the aperture disc.*

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[1] P.B. Sewell and K.N. Ramachandran, "Grid Aperture Contamination in Electron Guns Using Directly Heated Lanthanum Hexaboride Sources," SEM (1), (1978), pp. 221 - 232.