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Physical Changes in Tungsten and Thoriated Tungsten Electrodes After Subsecond Heating[1]

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Tungsten and thoriated tungsten rods are commonly used as cathodes for arcs operating in argon. Thoriated tungsten electrodes (2 wt% thorium oxide) have significantly longer lifetimes than pure tungsten electrodes, though the reason for this is not well understood. Samples of both types of electrode were heated to the melting point of tungsten using a subsecond pulse heating technique. The samples were then examined using electron microscopy and X-ray analysis and the results compared with similar examinations of unheated electrodes. There were definite physical changes apparent in the shape of the thoria particles, but no evidence of any reduction of the thoria.

KEY WORDS: electron microscopy; high temperatures; plasma arc; pulse heating; thoria; thoriated tungsten; X-ray analysis.

1. INTRODUCTION

Tungsten and thoriated tungsten are two of the most commonly used arc electrode materials. Thoriated tungsten electrodes contain only 2% by weight of thoria (ThO_2), which exists, at least initially, as discrete particles within the tungsten mass. The addition of thoria lowers the effective work function [1], leading to a lower operating temperature [2, 3] for the electrode and an increased electrode lifetime. Figures 1 and 2 show electrodes of both types after similar periods and conditions of use. Both electrodes began with a 60° cone at the tip and it can be seen that the tungsten electrode (Fig. 1) is considerably more deformed. However, tungsten electrodes

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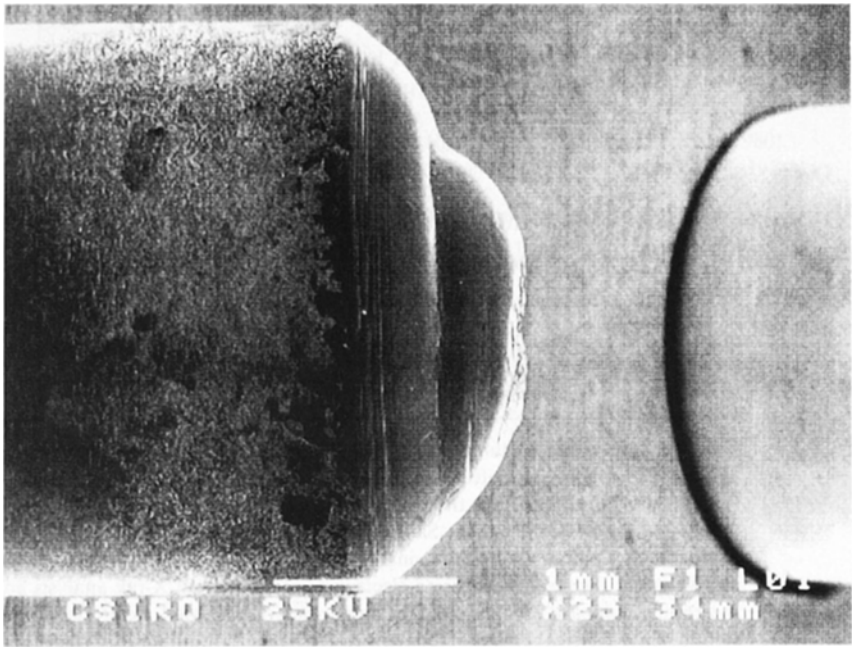

Fig. 1. Micrograph of a tungsten electrode after use in an argon arc.

have a second, quasi-stable operating mode which also increases the life of the electrode [4].

Examination of used thoriated tungsten electrodes show that the working tip appears to be depleted of detectable thoria, leaving only large tungsten crystals [5]. A ring of thorium metal can also be detected some millimeters back from the tip. It has been suggested [6, 7] that the thoria reacts with the tungsten during the operation of the arc and that pure thorium is formed in the process. However, the relative Gibbs free energies of the thoria and tungsten oxides suggests that thoria is not reduced by tungsten [8].

Thermophysical measurements were performed on both tungsten and thoriated tungsten electrodes. The samples were resistively heated to the tungsten melting point very quickly (times in the order of 1 s), but heating was stopped before fusion was complete and the samples remained intact. Technical details of the equipment used have been given elsewhere [9–11] and the results of the thermophysical measurements in tungsten [12, 13] and thoriated tungsten [14, 15] are given in complementary publications. The physical changes caused by the rapid heating were examined using electron microscopy and X-ray microanalysis.

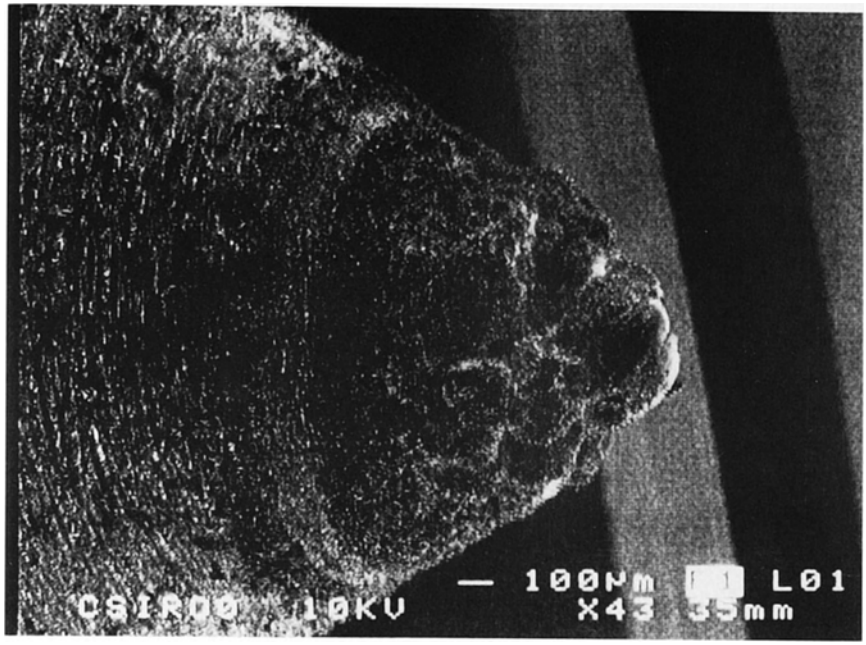

Fig. 2. Micrograph of a thoriated tungsten electrode after use in an argon arc.

2. METHOD

Samples were cut from both the heated and the unheated sections of both types of electrode. After the surface was examined, the samples were polished both in cross section and longitudinally to facilitate phase imaging and analysis of the material. They were then examined using a Jeol 6300F field emission scanning electron microscope (FESEM) fitted with both secondary electron (SE) and back-scattered electron (BSE) detectors. The elemental analysis was carried out using an Oxford exL II energy-dispersive X-ray (EDX) analysis system which was also fitted to the FESEM. The EDX detector has a thin window which allows the detection of low atomic number elements such as oxygen.

A BSE detector is ideal for imaging materials with different phases. On a polished surface where the topography is minimized, the BSE detector shows variations in average atomic number (Z). Areas of low Z appear darker than those with a higher Z; consequently thoria ($Z=33$) appears dark in tungsten ($Z=74$). Once the phases have been identified, their elemental composition can be determined using EDX analysis by focusing

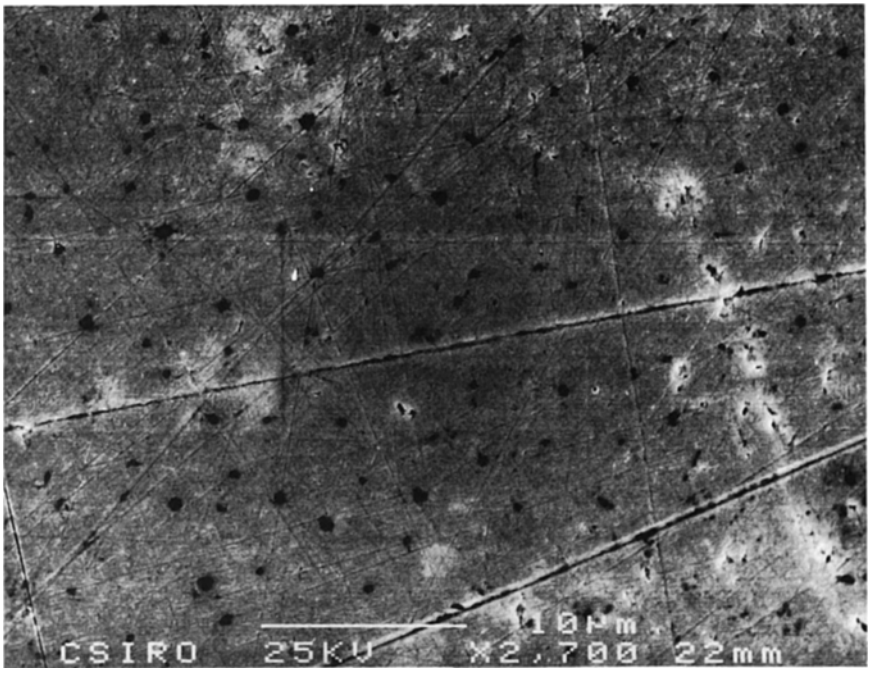

Fig. 3. Back-scattered electron image of the polished cross section of an unheated portion of thoriated tungsten electrode.

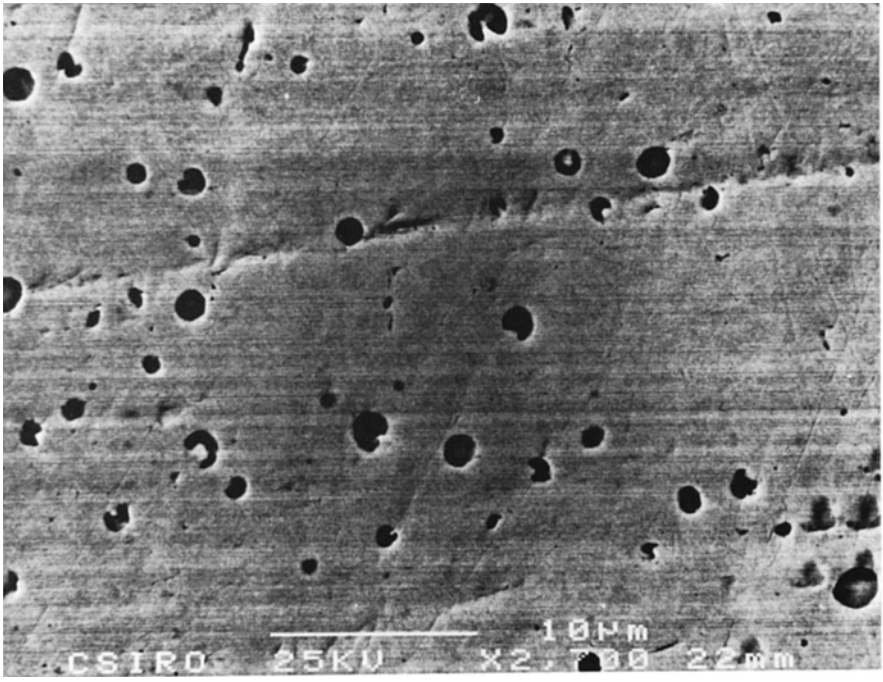

Fig. 4. Back-scattered electron image of the polished cross section of a portion of thoriated tungsten electrode after heating.

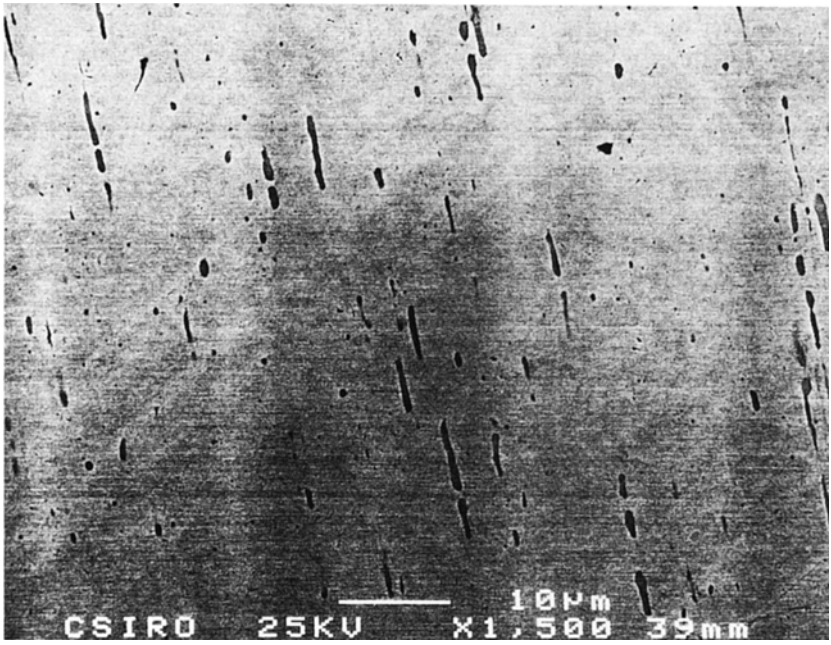

Fig. 5. Back-scattered electron image of the polished longitudinal section of an unheated portion of thoriated tungsten electrode.

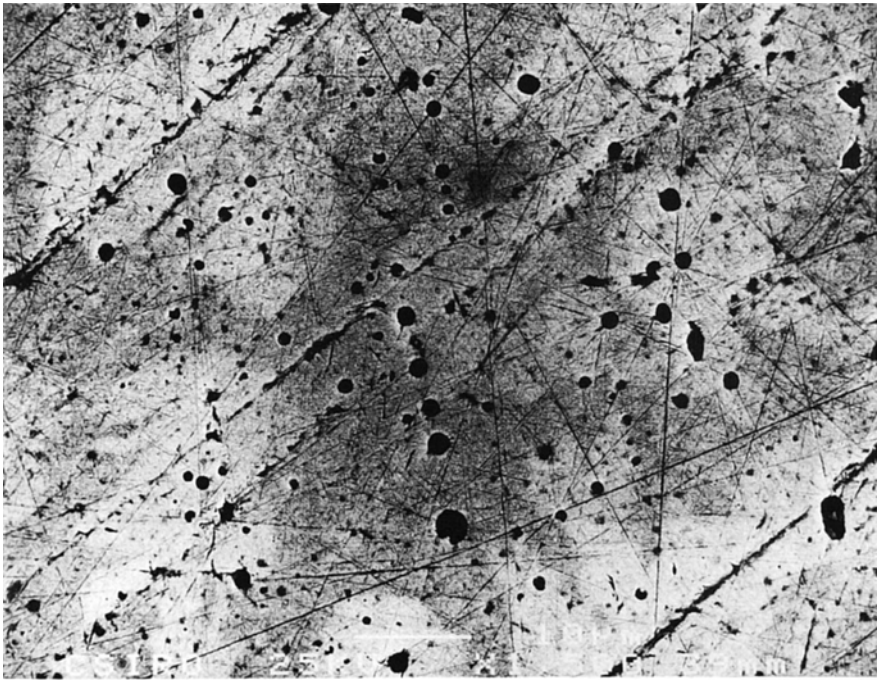

Fig. 6. Back-scattered electron image of the polished longitudinal section of portion of thoriated tungsten electrode after heating.

the electron beam on the spot or area to be analysed. The characteristic X-rays emitted by the elements at that point are counted and sorted according to energy using a multichannel analyzer.

3. RESULTS

The tungsten electrodes showed no visible differences between the heated and the unheated samples.

Figures 3 and 4 show the BSE image of the cross section of an unheated and a heated thoriated tungsten electrode respectively. Both images have the same magnification and are taken under the same conditions. The thoria particles are quite distinct and it is obvious that the average diameter of the thoria particles in the unheated electrode is quite different from that in the heated one, though they are both approximately circular in section.

Longitudinal sections of the same samples, shown in Figs. 5 and 6, are, however, quite different. In the unheated sample, the thoria particles are long and thin, while in the heated ones they are again circular in cross

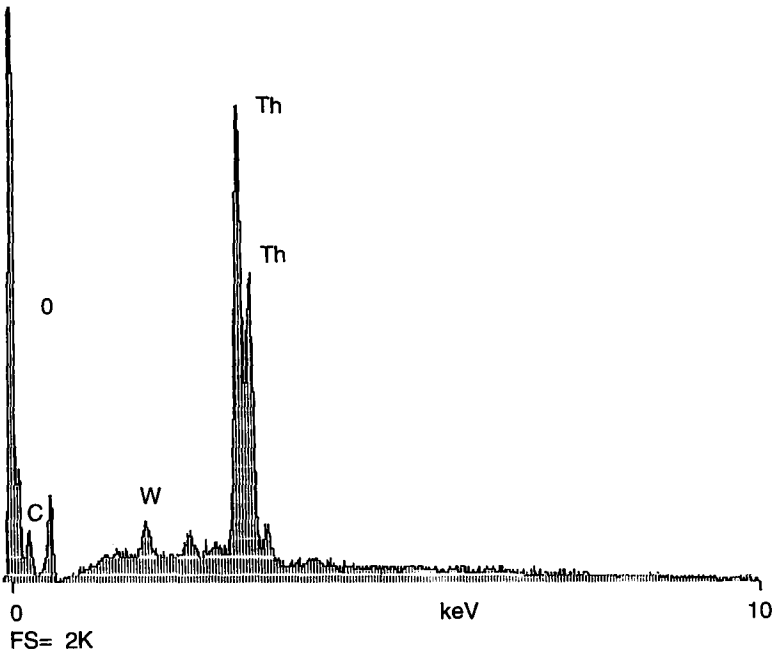

Fig. 7. X-ray spectrum of a thoria particle in an unheated electrode.

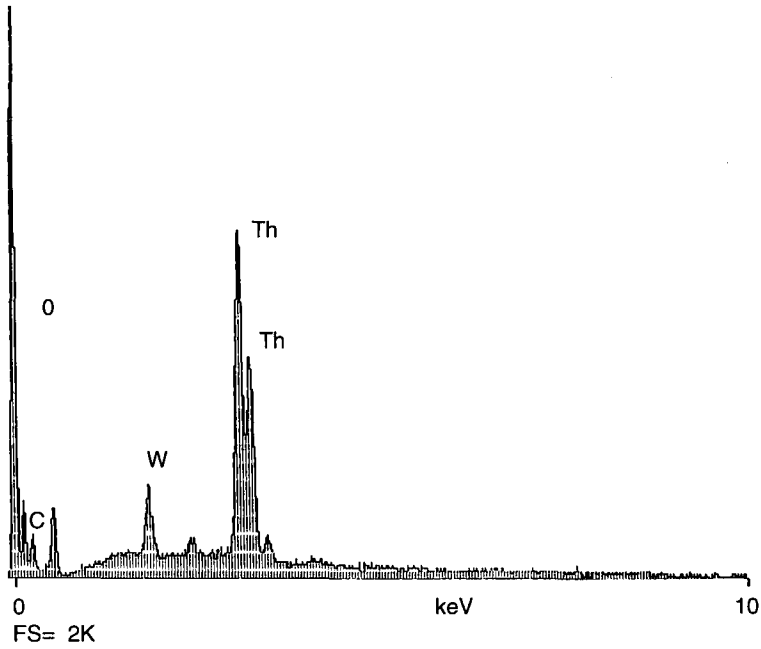

Fig. 8. X-ray spectrum of a thoria particle in a heated electrode.

section. The EDX spectra of the thoria particles in the unheated and heated samples can be seen in Figs. 7 and 8, respectively. The ratio of the peak heights of thorium to oxygen in these spectra is 1.4 and 1.3, respectively. The error in this method is at least $\pm 5\%$, so these ratios are not significantly different. Although extensive analyses were carried out on the material, no pure thorium was detected. Analysis of the tungsten matrix showed no evidence of thorium within the mass of the electrode.

4. DISCUSSION

Changes to the tungsten electrodes are confined to grain growth and possible surface oxidation. The method of sample preparation used for this study does not emphasize the grain boundaries so there were no observable differences between the tungsten samples. It is also possible that the time scale of the heating, even though repeated a number of times, was too short for any noticeable grain growth to occur.

The elongated shape of the thoria particles in the unheated thoriated tungsten samples is probably caused by the drawing process used to reduce

the rod diameter to the required size (3.2 mm). The melting point of thoria (3666 ± 25 K) is below that of tungsten (3693 K). The thoria must be strongly cohesive because it is drawn together on melting despite being confined by the tungsten. The softening of tungsten at its melting point, though only for a brief time, allows these particles to assume their preferred spherical shape.

Examination of the EDX spectra of the thoria particles before and after heating shows that the ratio of the oxygen and thorium peak heights remains the same within the limits of the method used (5%). In addition, there was no sign of thorium in the tungsten matrix as would be expected if tungsten acted as a reductant for thoria. However, the EDX analysis method will not detect trace amounts of material, and it is possible that the short time span of the experiment did not allow sufficient thoria to be reduced to form detectable amounts of thorium either on its own or dissolved in the tungsten mass.

One possible explanation of the observations carried out [1, 2] on used electrodes is that the thoria melts and as the tungsten crystals become larger, the thoria escapes from the electrode tip into the arc itself. The temperature here is high enough not only to vaporize the thoria but to cause it to dissociate. Some of this dissociated material is swept back to cooler parts of the electrode surface where some of the thorium condenses, forming a ring of thorium on the electrode. However, the reason for the extended electrode lifetime is still not clear, especially if the tip becomes pure tungsten in a relatively short period of use. It is possible that it may be due to trace amounts of thoria or thorium in the tungsten matrix, or it may be related to the two operating modes of tungsten. Further work is to be done in this area.

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