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Optical and SEM Observations on Effect of Heat Treatment and Cabling Processes on RRP Strands

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1) Introduction:

The purpose of this work was to examine the effect of heat treatment and forming the 0.7 mm RRP strands (Restacked Rod Process) into 39 strand Rutherford Cable on the structure of the RRP strands. The four samples that were examined were from the heat treated coil 16 (Coil 16HT), heat treated coil 17 (Coil17HT), non-heat treated coil 16 (Coil 16NHT), and non-heat treated coil 17 (Coil 17NHT). Figure 1 below shows the cross-sectional picture of Coil 16NHT.

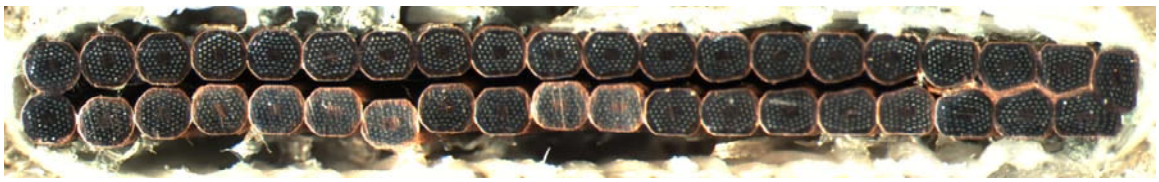


Figure 1: Cross-Sectional Picture of Sample Coil 16NHT

As can be seen in the figure, the Coil 16 sample has 39 individual 0.7 mm RRP strands. All of the samples had 39 RRP strands. The difference between the heat treated and non-heat treated samples is that the heat treated samples have been heated to a certain temperature to react the tin and niobium. Figure 2 shows a typical light microscope picture of a single RRP strand from the Coil 17HT sample. In all samples each coil contains 54 individual multi-metal sub-elements. Each sub-element is produced by the internal tin method with thousands of niobium filaments. Figure 3 shows a SEM picture of an individual multi-metal sub-element. Each multi metal sub-element is comprised of niobium, tin, and copper.

The cable of the Coil 16 was key-stoned with a 0.98° angle in one step with 14.342 mm width and 1.204 average thickness. The Coil 17 cable was first made into a rectangular cable, which was 14.345 mm wide and had a 1.203 mm mean thickness. And

in the second step, it was key-stoned to a 0.91° angle, with a 14.36 mm width and a 1.2 mm mean thickness.

Figure 2: Light Microscope Picture of a Single RRP Strand from Sample Coil 17HT

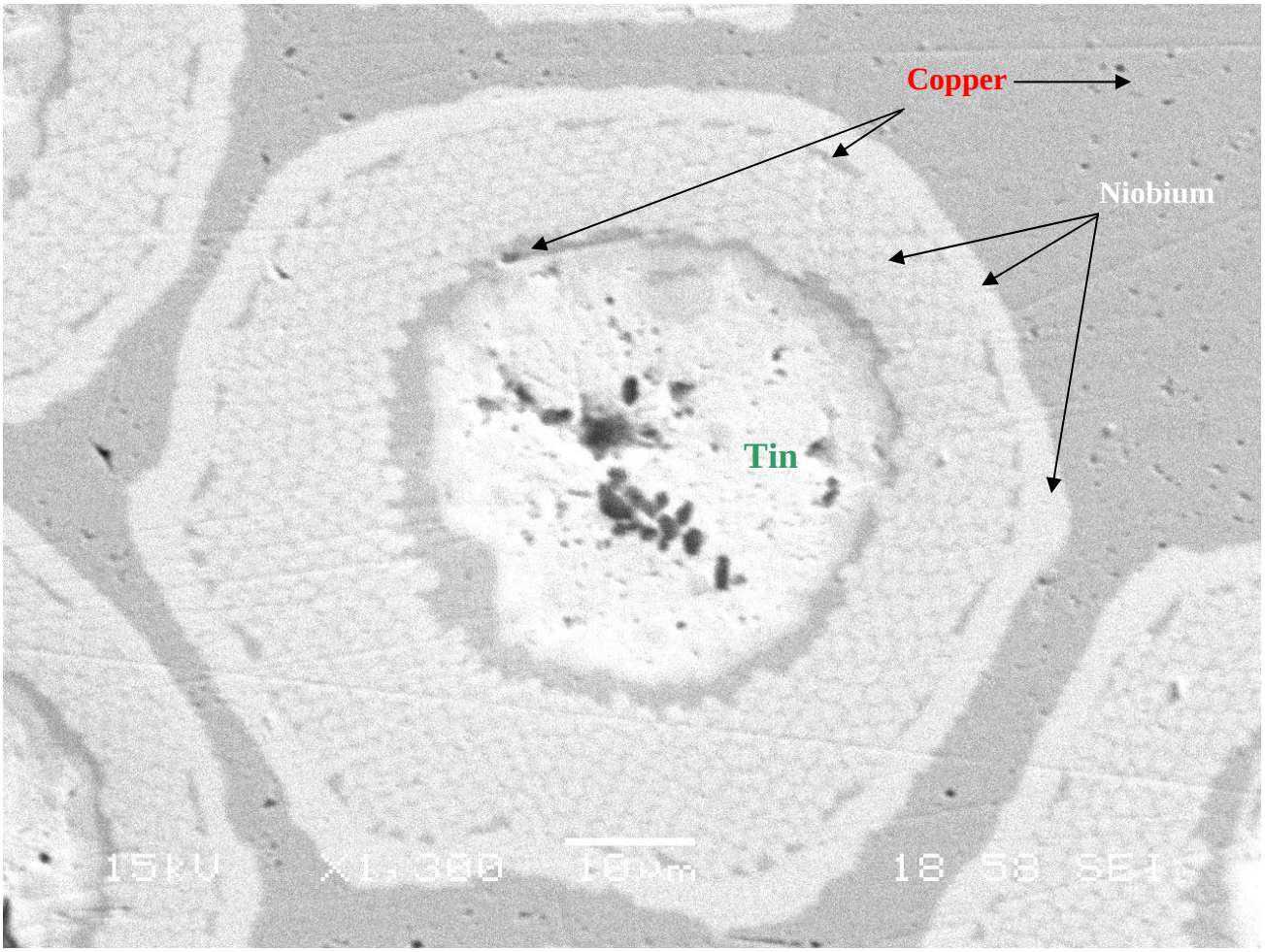


Figure 3: SEM Picture of an Individual Multi-Metal Filament from Sample Coil 17NHT

Each multi-metal sub-element has an outer shell of Niobium, referred to as the niobium barrier (with 10% tantalum by weight), that is 2-3 microns thick. Before heat treatment the inner core of the multi-metal filament is pure tin (within the limits of EDS detection, so at least 99% pure Sn). The layer between the niobium barrier and the inner core is comprised of pure copper and hundreds of hexagonal niobium filaments that are approximately 1.5 μm across. The niobium filaments, as well as all other niobium, were found to have approximately 10% by weight tantalum before heat treating. Before heat treatment there is a thin layer of copper that surrounds each niobium filament. There is also a thin layer of copper that separates the niobium filaments from the outer niobium wall.

During heat treatment the tin from the center of the sub-element diffuses to the niobium filament layer and reacts with the niobium. The goal of this is to form a Nb_3Tn superconductor. At the same time the copper that had previously surrounded the pure niobium filaments diffuses to the center of the sub-element to replace some of the leaving tin. Figure 4 below shows an SEM picture of heat treated sample Coil 17HT. In this picture the niobium looks white and the copper looks gray. It can be seen that there is a thin layer of copper separating the niobium barrier and the niobium/tin layer.

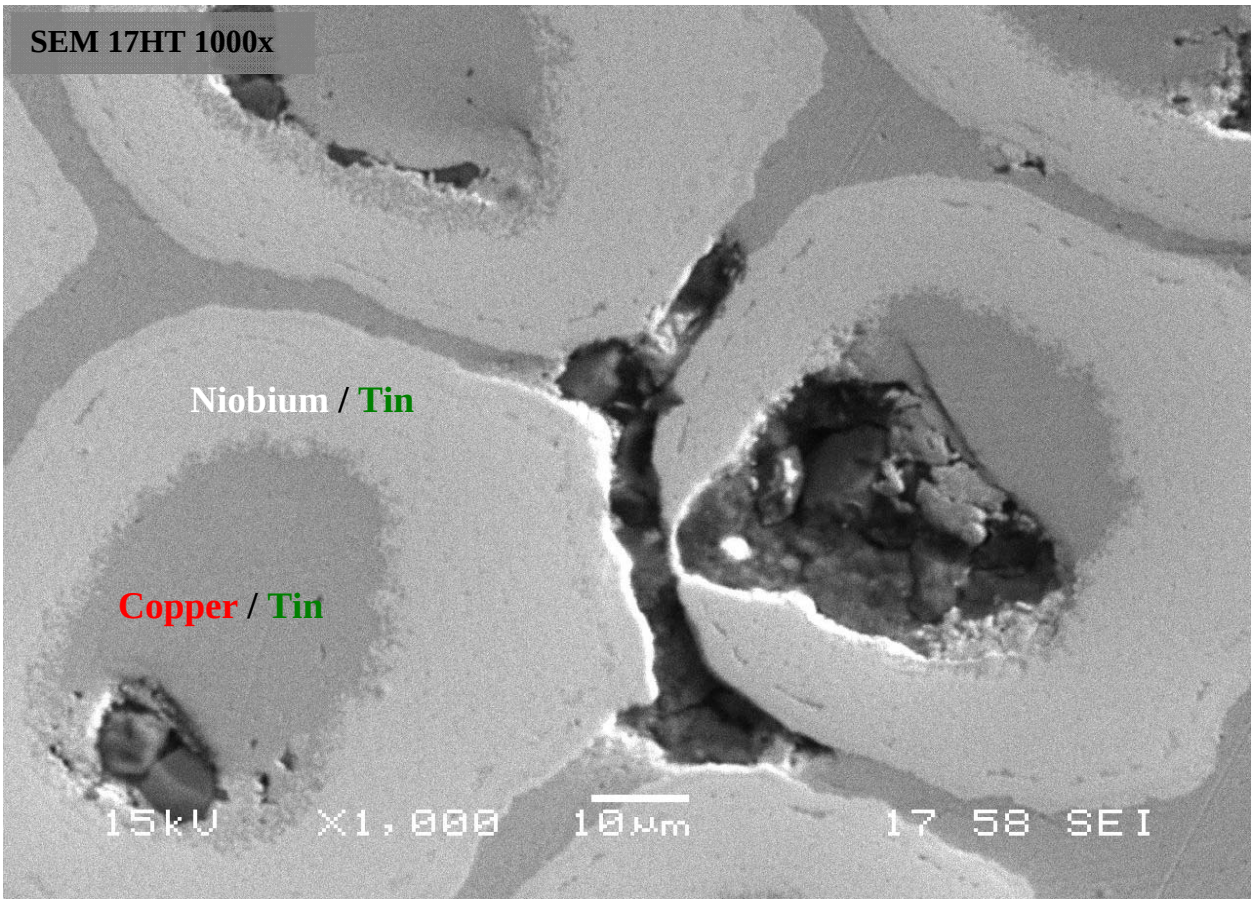


Figure 4: SEM Picture of Several Multi-Metal Filaments from Coil 17HT

2) Effect of Cabling Process:

2A) Physical Effects:

The individual filaments in general seem to be in tact before going through the cabling process. During the cabling process however, much stress is put on the outside 3 or 4 RRP strands that are coming in contact with the edge rollers. The next 7 pictures, Figures 5 and 6, show defects that were caused during the cabling process. More pictures can be seen in Appendixes A-D.

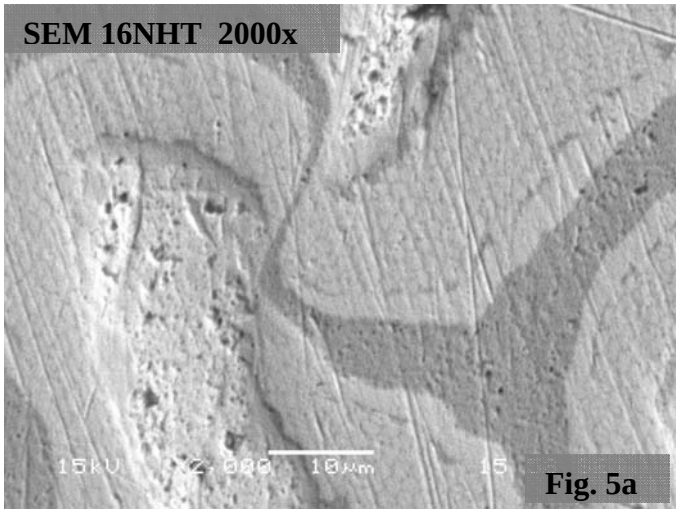


Fig. 5a

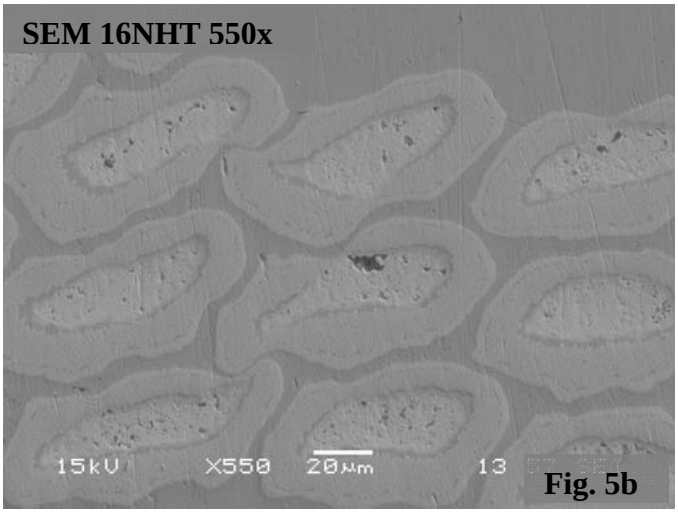
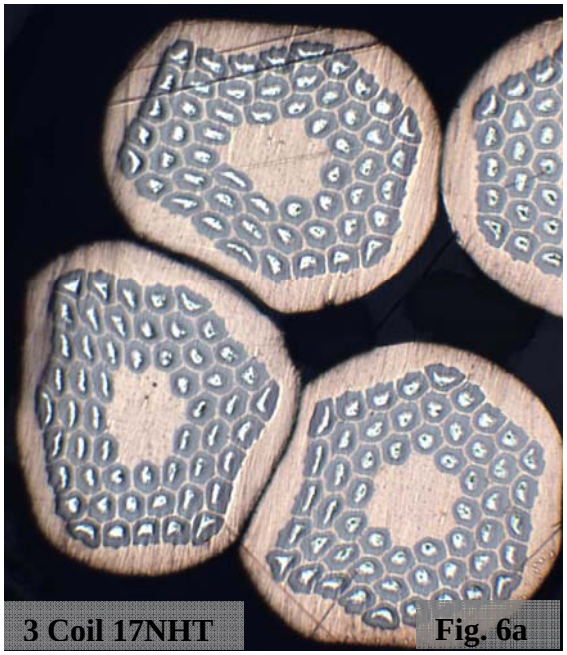
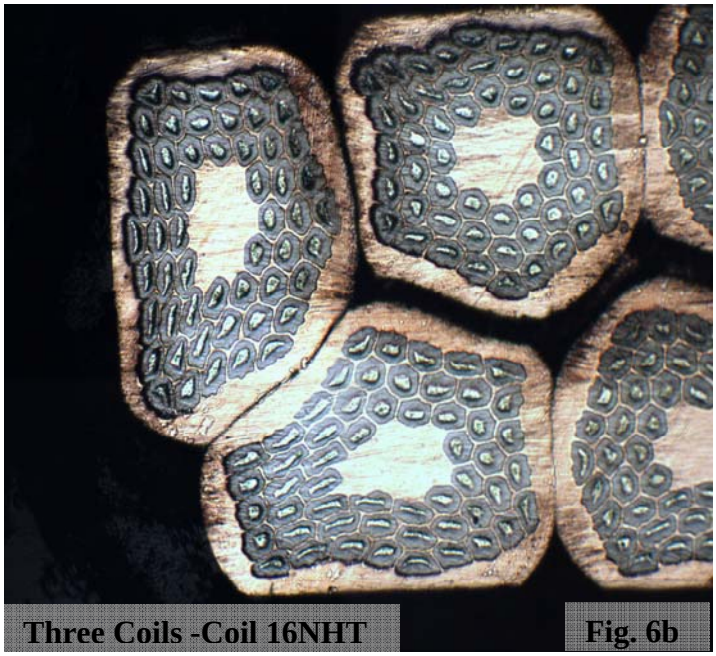


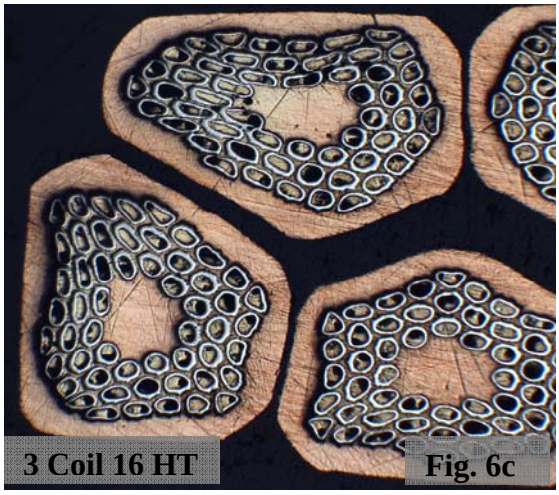
Fig. 5b

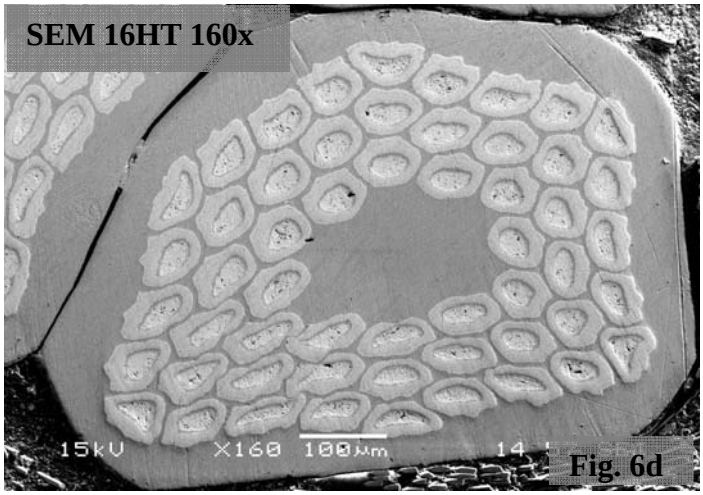
Figure 5a is particularly bad and shows one filament from Coil 16NHT cutting into another filament to the extent where the inner layer of tin is almost in direct contact with the bulk cooper. It would be expected that this would cause a failure in the superconductor. Figure 5b shows a similar phenomenon as seen in Figure 5a, but not to the same extent. All of these pictures are of the last 3 RRP strands of a cable cross section.

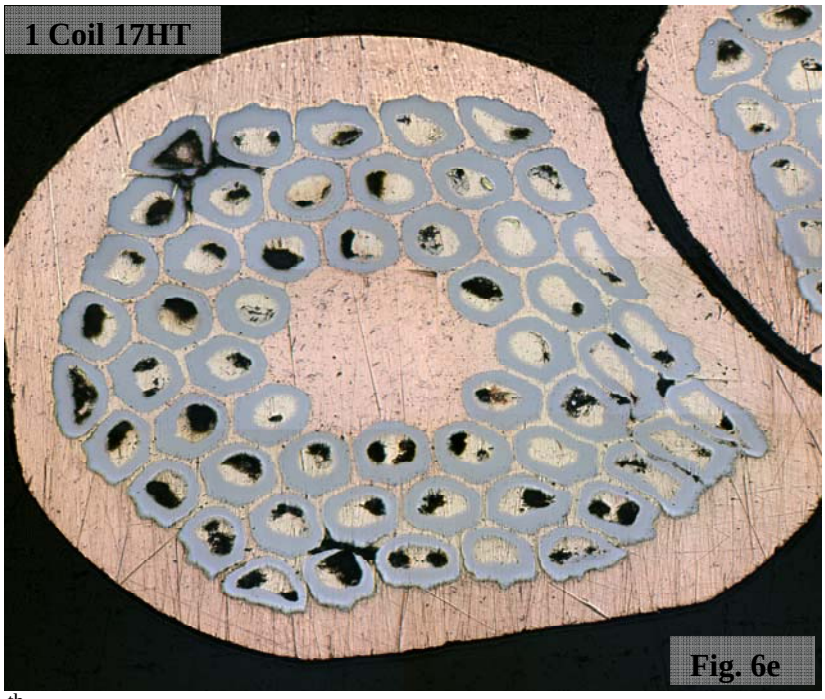
Figures 6a through 6e give a general idea of the kind of stress the last 3 RRP strands are exposed to. It can be seen that the strands are loosing there hexagonal shape, and in some cases, going to a much distorted elliptical shape. Since the hexagonal strand is loosing shape the hexagonal filaments within are also loosing shape. In the following section EDS analysis will demonstrate the metal distribution in the RRP strands.


3 Coil 17NHT
Fig. 6a


Three Coils -Coil 16NHT
Fig. 6b


3 Coil 16 HT
Fig. 6c


SEM 16HT 160x
15kV X160 100µm 14
Fig. 6d


1 Coil 17HT
Fig. 6e

2B) <u>Elemental Analysis</u>:

Energy Dispersive Spectroscopy, EDS, is a tool that can be used to give an idea of what the elemental composition of a sample is. EDS can not give chemical composition. All the samples analyzed here were cut with a carbide blade and then polished mechanically. The mechanical polishing and the cutting of the samples introduced carbon, silica, and alumina to the samples in small amounts. The polishing and cutting could also remove metal from one place on the strand and deposit it on another. Before analysis and after polishing all the samples were washed with soap and water, water, methanol, and finally with acetone in an ultrasound. The EDS can give a good idea of the elemental composition of these samples but not an exact one.

For example, Figure 7 shows where an EDS point scan was done on Coil 16NHT. Table 1 shows the elemental analysis from the point shown in Figure 7. For a point scan from EDS the beam spot size is approximately 1 μm^2. This particular analysis was done before the sample was cleaned. It shows a large amount of carbon and oxygen which are artifacts of polishing. In general, if there was a small amount of contaminant in the analysis it was omitted and defined as contaminants from sample preparation.

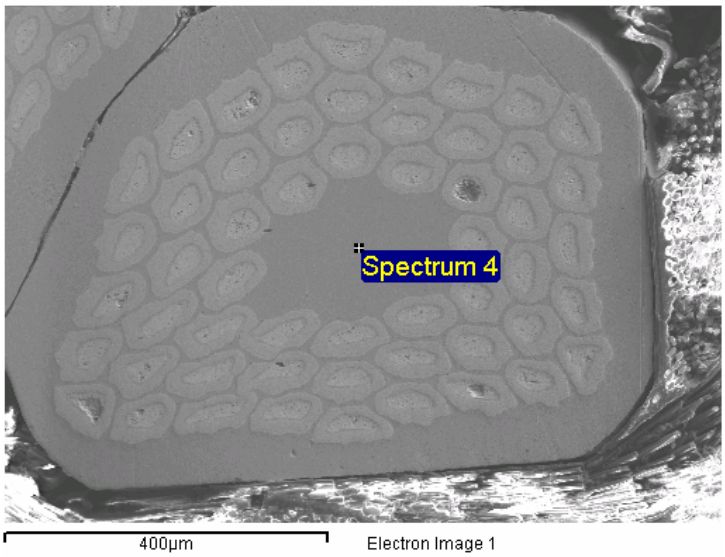
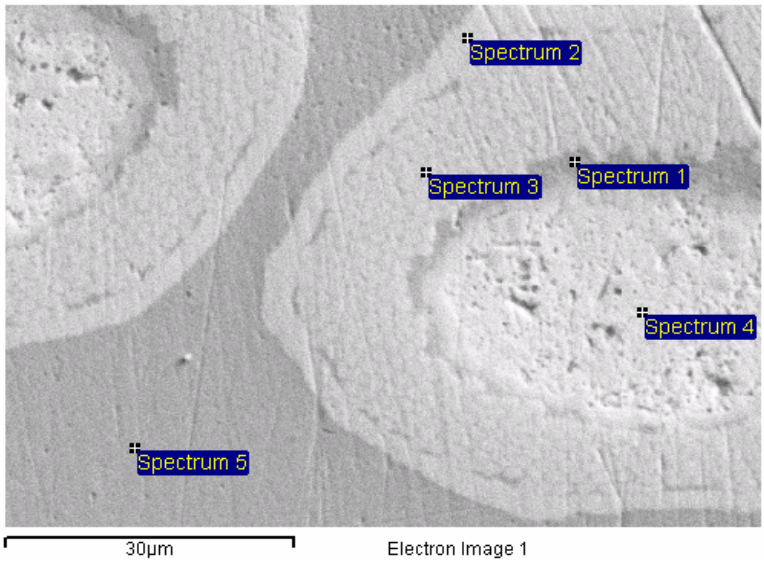


Figure 7: Point Scan of Coil 16NHT

Element	Weight%	Atomic%
C K	12.10	41.12
O K	1.27	3.23
Cu L	86.63	55.65
Totals	100.00	100.00

Table 1: Elemental Analysis of Point Scan of Coil 16NHT

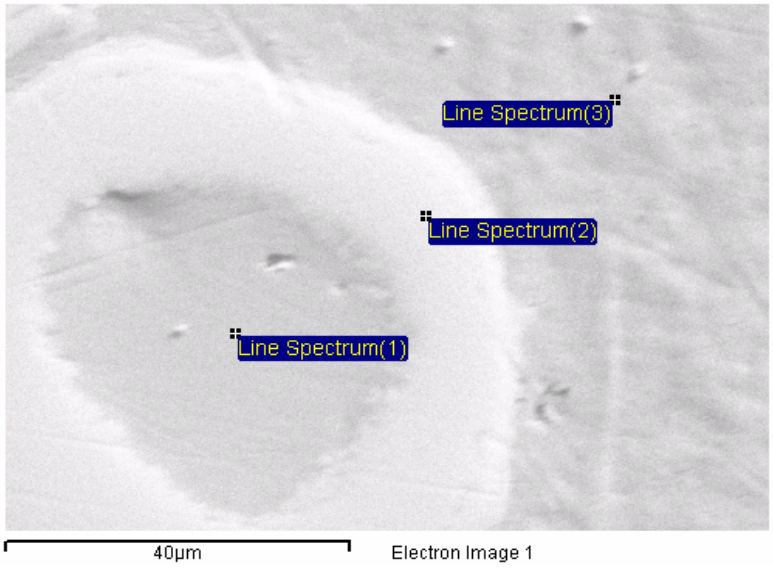


Spectrum	Cu	Nb	Sn	Ta	Total
Spectrum 1	98.09	0.77	-0.34	1.48	100.00
Spectrum 2	3.59	85.72	1.27	9.43	100.00
Spectrum 3	11.84	80.24	-0.13	8.06	100.00
Spectrum 4	0.46	-0.75	99.10	1.19	100.00
Spectrum 5	97.71	0.25	1.19	0.86	100.00

Table 2: Elemental Analysis of Points in Figure 8 (Weight %)

Figure 8: 5 Point Scan of Coil 16NHT

Figure 8 shows 5 point scans done on sample Coil 16NHT. Table 2 gives the weight % of each element found at these points. Tantalum is shown at all points taken. However it is within experimental error for all points except 2 and 3. It is most likely that there is tantalum in all of the niobium in the filament. Apparently the "pure" niobium is actually about 10 wt% tantalum through the sample. Point 4, the middle of the filament appears to be pure tin. Some copper and tantalum are shown for Point 4 but they are both within experimental error. Point 1, the area separating the middle from the niobium filaments appears to be pure copper. All of these data in Figure 8 are expected.



Spectrum	Cu	Nb	Sn	Ta	Total
Line Spectrum(1)	88.82	-0.35	11.26	0.27	100.00
Line Spectrum(2)	5.10	61.43	27.95	5.53	100.00
Line Spectrum(3)	101.11	-1.14	-0.56	0.59	100.00

Table 3: Elemental Analysis of Points in Figure 9 (Weight %)

Figure 9: Line Scan of Coil 16HT

Figure 9 shows 3 point scans taken of sample Coil 16HT. The results shown in Table 3 are very good as they are representative of all the data taken for the heat treated samples. In the middle of each filament multi-metal there is mainly copper with 9-11 wt. % of tin that did not diffuse to the niobium filaments. In the section of spectrum 2 there

is typically 65-60 wt% Nb and 30-25 wt% Sn and the balance tantalum and residual copper that did not diffuse out. So the middle layer looks more like $Nb_{2.5}Sn$ than Nb_3Sn. The bulk copper, spectrum 3, is not contaminated by the heat treatment process unless there is a break in one of the filaments and it is near the filament wall.

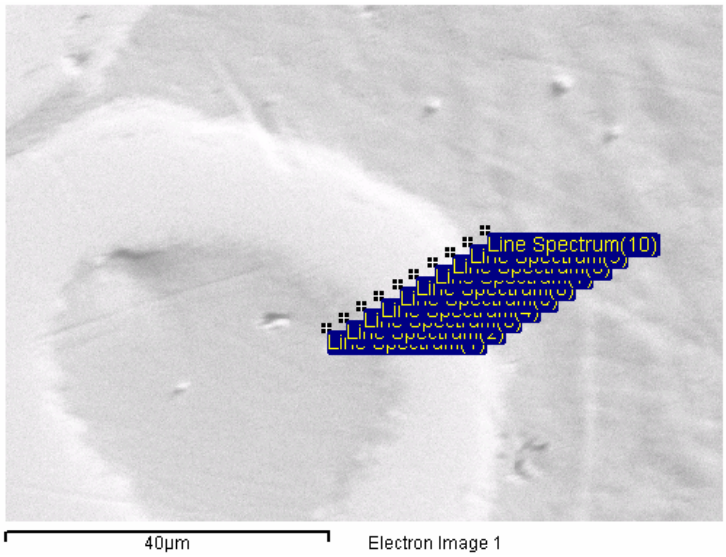
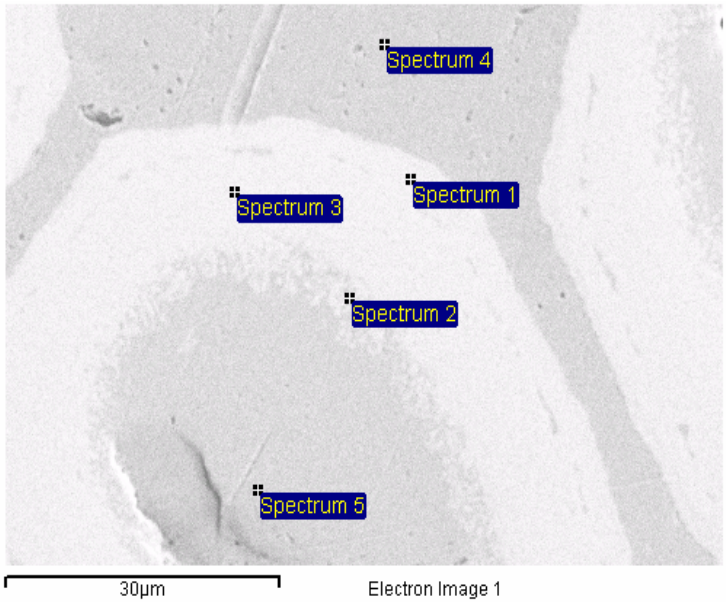


Figure 10: Line Scan of Coil 16HT

Spectrum	Cu	Nb	Sn	Ta	Total
Spectrum(1)	88.90	0.36	9.92	0.82	100.00
Spectrum(2)	69.01	16.08	13.27	1.64	100.00
Spectrum(3)	21.76	49.03	24.14	5.08	100.00
Spectrum(4)	4.32	60.78	27.55	7.34	100.00
Spectrum(5)	2.25	65.78	27.12	4.85	100.00
Spectrum(6)	2.70	62.44	28.35	6.50	100.00
Spectrum(7)	3.40	64.59	25.82	6.19	100.00
Spectrum(8)	3.35	82.79	4.47	9.39	100.00
Spectrum(9)	99.54	-1.04	0.61	0.89	100.00
Spectrum(10)	99.32	-0.86	0.62	0.92	100.00

Table 4: Elemental Analysis of Points in Figure 10 (Weight %)

Figure 10 shows a line scan across a filament wall of sample Coil 16HT. Table 4 shows that the copper concentration decreases until the bulk copper is reached. The niobium and tantalum concentration increases from the inside out until the bulk copper is reached. The tin reaches a maximum concentration about half the way through the Nb/Sn layer. All of these data should be expected. Figure 11 and Table 5 show the results from sample Coil 17HT. The data is similar to that from Coil 16HT in that the elemental distribution is similar. The data show that copper, tantalum, and niobium are diffusing inward and tin is diffusing outward.



Spectrum	Cu	Nb	Sn	Ta	Total
Spectrum 1	1.18	66.75	25.40	6.68	100.00
Spectrum 2	67.56	15.97	15.50	0.97	100.00
Spectrum 3	4.31	61.05	28.12	6.51	100.00
Spectrum 4	98.44	1.03	0.41	0.12	100.00
Spectrum 5	90.77	-0.15	10.03	-0.65	100.00

Table 5: Elemental Analysis of Points in Figure 11 (Weight %)

Figure 11: 5 Point Scans of Coil17HT

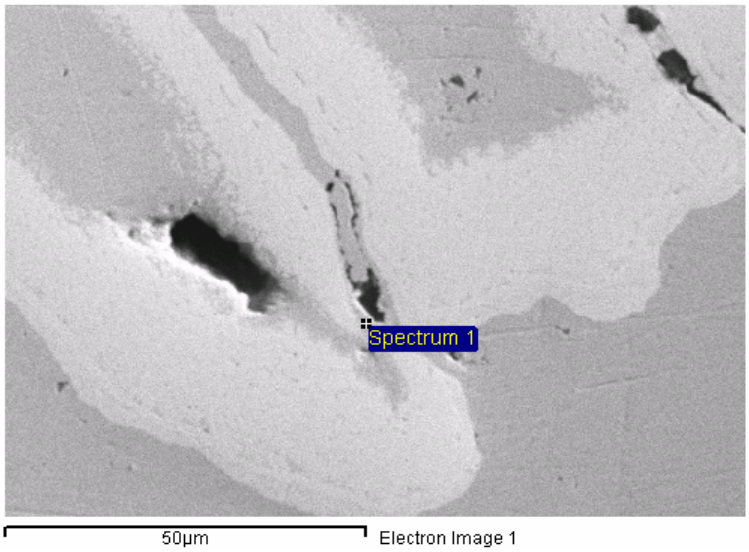


Figure 12a: 1 Point Scan of Coil17HT

Spectrum	Cu	Nb	Sn	Ta	Total
Spectrum 1	55.72	35.73	6.00	2.55	100.00

Table 6: Elemental Analysis of Points in Figure 12a (Weight %)

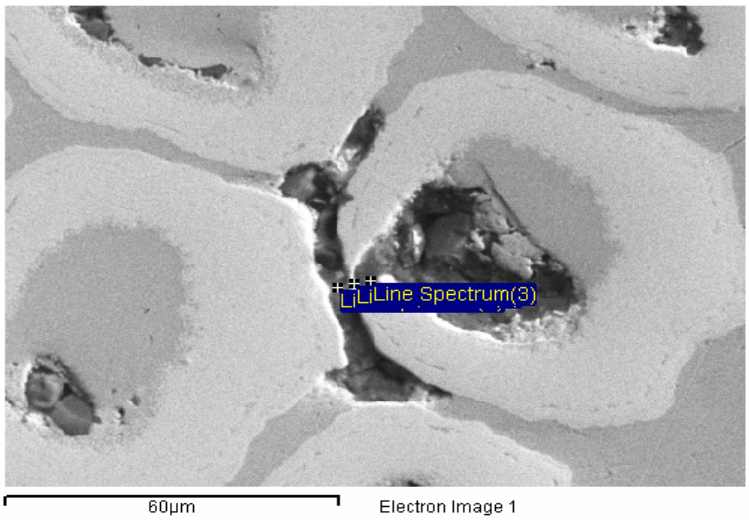


Figure 12b: 3 Point Scans of Coil17HT

Spectrum	Cu	Nb	Sn	Ta	Total
Spectrum(1)	9.18	60.42	20.35	10.06	100.00
Spectrum(2)	40.44	33.56	16.99	9.01	100.00
Spectrum(3)	41.66	7.21	-7.44	58.57	100.00

Table 7: Elemental Analysis of Points in Figure 12b (Weight %)

Figure 12 shows 2 EDS scans of points where the niobium barrier of the filament failed and tin diffused into the bulk copper. Both Figure 12a and 12b show areas that should cause the superconductor to have smaller RRR values. These failures would be caused from defects that occur during the cabling process.

3) <u>Summary</u>:

- The cabling process is causing problems in the sub-elements to the point where the superconductor may have smaller RRR values.

- There is approximately 10 weight % tantalum in the niobium.

- The atomic niobium to tin ratio is approximately 2.5 (not 3) in the niobium tin region, after heat treatment, suggesting formation of Nb_3Sn.

- After heat treatment the center of the filament is still approximately 10 wt% tin, due to the fact that all of the tin was unable to diffuse to the niobium layer.

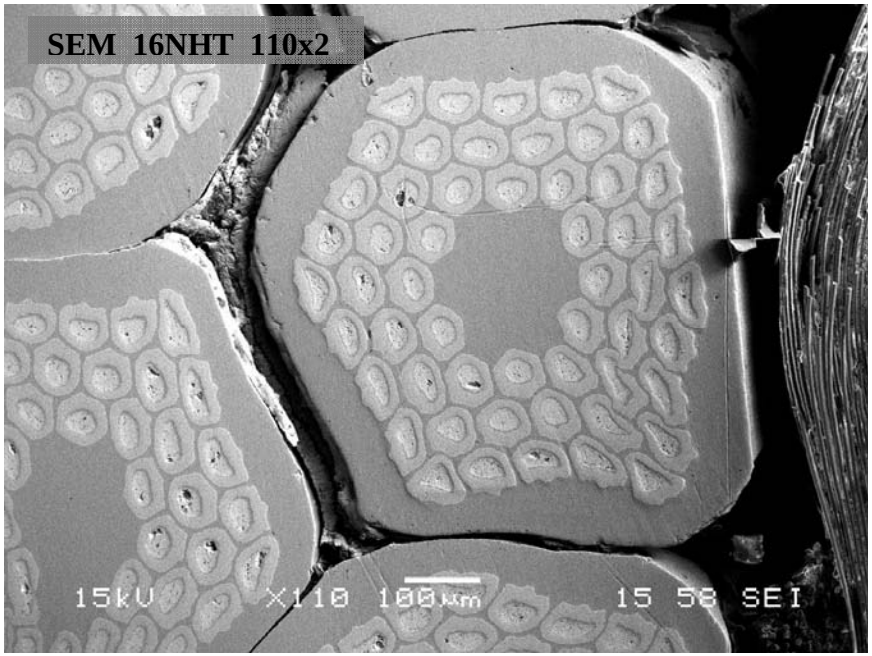
- There was no noticeable difference between Coil 16 and 17 from SEM, EDS, and light microscope analysis.

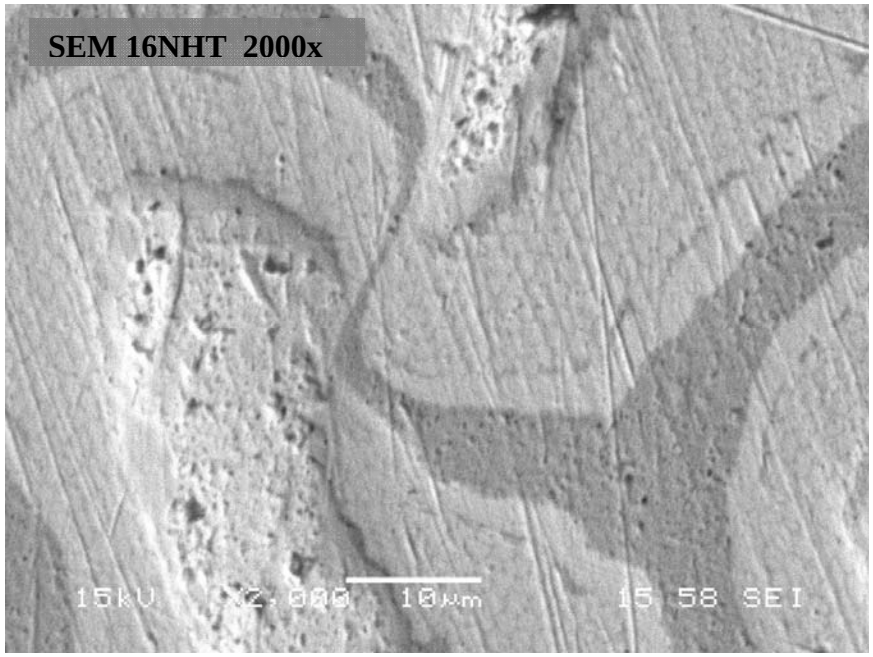
- There is **a lot** of data in Appendices A-D that is not presented above.

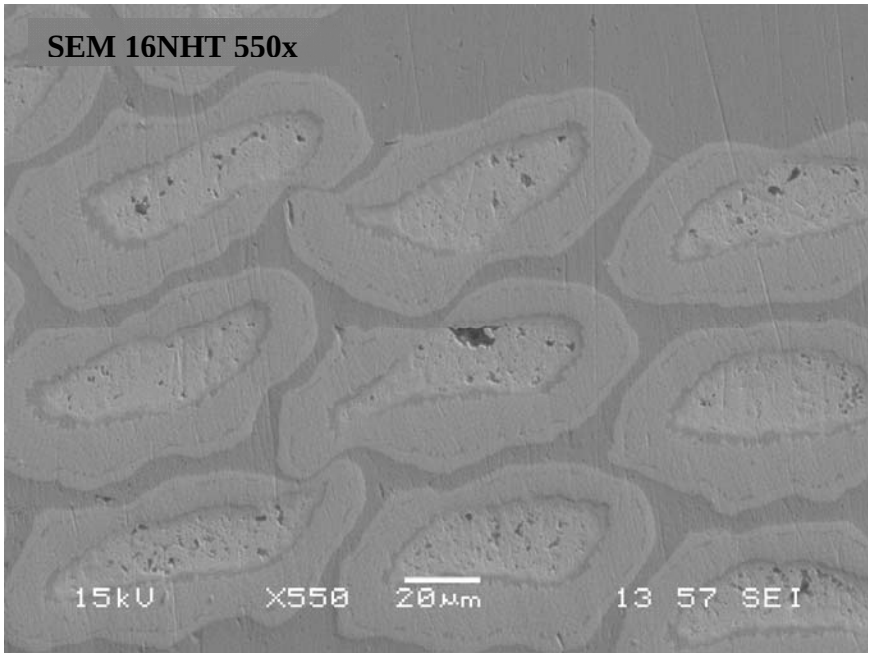
- Both types of cables have substantial cable damages done at the narrow edges, regardless of the one or two step processes, suggesting tin leakage.

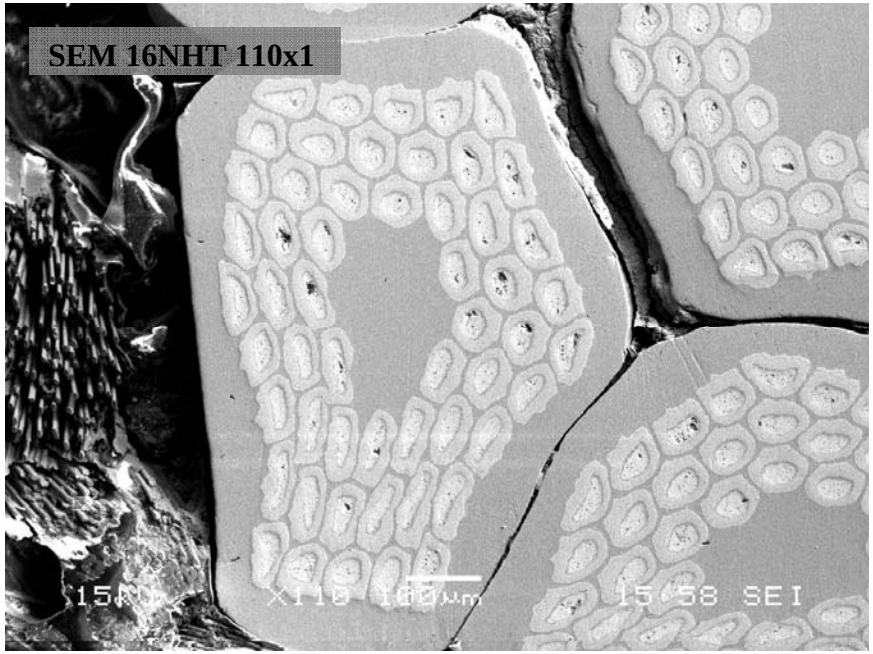
- The Coil 16 and Coil 17 were tested as the Mirror Magnets HFDM-04 and HFDM-05 without success. Their data together with short sample data will be reported separately.

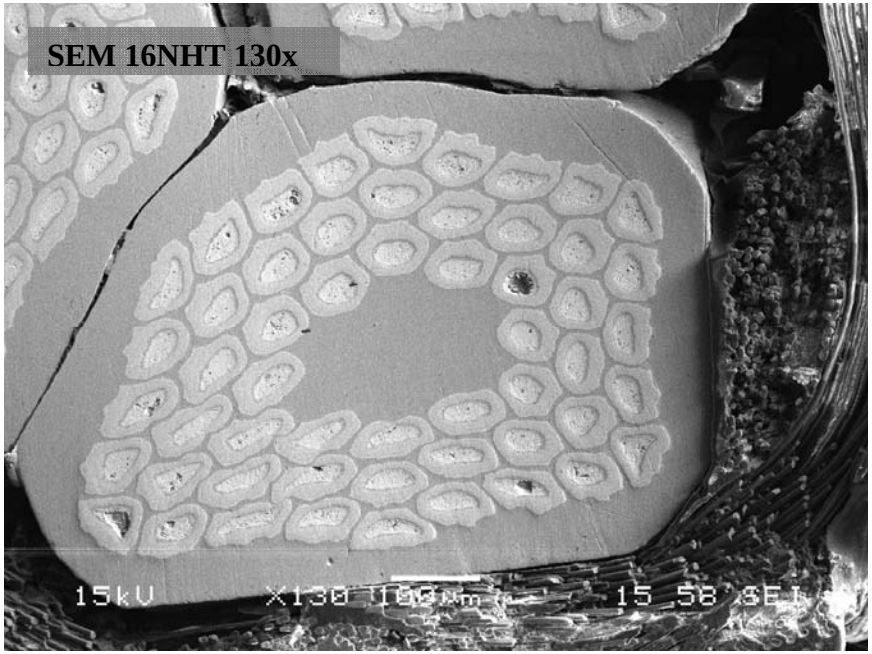
Appendix A
Coil 16 NHT

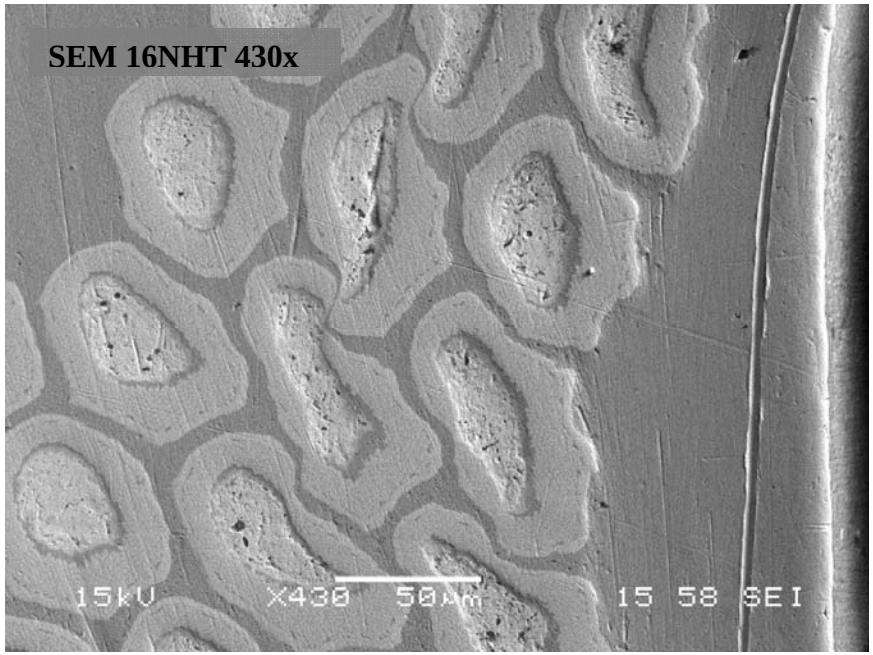


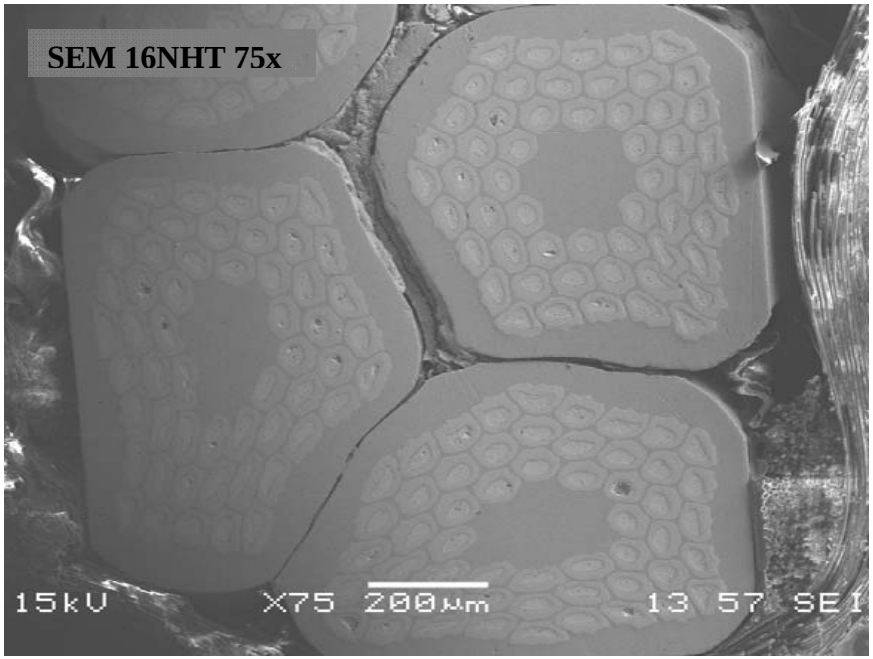


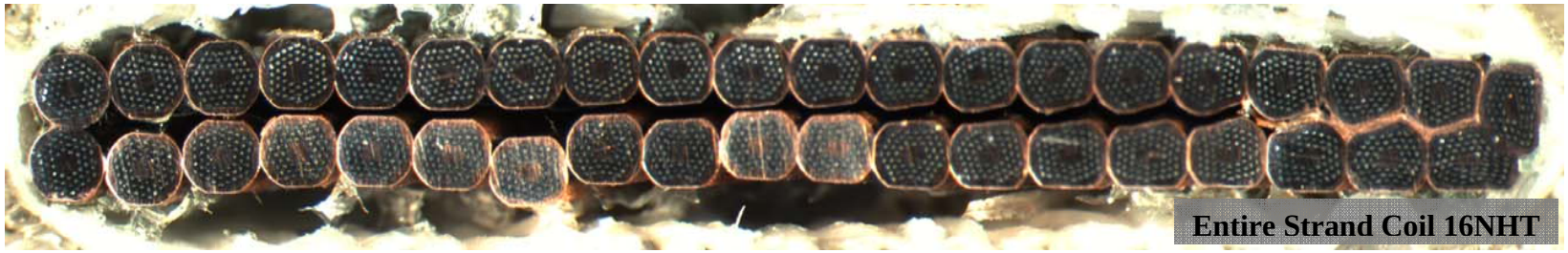


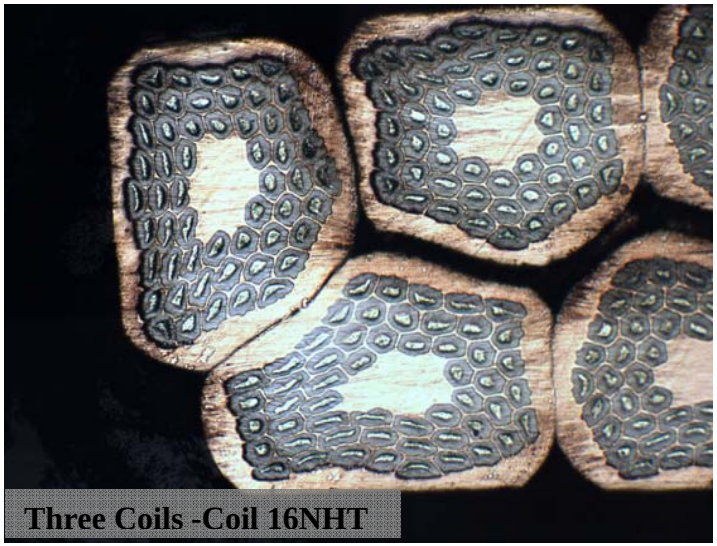

SEM 16NHT 110x1
15kV X110 100µm 15 58 SEI

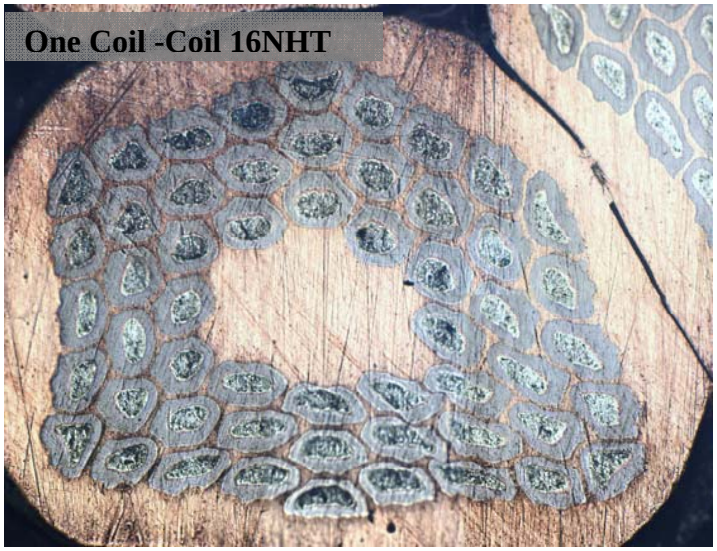

SEM 16NHT 130x
15kV X130 100µm 15 58 SEI


SEM 16NHT 430x
15kV X430 50µm 15 58 SEI


SEM 16NHT 75x
15kV X75 200µm 13 57 SEI


Entire Strand Coil 16NHT


Three Coils -Coil 16NHT


One Coil -Coil 16NHT

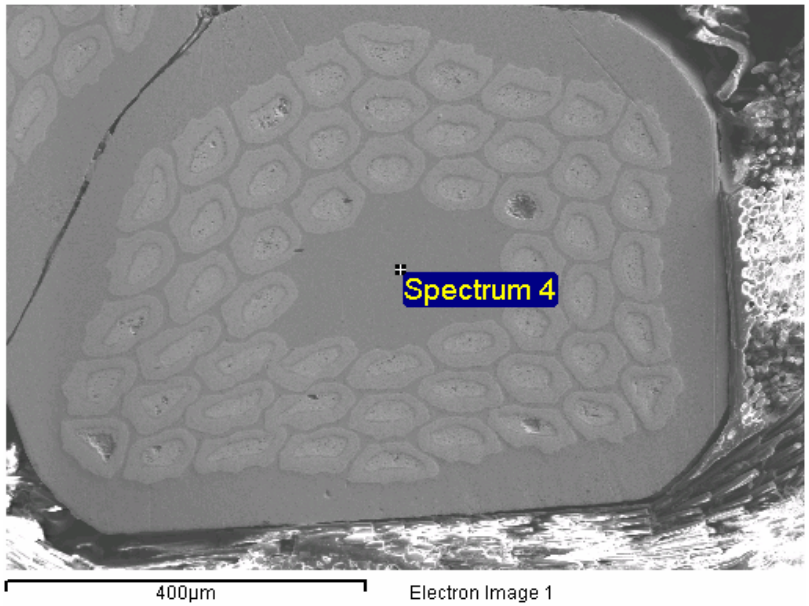
Coil 16 Non Heat treated

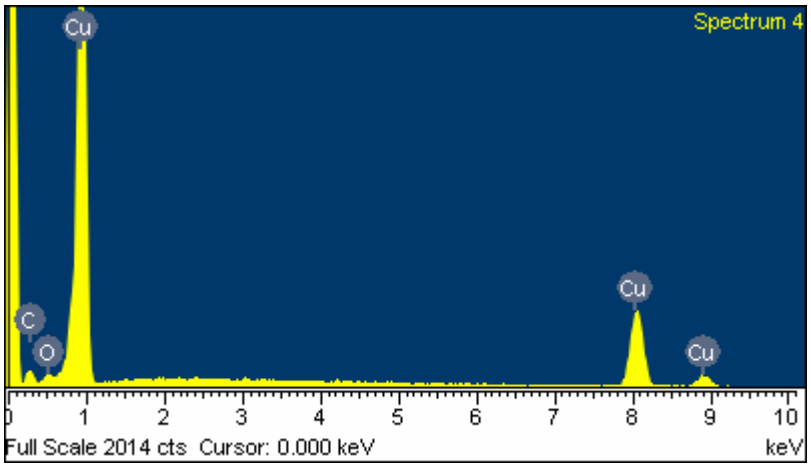
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	12.10	41.12
O K	1.27	3.23
Cu L	86.63	55.65
Totals	100.00	





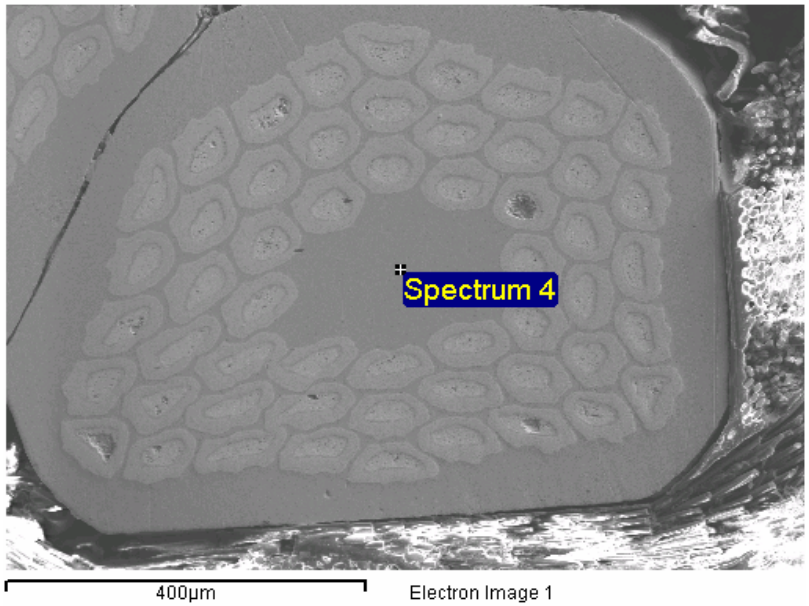
Coil 16 non heat treated

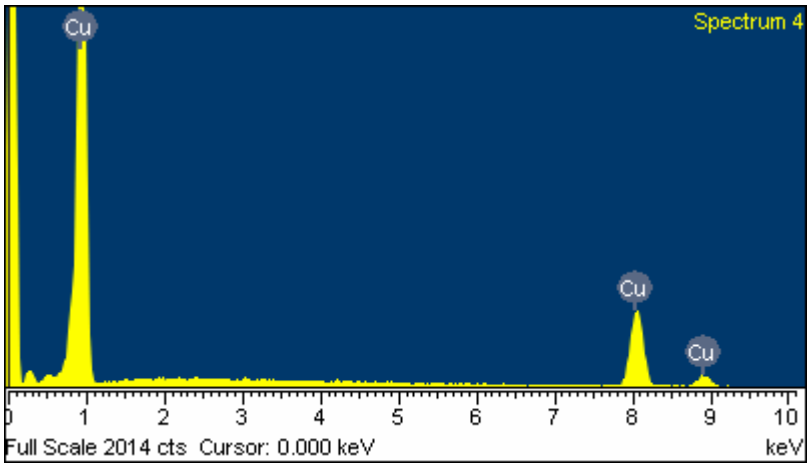
Spectrum processing :
Peak possibly omitted : 0.267 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	100.00	100.00
Totals	100.00	





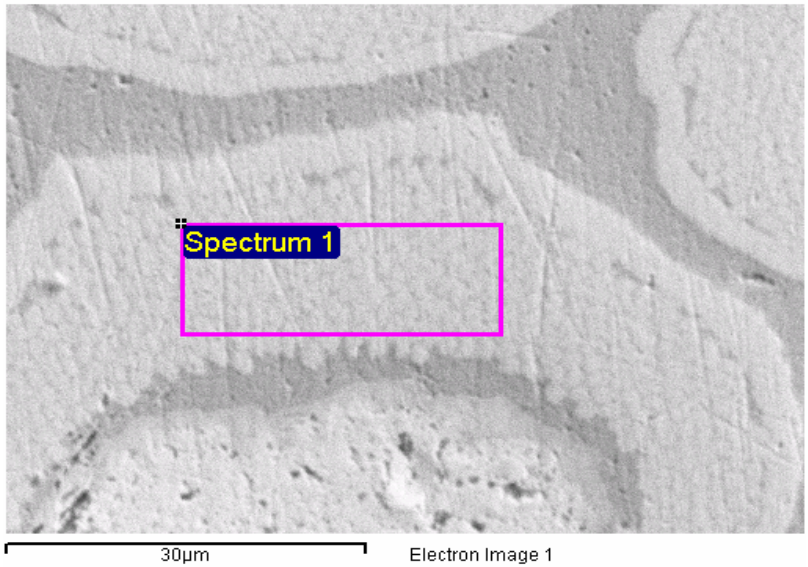
Coil 16NHT

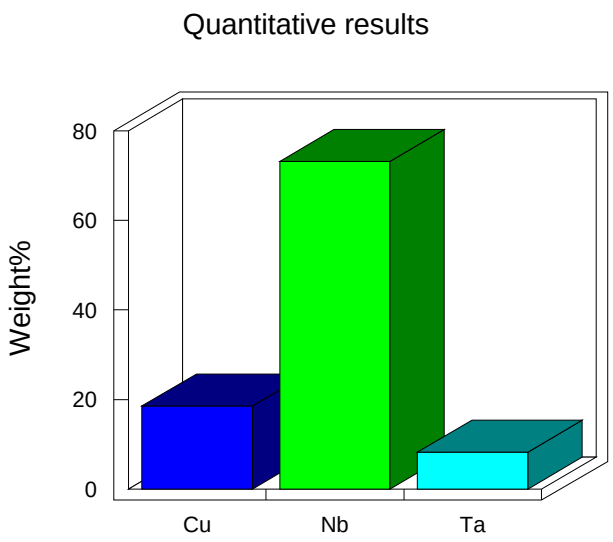
Spectrum processing:
No peaks omitted

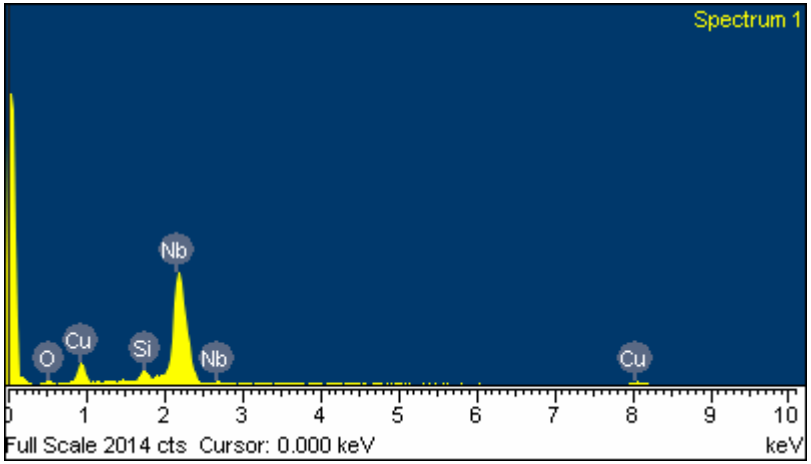
Processing option: All elements analyzed (Normalised)
Number of iterations = 3

Standard:
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	18.58	25.98
Nb L	73.18	69.97
Ta M	8.24	4.05
Totals	100.00	







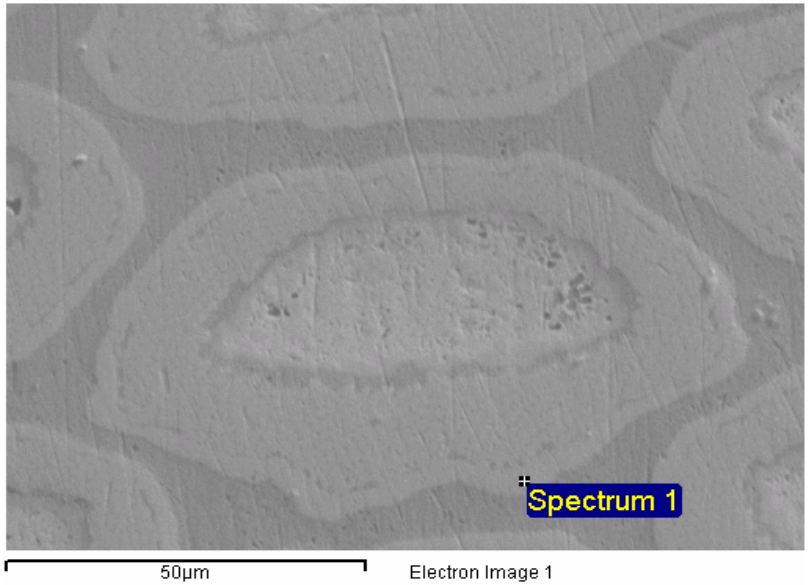
Coil 16 non heat treated outer Nb layer

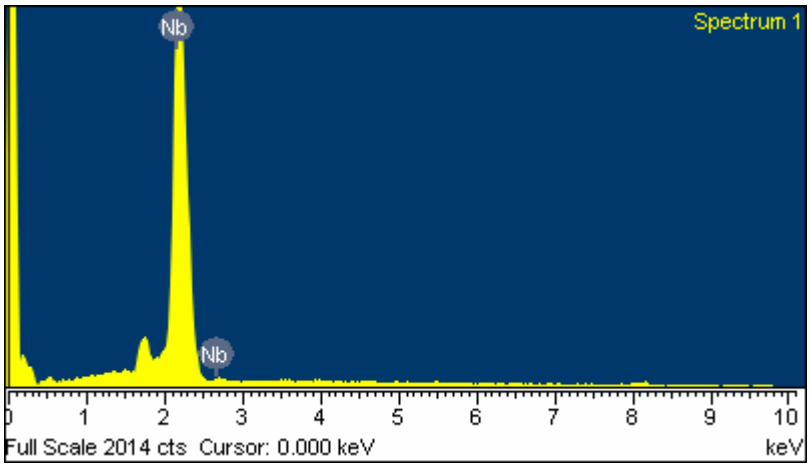
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Nb Nb 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Nb L	100.00	100.00
Totals	100.00	





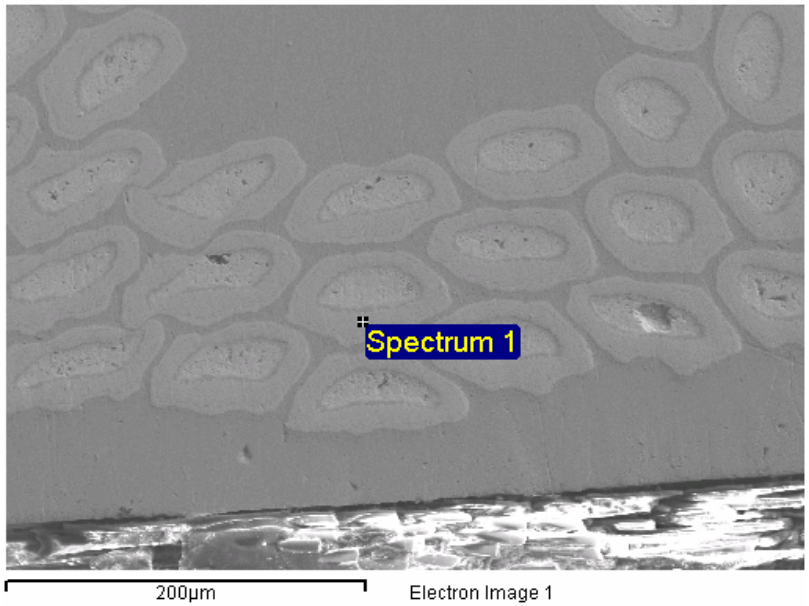
Coil 16 non heat treated Nb wall

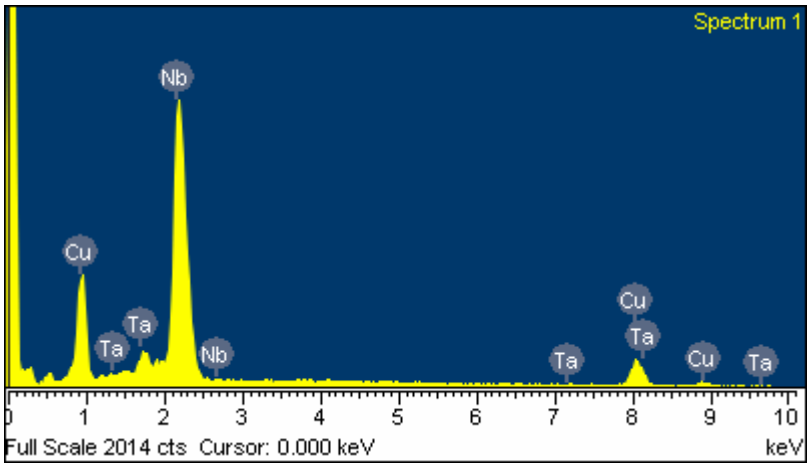
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	30.57	40.21
Nb L	63.34	56.98
Ta M	6.10	2.82
Totals	100.00	





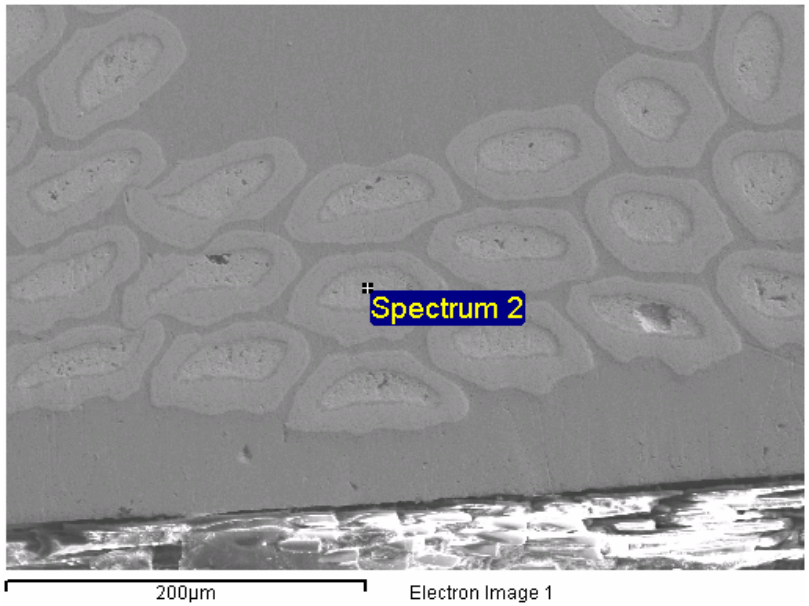
Coil 16 non ht Tin

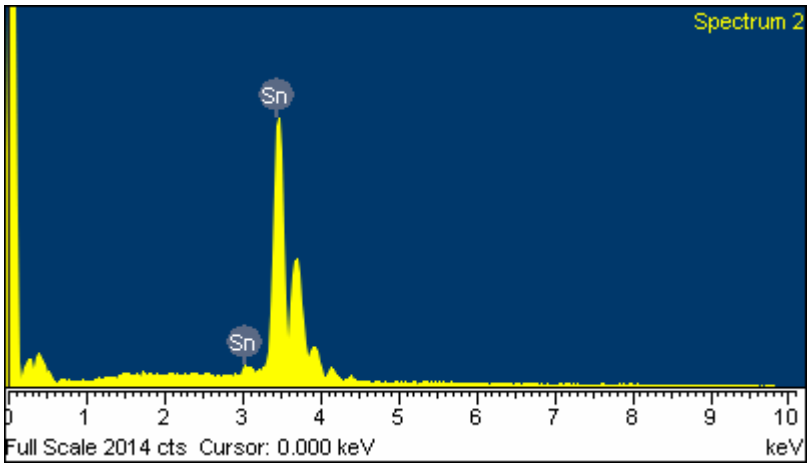
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Sn Sn 1-Jun-1999 12:00 AM

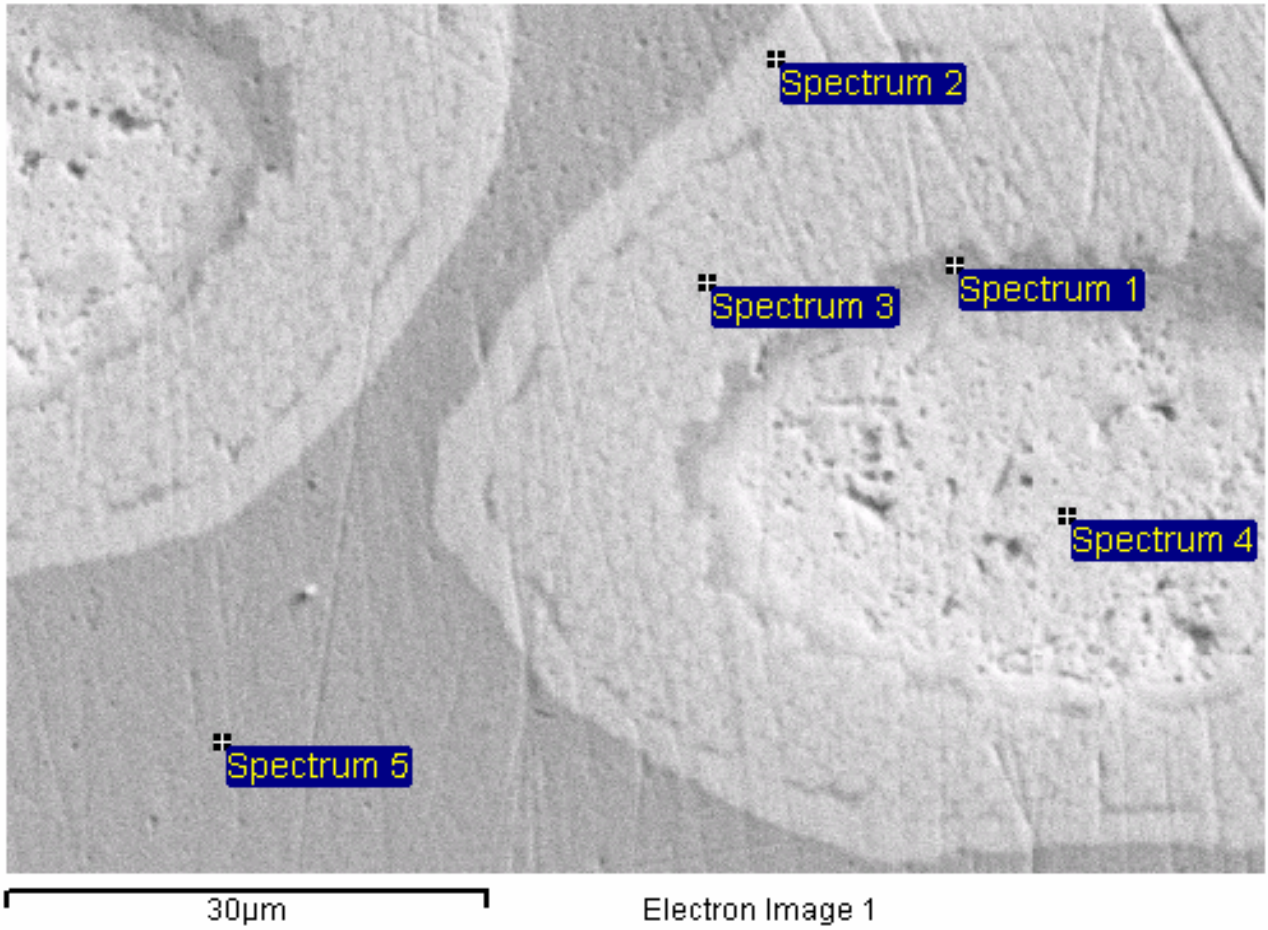
Element	Weight%	Atomic%
Sn L	100.00	100.00
Totals	100.00	





Ryuji Coil 16NHT

4/12/2005 4:00

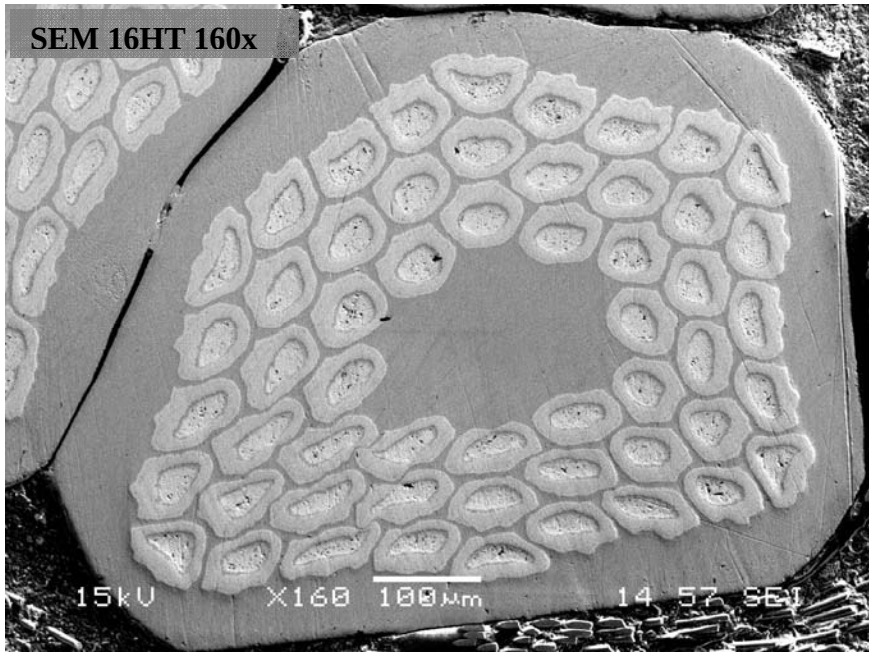


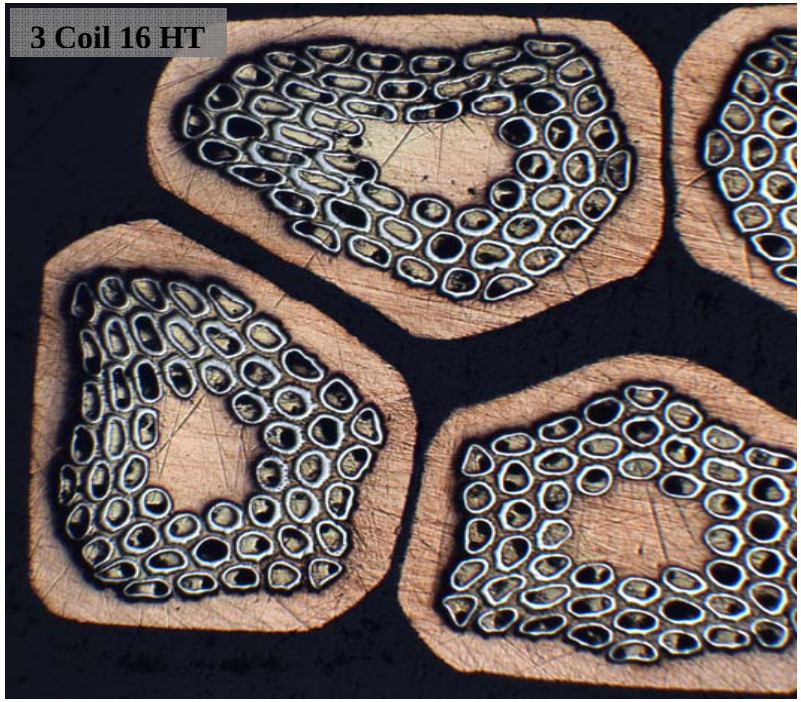
Processing option : All elements analysed (Normalised)

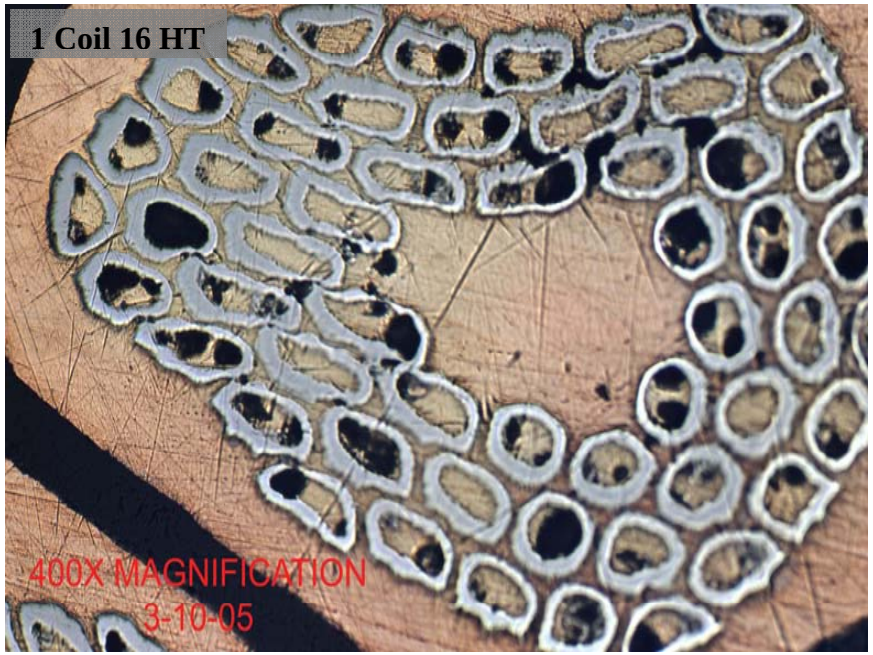
Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Spectrum 1	Yes	98.09	0.77	-0.34	1.48	100.00
Spectrum 2	Yes	3.59	85.72	1.27	9.43	100.00
Spectrum 3	Yes	11.84	80.24	-0.13	8.06	100.00
Spectrum 4	Yes	0.46	-0.75	99.10	1.19	100.00
Spectrum 5	Yes	97.71	0.25	1.19	0.86	100.00
Mean		42.34	33.24	20.22	4.20	100.00
Std. deviation		50.89	45.44	44.10	4.18	
Max.		98.09	85.72	99.10	9.43	
Min.		0.46	-0.75	-0.34	0.86	

All results in weight%

Appendix B
Coil 16 HT







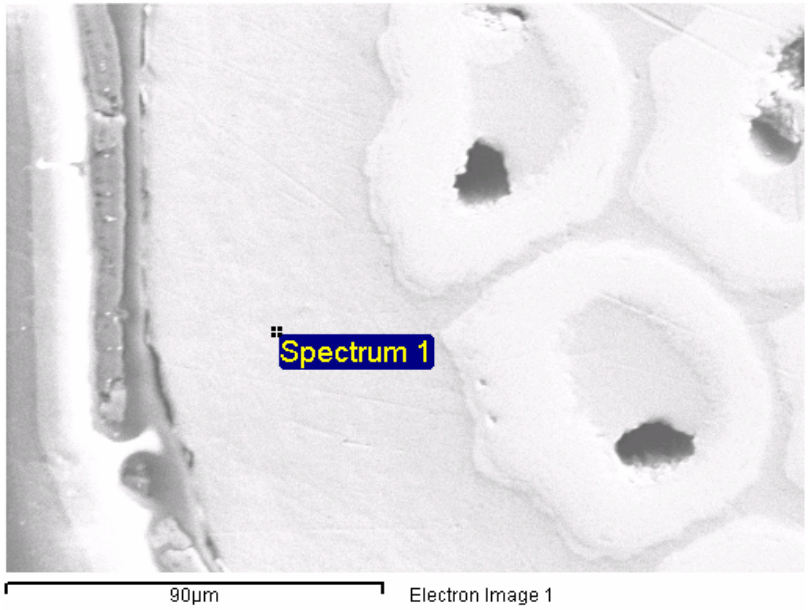
Coil 16 HT

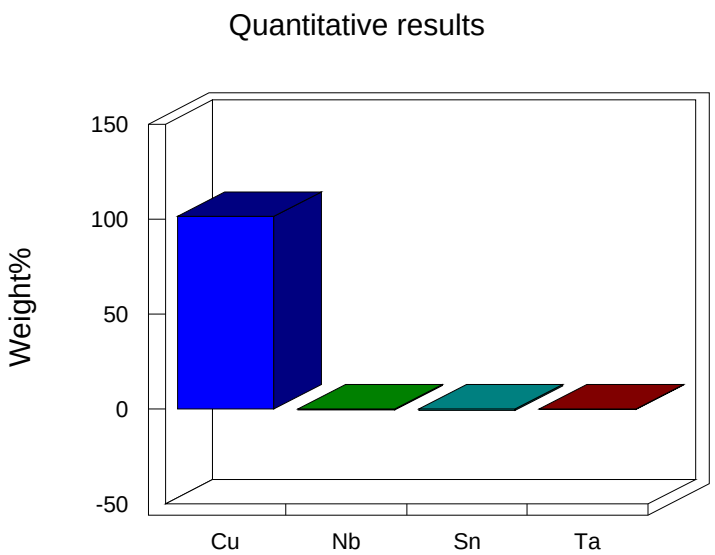
Spectrum processing :
No peaks omitted

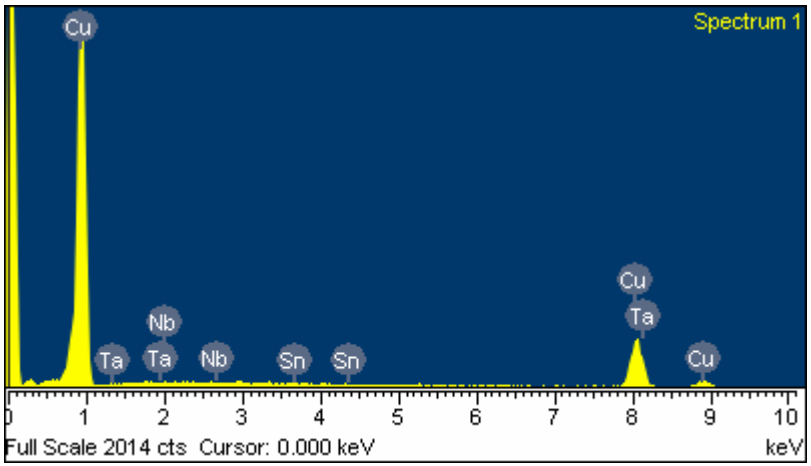
Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	101.52	100.85
Nb L	-0.58	-0.40
Sn L	-0.72	-0.39
Ta M	-0.21	-0.07
Totals	100.00	







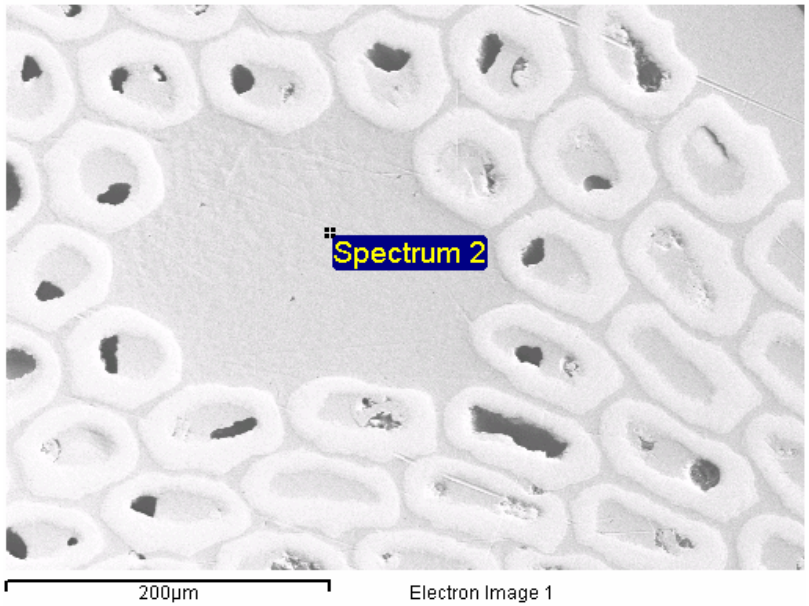
Coil 16 HT

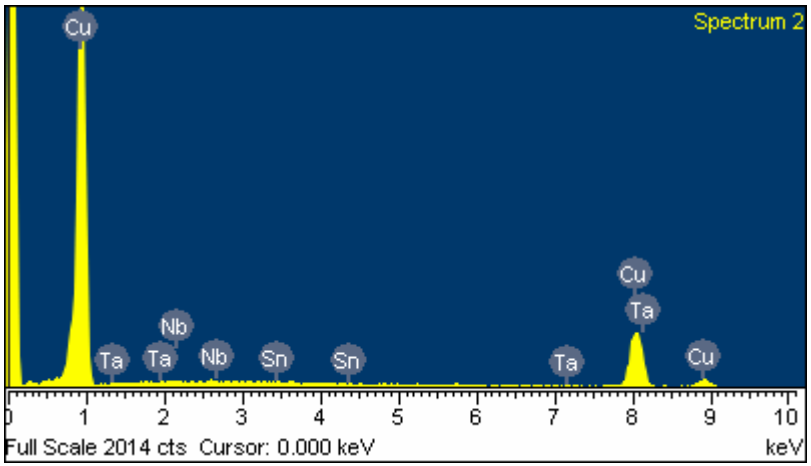
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 2

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	99.75	99.87
Nb L	0.19	0.13
Sn L	-0.10	-0.05
Ta M	0.16	0.06
Totals	100.00	





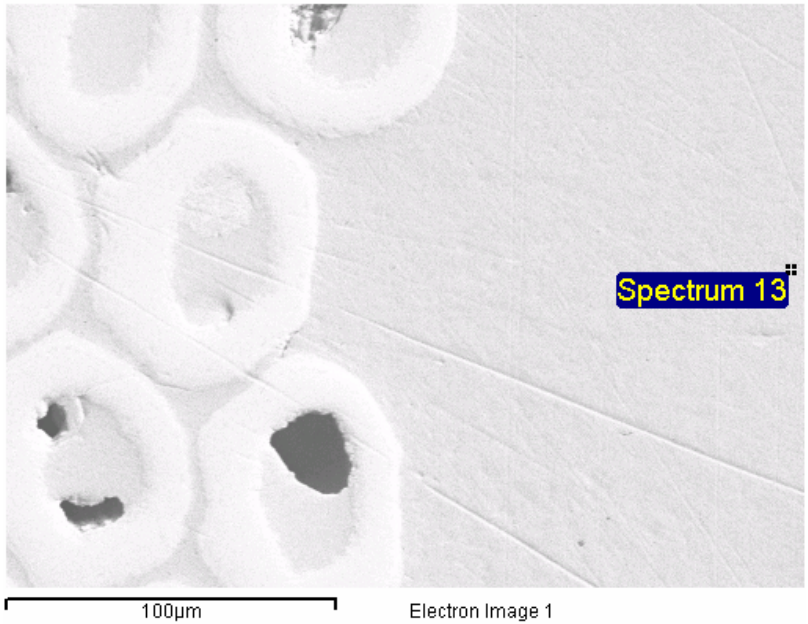
Coil 16 HT

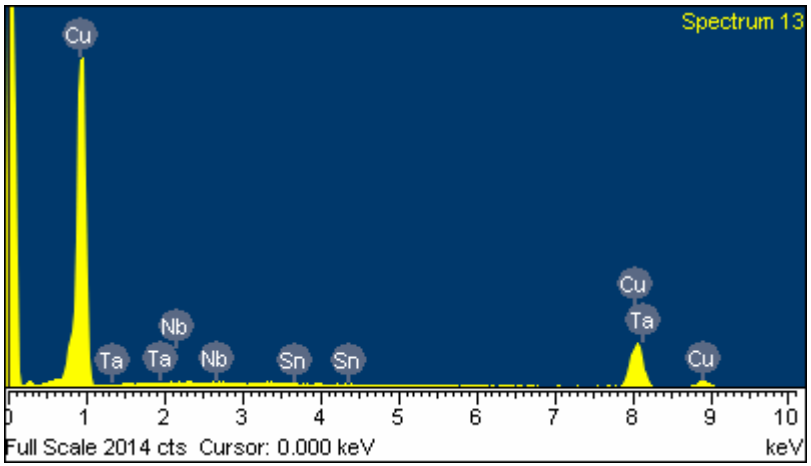
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	100.56	100.23
Nb L	0.08	0.06
Sn L	-0.33	-0.18
Ta M	-0.31	-0.11
Totals	100.00	





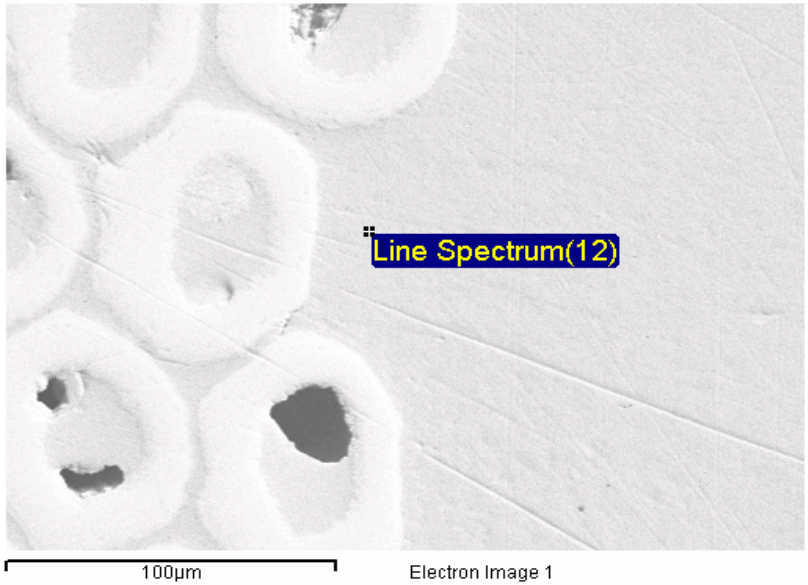
Coil 16 HT

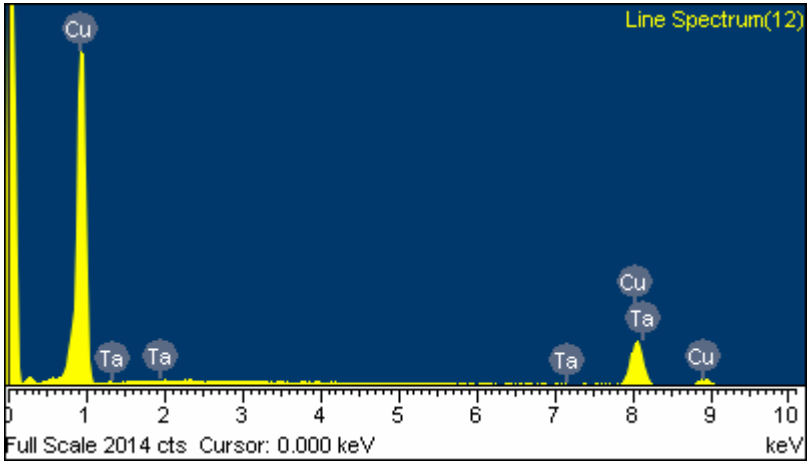
Spectrum processing :
Peak possibly omitted : 0.271 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	99.81	99.93
Ta M	0.19	0.07
Totals	100.00	





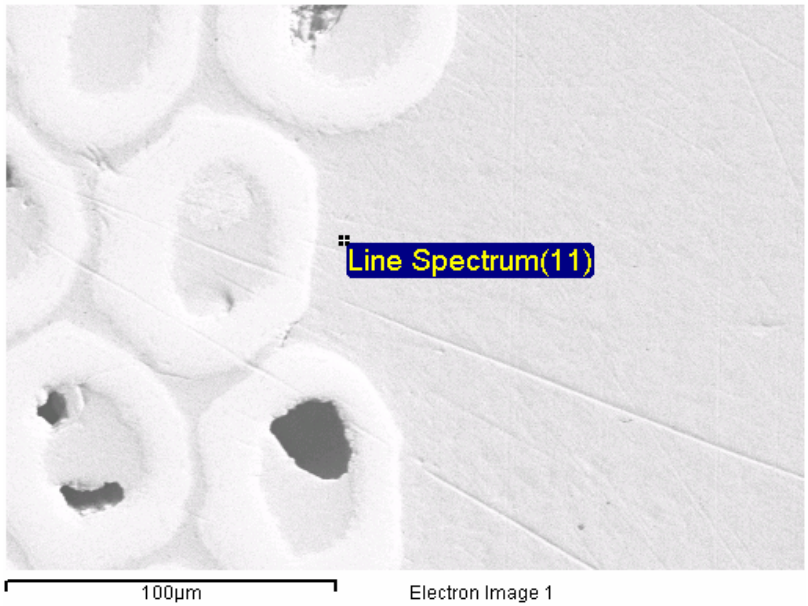
Coil 16 HT

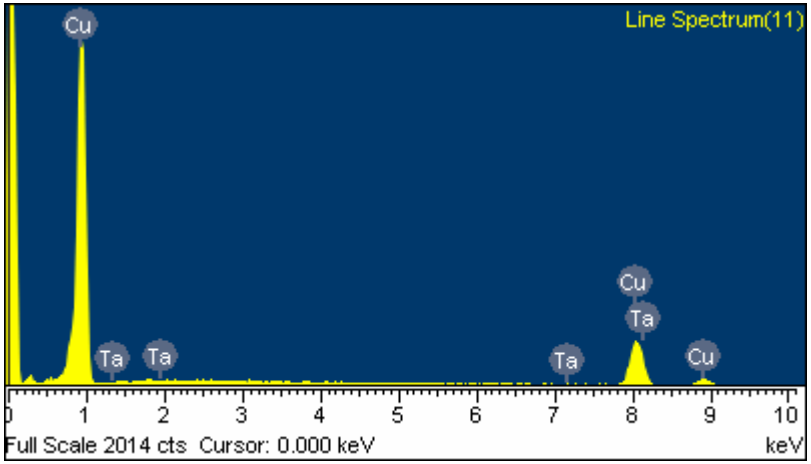
Spectrum processing :
Peak possibly omitted : 0.259 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	99.71	99.90
Ta M	0.29	0.10
Totals	100.00	





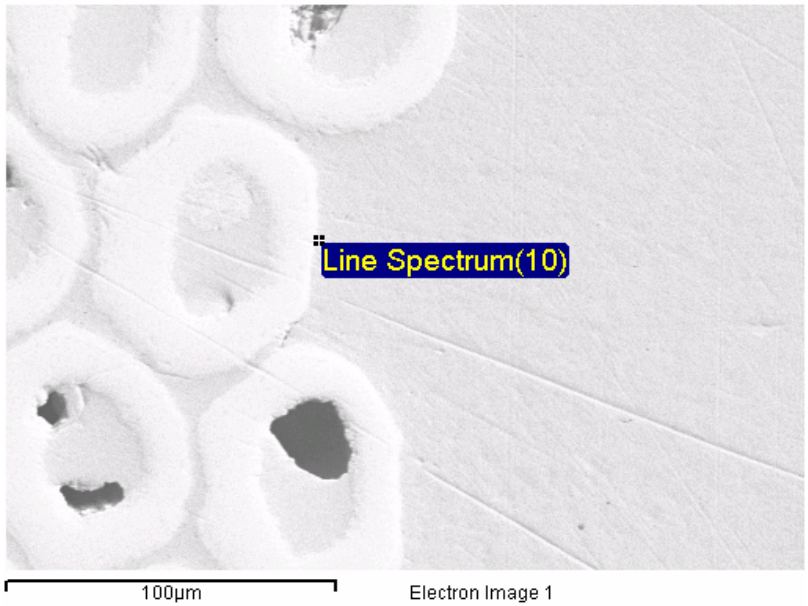
Coil 16 HT

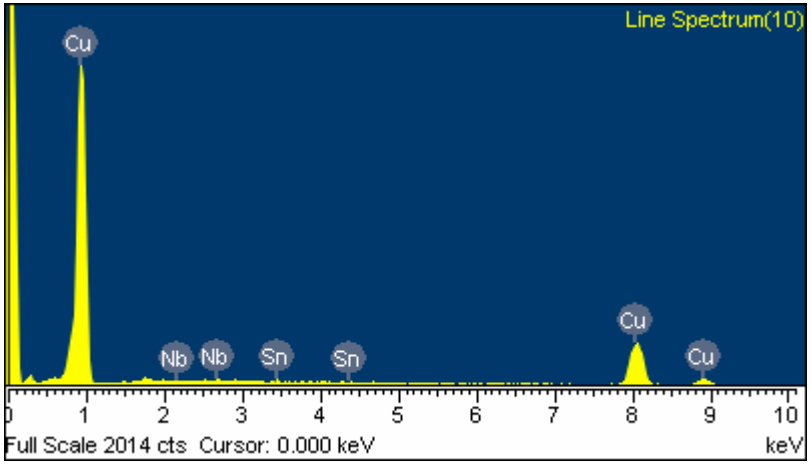
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	99.12	99.47
Nb L	0.39	0.27
Sn L	0.49	0.26
Totals	100.00	





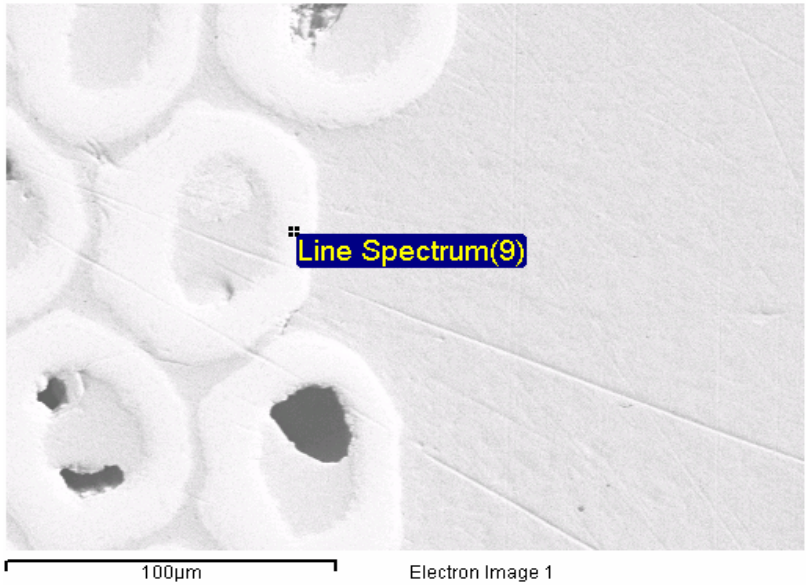
Coil 16 HT

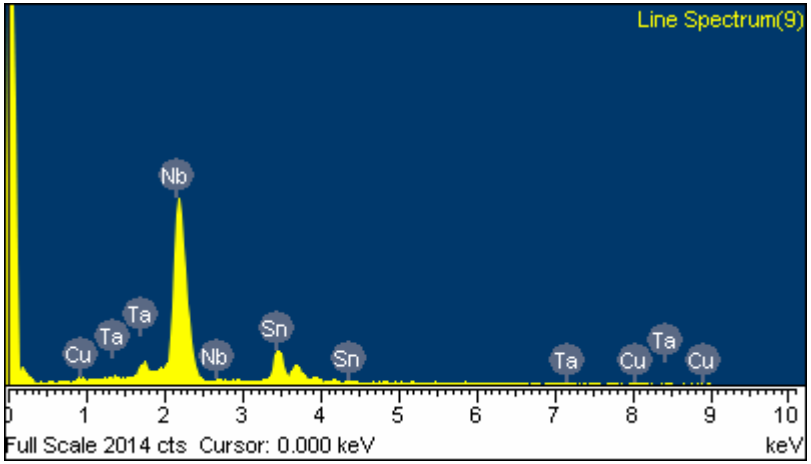
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 2

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	2.14	3.39
Nb L	65.74	71.03
Sn L	26.68	22.57
Ta M	5.44	3.02
Totals	100.00	





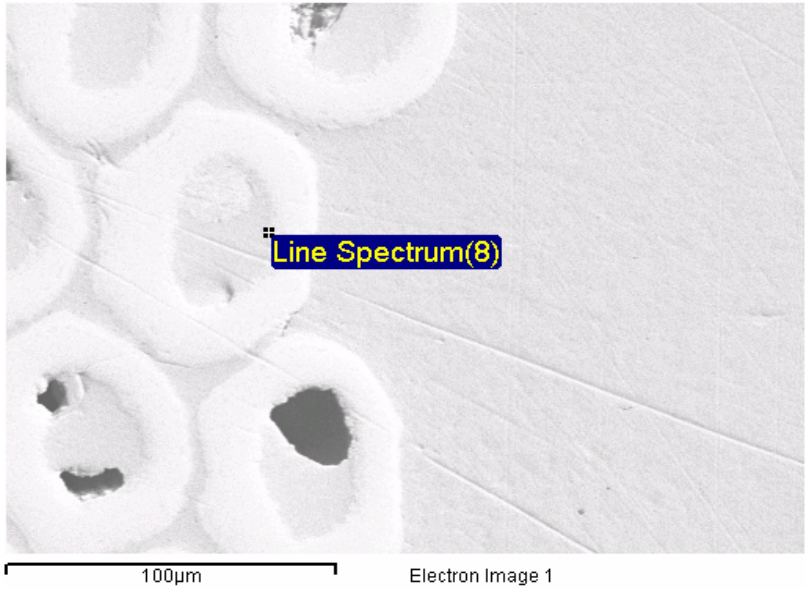
Coil 16 HT

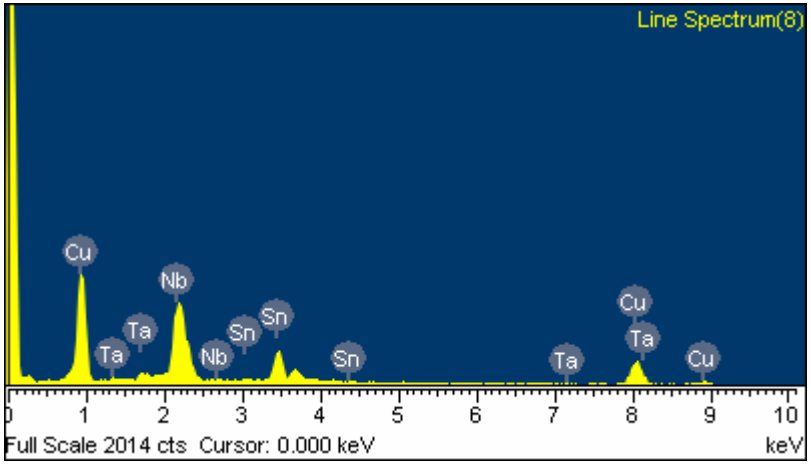
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	48.54	60.60
Nb L	30.54	26.08
Sn L	18.06	12.07
Ta M	2.86	1.25
Totals	100.00	





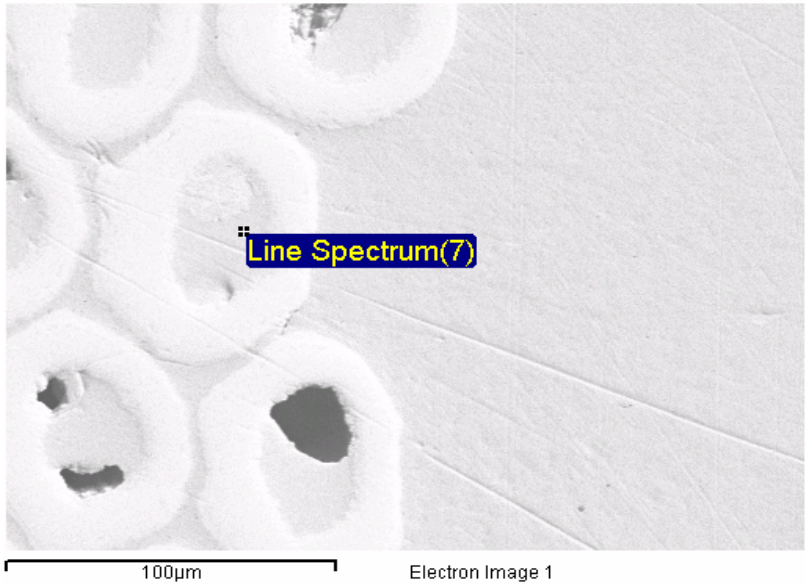
Coil 16 HT

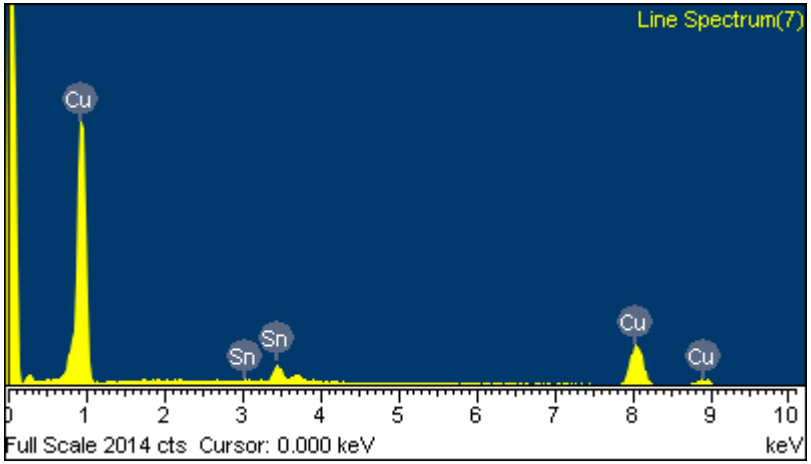
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	90.11	94.45
Sn L	9.89	5.55
Totals	100.00	





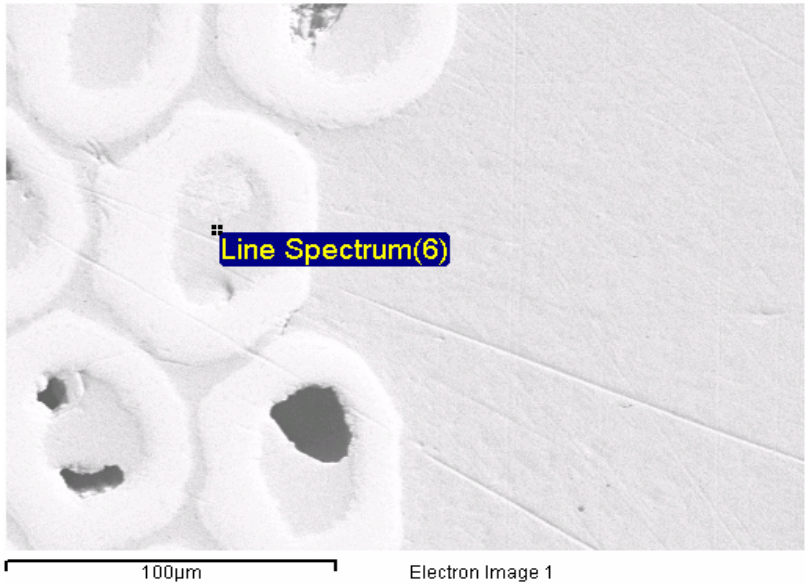
Coil 16 HT

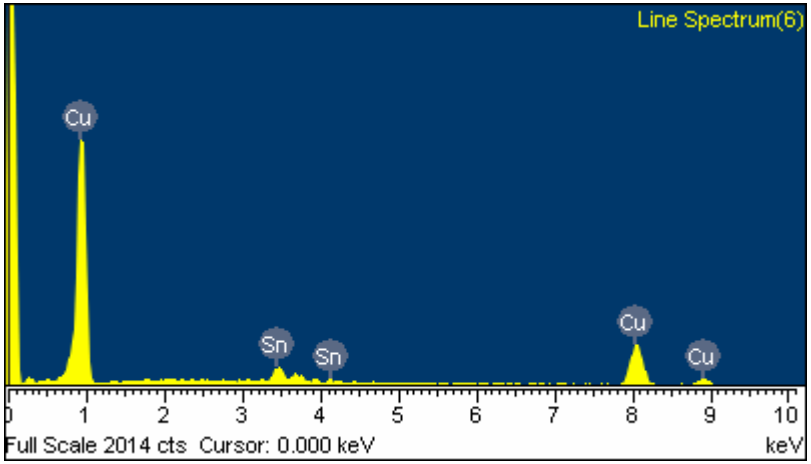
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	89.22	93.92
Sn L	10.78	6.08
Totals	100.00	





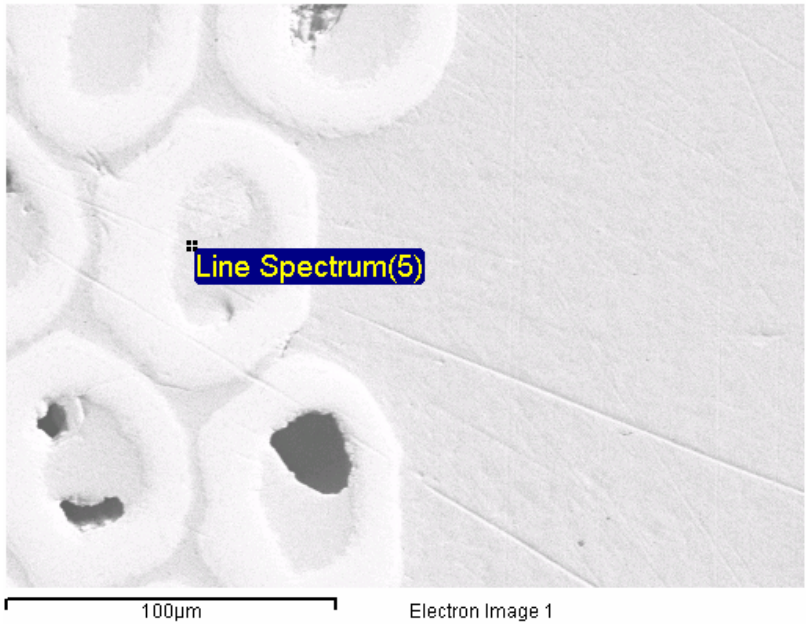
Coil 16 HT

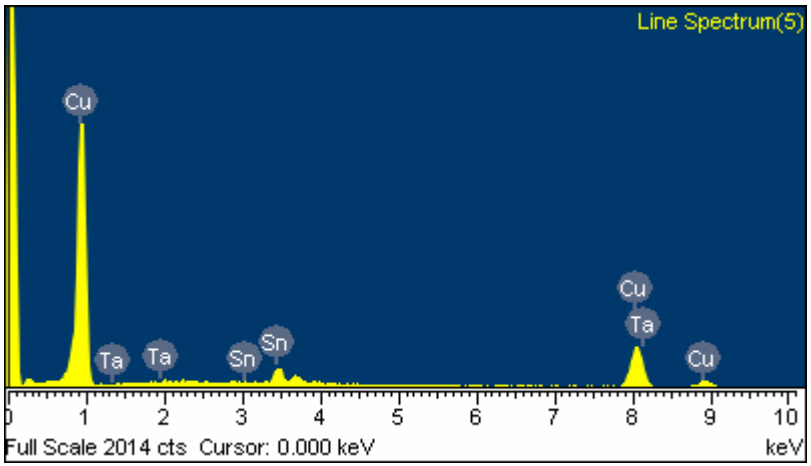
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	88.92	93.80
Sn L	10.82	6.11
Ta M	0.25	0.09
Totals	100.00	





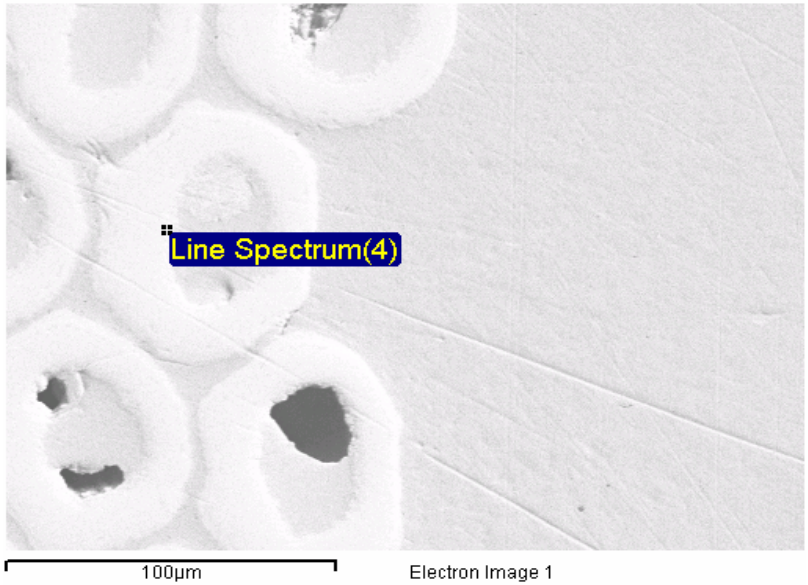
Coil 16 HT

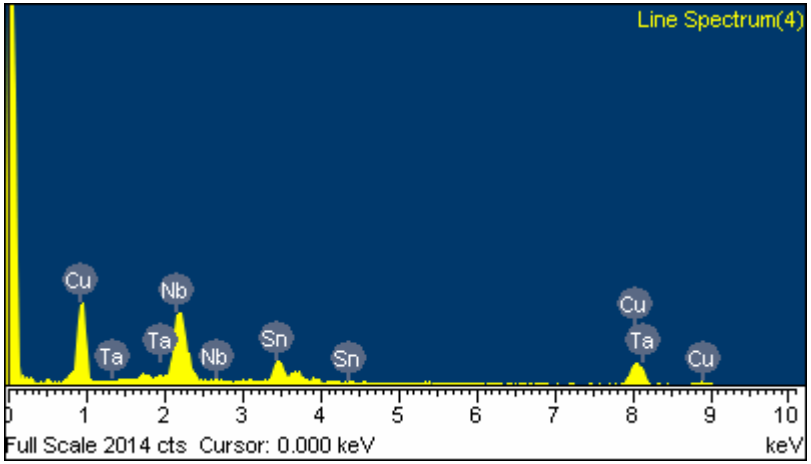
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	46.26	58.29
Nb L	33.02	28.46
Sn L	17.60	11.87
Ta M	3.12	1.38
Totals	100.00	





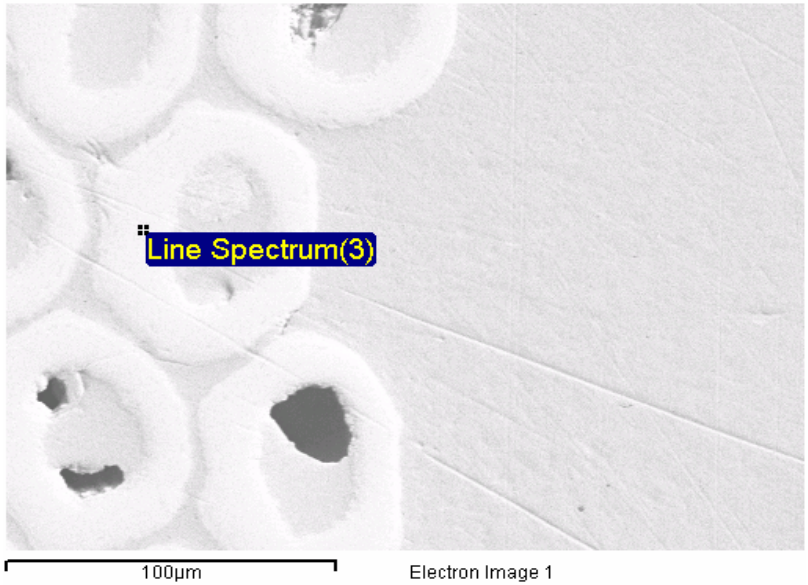
Coil 16 HT

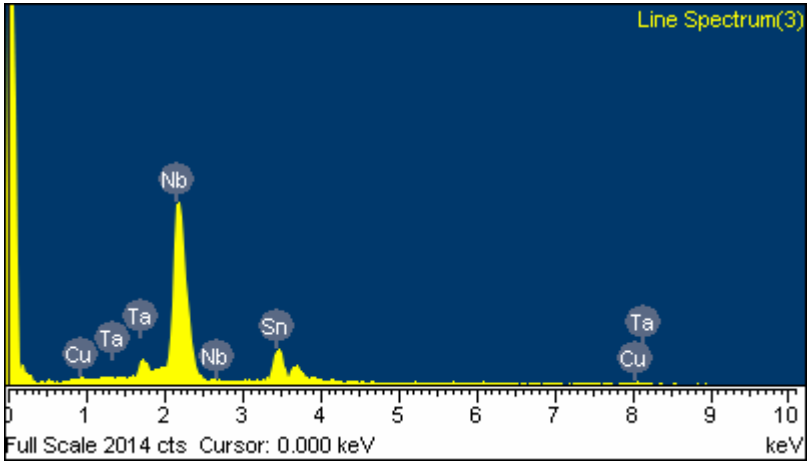
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 2

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	2.06	3.28
Nb L	65.06	70.81
Sn L	25.73	21.92
Ta M	7.14	3.99
Totals	100.00	





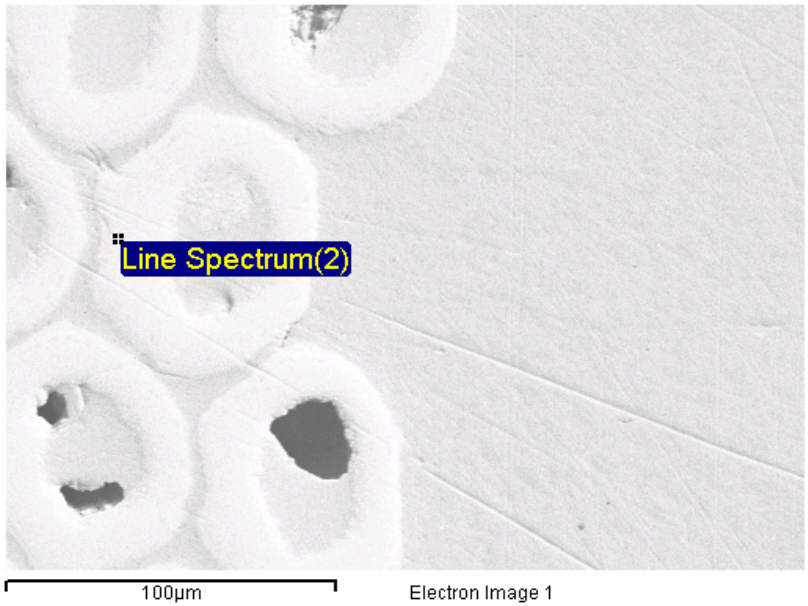
Coil 16 HT

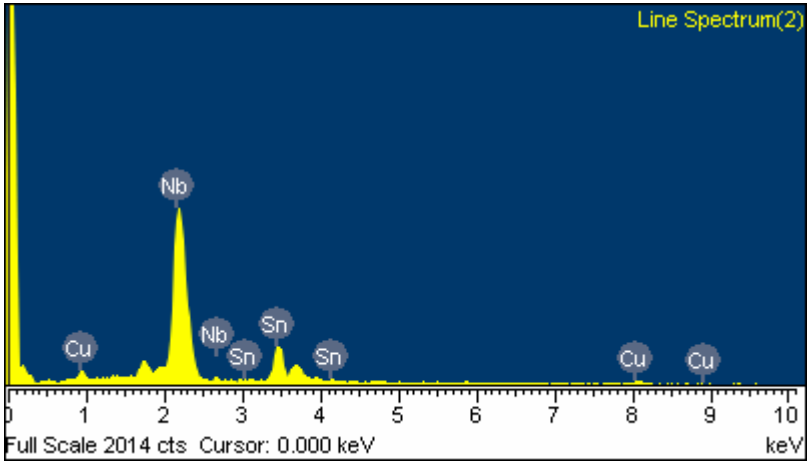
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	6.71	10.12
Nb L	64.85	66.91
Sn L	28.44	22.97
Totals	100.00	





Coil 16 HT

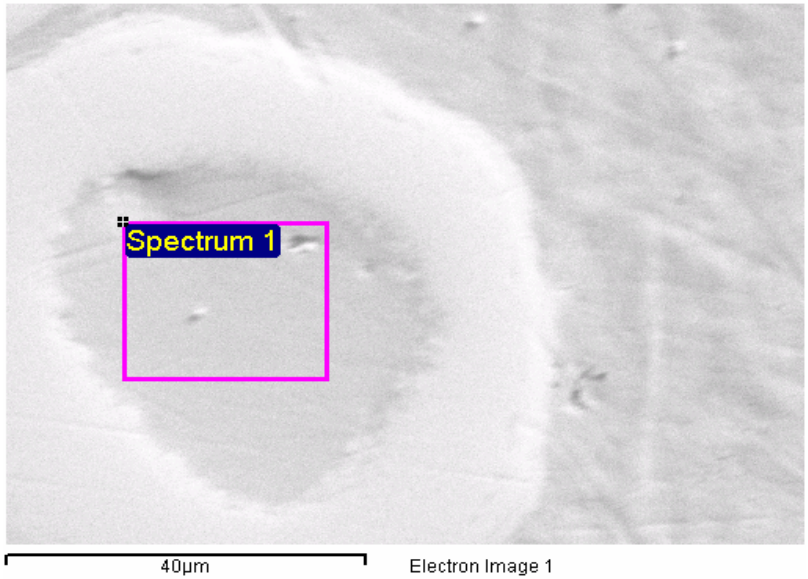
4/12/2005 4:56:59 PM

Spectrum processing :
No peaks omitted

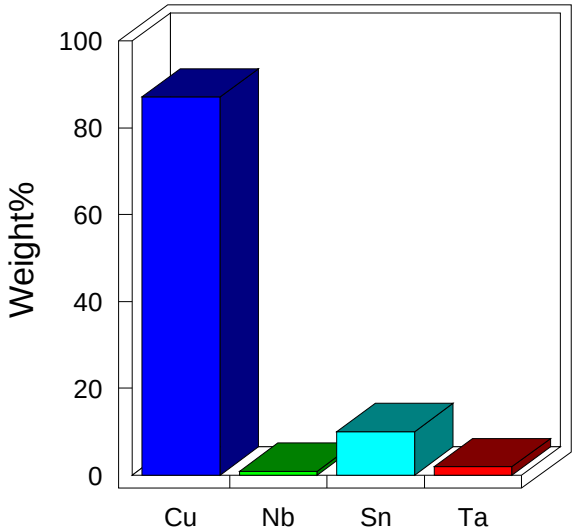
Processing option : All elements analyzed (Normalised)
Number of iterations = 3

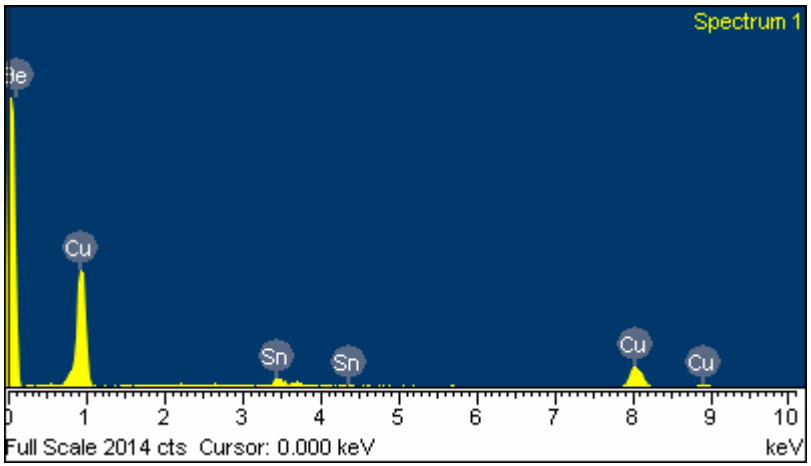
Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	87.08	92.86
Nb L	0.92	0.67
Sn L	10.04	5.73
Ta M	1.97	0.74
Totals	100.00	



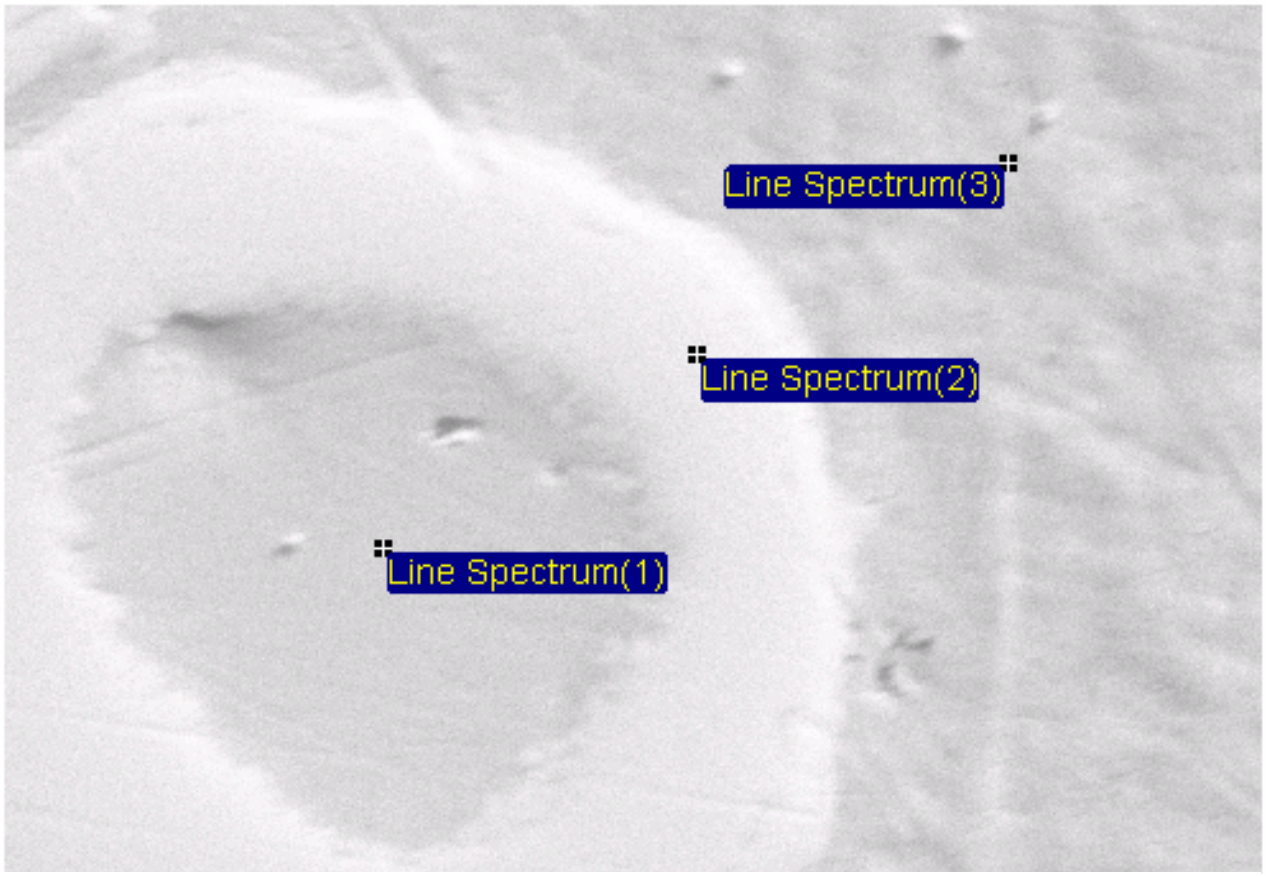
Quantitative results





Coil 16 HT

4/12/2005 4:54:46 PM



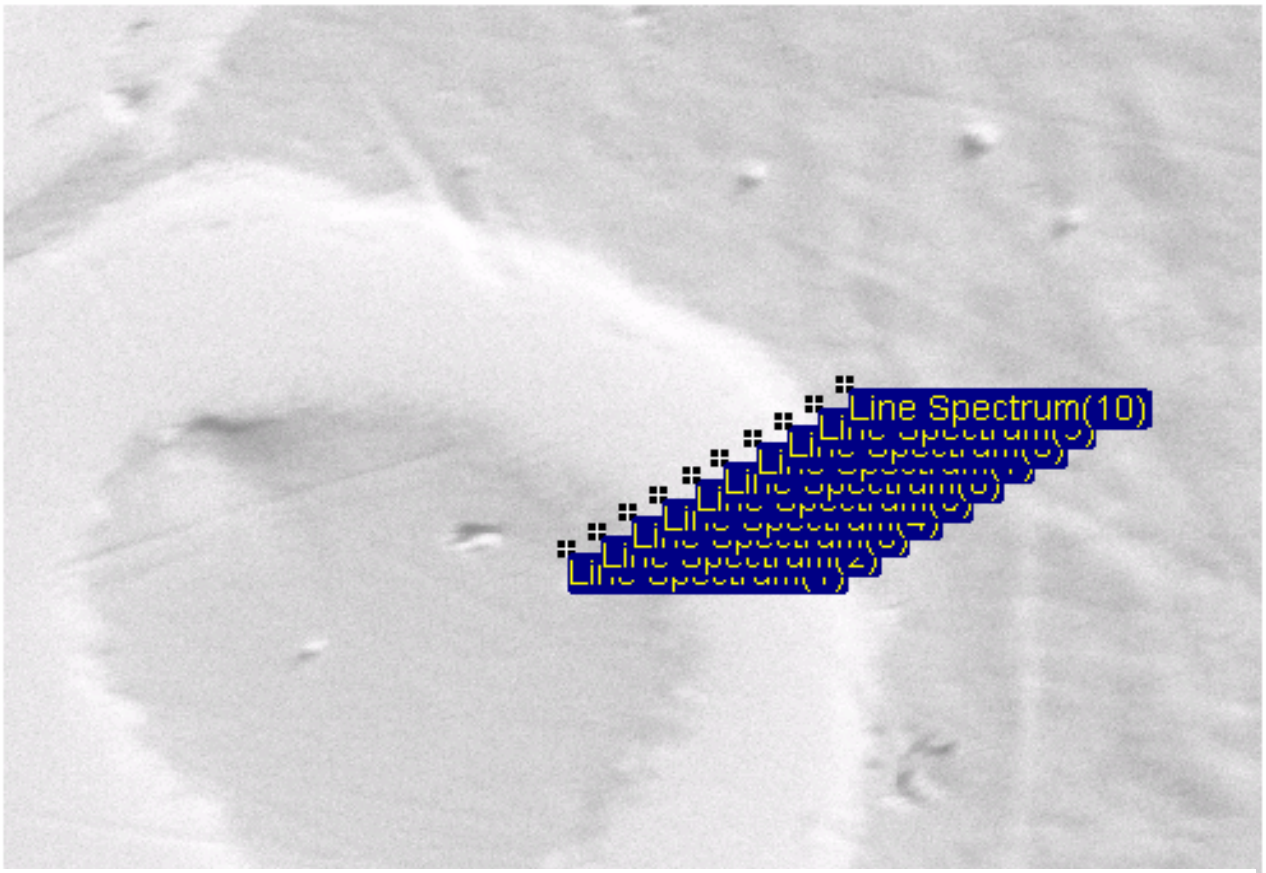
Processing option : All elements analysed (Normalised)

Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Line Spectrum(1)	Yes	88.82	-0.35	11.26	0.27	100.00
Line Spectrum(2)	Yes	5.10	61.43	27.95	5.53	100.00
Line Spectrum(3)	Yes	101.11	-1.14	-0.56	0.59	100.00
Mean		65.01	19.98	12.88	2.13	100.00
Std. deviation		52.25	35.90	14.33	2.95	
Max.		101.11	61.43	27.95	5.53	
Min.		5.10	-1.14	-0.56	0.27	

All results in weight%

Coil 16 HT

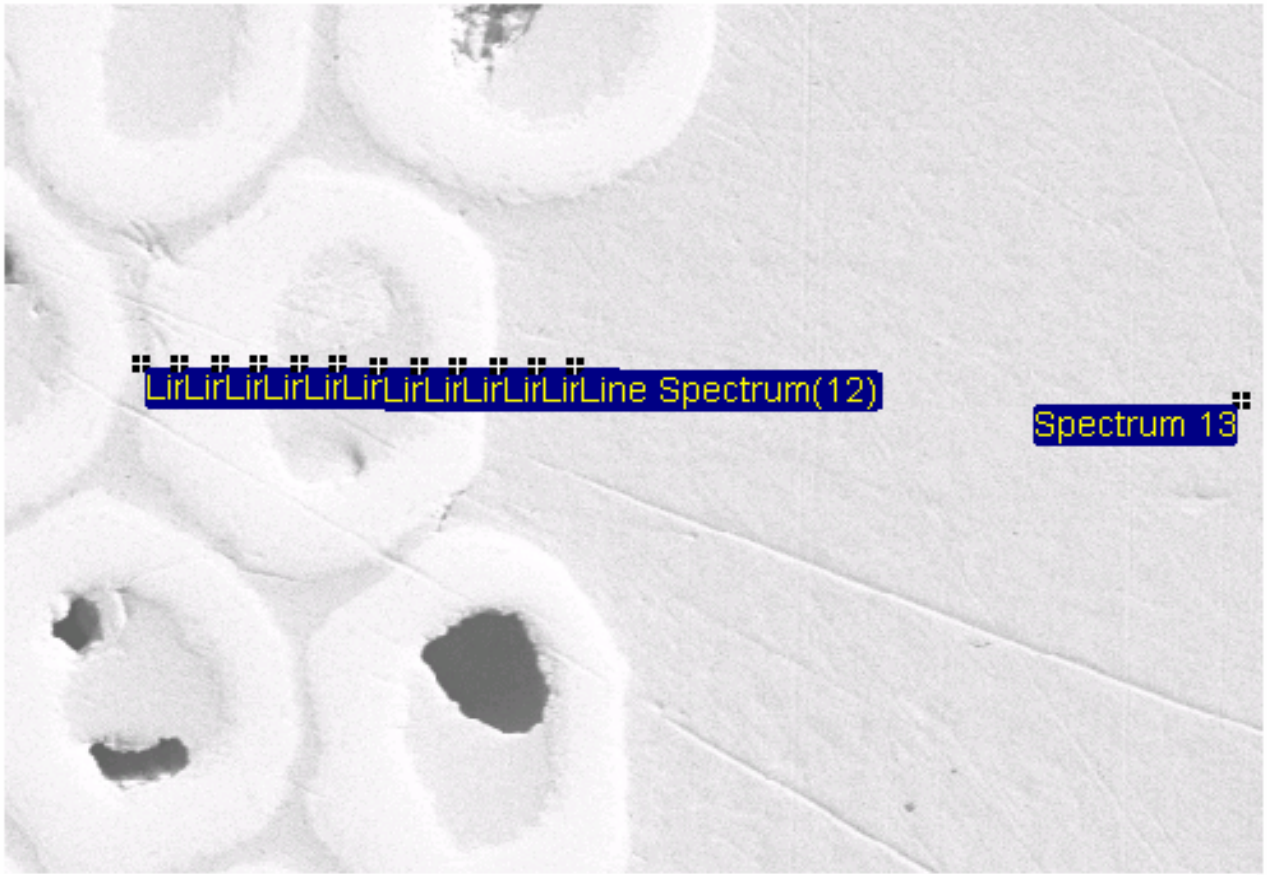
4/12/2005 4:48:17



Processing option : All elements analysed (Normalised)

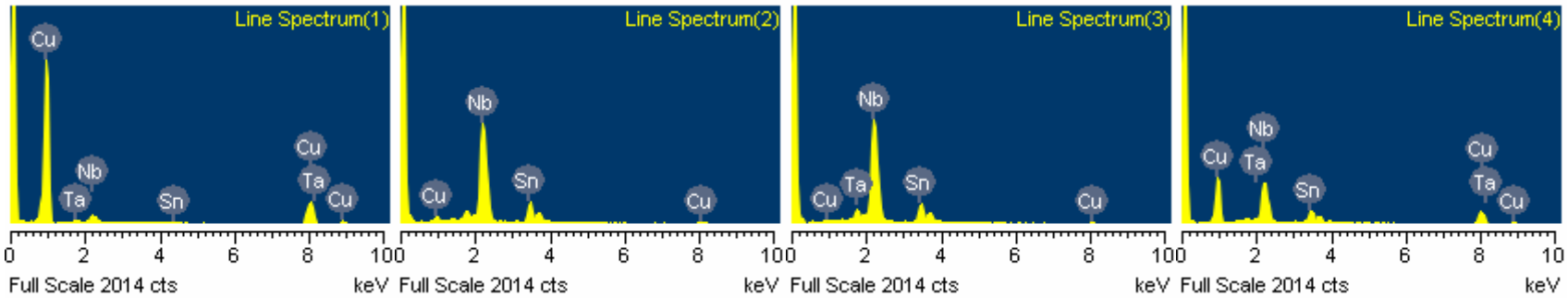
Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Line Spectrum(1)	Yes	88.90	0.36	9.92	0.82	100.00
Line Spectrum(2)	Yes	69.01	16.08	13.27	1.64	100.00
Line Spectrum(3)	Yes	21.76	49.03	24.14	5.08	100.00
Line Spectrum(4)	Yes	4.32	60.78	27.55	7.34	100.00
Line Spectrum(5)	Yes	2.25	65.78	27.12	4.85	100.00
Line Spectrum(6)	Yes	2.70	62.44	28.35	6.50	100.00
Line Spectrum(7)	Yes	3.40	64.59	25.82	6.19	100.00
Line Spectrum(8)	Yes	3.35	82.79	4.47	9.39	100.00
Line Spectrum(9)	Yes	99.54	-1.04	0.61	0.89	100.00
Line Spectrum(10)	Yes	99.32	-0.86	0.62	0.92	100.00
Mean		39.46	40.00	16.19	4.36	100.00
Std. deviation		43.97	32.68	11.66	3.10	
Max.		99.54	82.79	28.35	9.39	
Min.		2.25	-1.04	0.61	0.82	

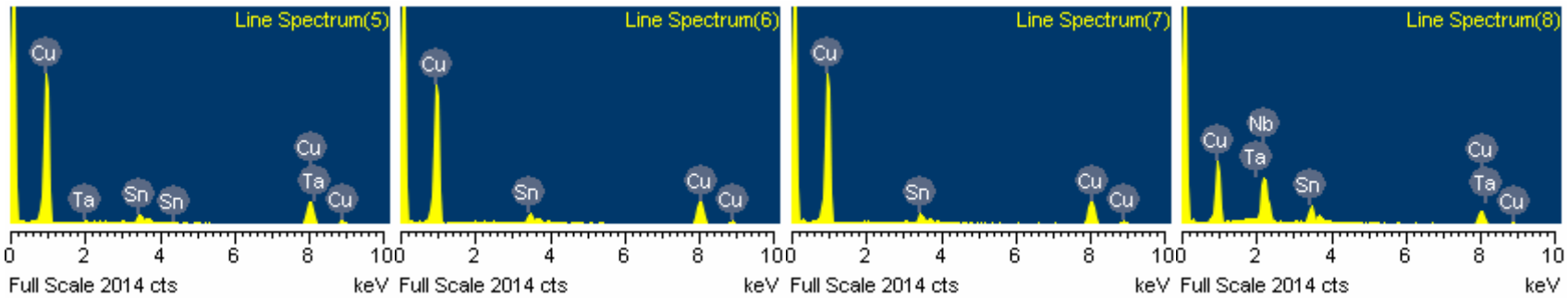
All results in weight%

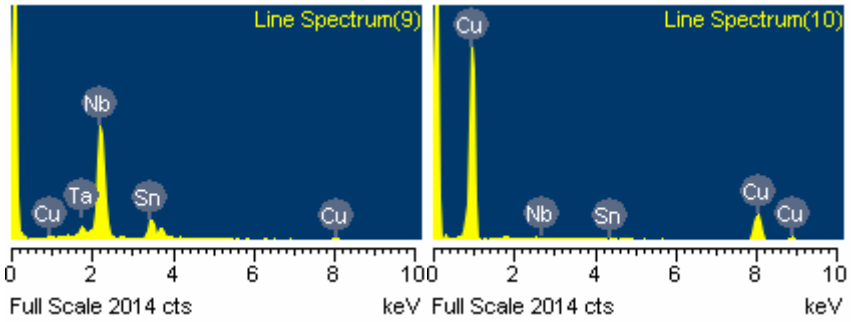


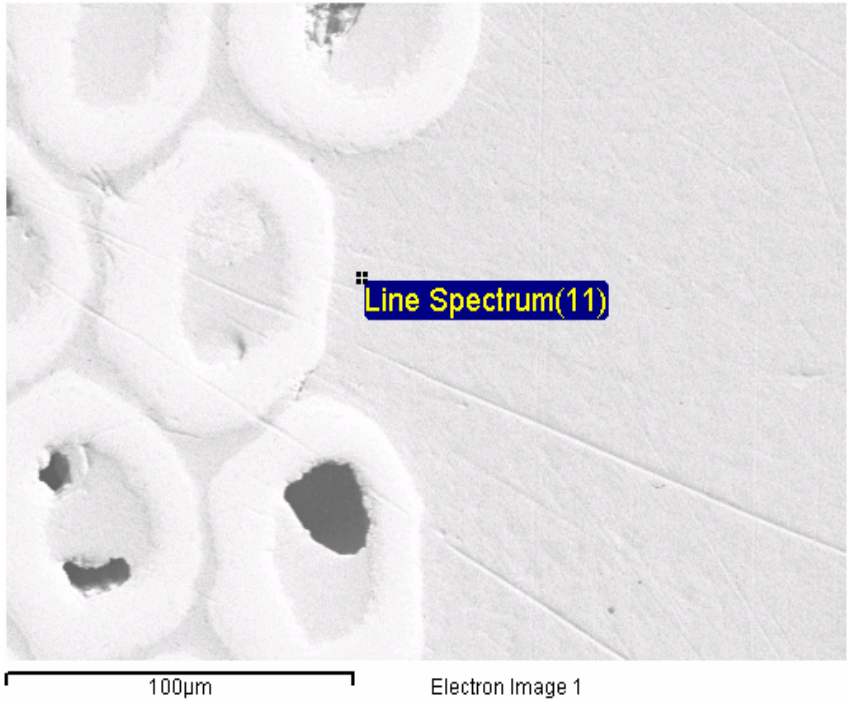
Processing option : All elements analysed (Normalised) All results in weight%

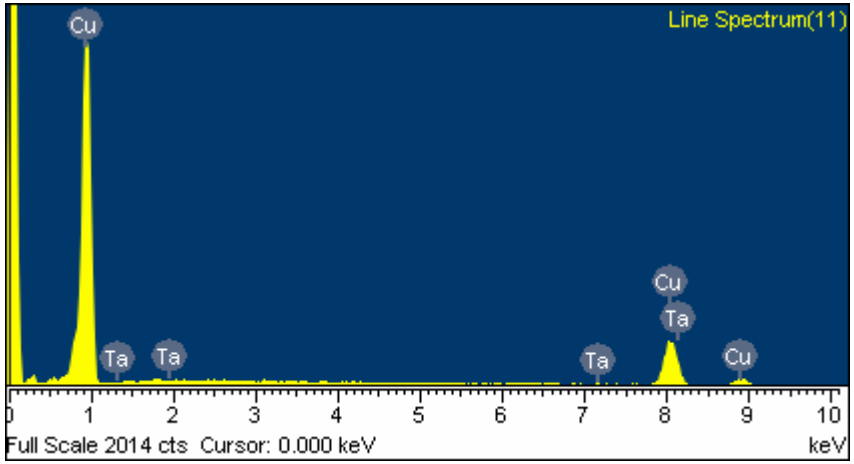
Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Line Spectrum(1)	Yes	92.27	6.32	0.73	0.68	100.00
Line Spectrum(2)	Yes	5.96	61.61	26.13	6.30	100.00
Line Spectrum(3)	Yes	2.06	65.06	25.73	7.14	100.00
Line Spectrum(4)	Yes	46.26	33.02	17.60	3.12	100.00
Line Spectrum(5)	Yes	88.82	0.13	10.81	0.25	100.00
Line Spectrum(6)	Yes	88.39	0.25	10.66	0.69	100.00
Line Spectrum(7)	Yes	88.90	0.26	9.74	1.09	100.00
Line Spectrum(8)	Yes	48.54	30.54	18.06	2.86	100.00
Line Spectrum(9)	Yes	2.14	65.74	26.68	5.44	100.00
Line Spectrum(10)	Yes	97.99	0.38	0.48	1.15	100.00
Line Spectrum(11)	Yes	99.62	0.02	0.07	0.29	100.00
Line Spectrum(12)	Yes	100.35	-0.11	-0.43	0.19	100.00
Spectrum 13	Yes	100.56	0.08	-0.33	-0.31	100.00
Mean		66.30	20.26	11.22	2.22	100.00
Std. deviation		40.03	27.51	10.73	2.55	
Max.		100.56	65.74	26.68	7.14	
Min.		2.06	-0.11	-0.43	-0.31	


Line Spectrum(1)
Cu
Nb
Ta
Sn
Cu
Ta
Cu
Line Spectrum(2)
Nb
Cu
Sn
Cu
Line Spectrum(3)
Nb
Cu
Ta
Sn
Cu
Line Spectrum(4)
Nb
Cu
Ta
Sn
Cu
Ta
Cu
0 2 4 6 8 100 2 4 6 8 100 2 4 6 8 100 2 4 6 8 10
Full Scale 2014 cts keV Full Scale 2014 cts keV Full Scale 2014 cts keV Full Scale 2014 cts keV

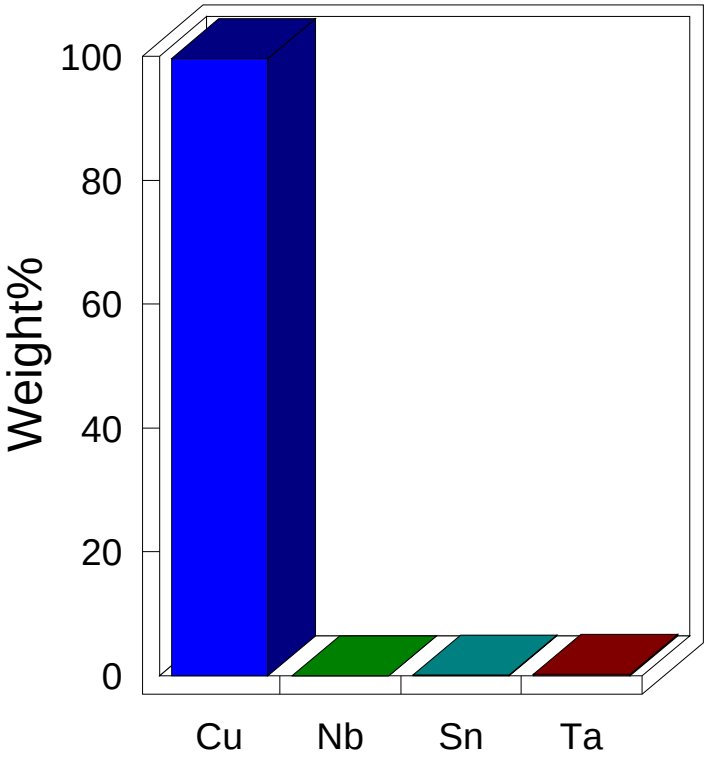

Line Spectrum(5)
Cu
Ta
Sn
Sn
Cu
Ta
Cu
Line Spectrum(6)
Cu
Sn
Cu
Cu
Line Spectrum(7)
Cu
Sn
Cu
Cu
Line Spectrum(8)
Nb
Cu
Ta
Sn
Cu
Ta
Cu
0 2 4 6 8 100 2 4 6 8 100 2 4 6 8 100 2 4 6 8 10
Full Scale 2014 cts keV Full Scale 2014 cts keV Full Scale 2014 cts keV Full Scale 2014 cts keV

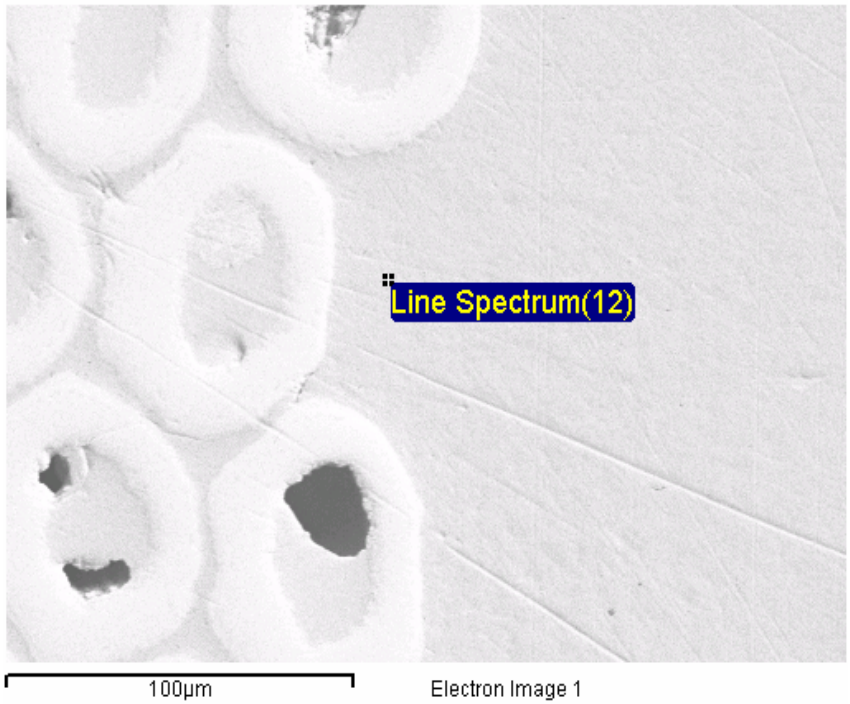

Line Spectrum(9)
Nb
Cu
Ta
Sn
Cu
Line Spectrum(10)
Cu
Nb
Sn
Cu
Cu
0 2 4 6 8 100 2 4 6 8 10
Full Scale 2014 cts keV Full Scale 2014 cts keV

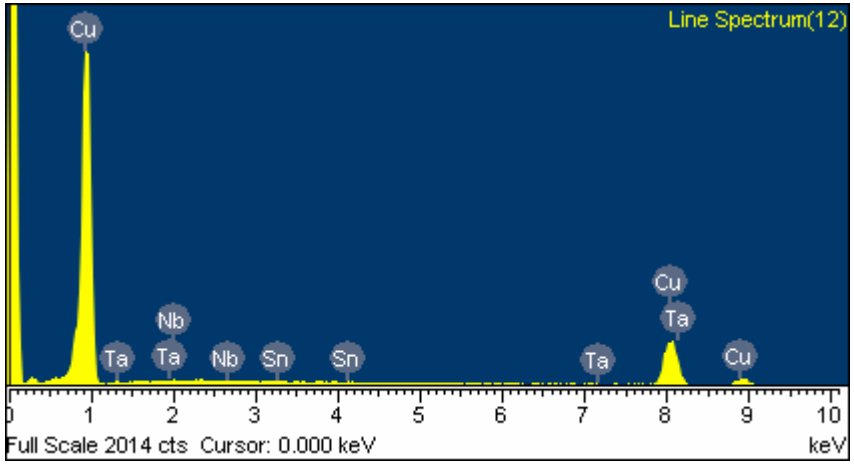




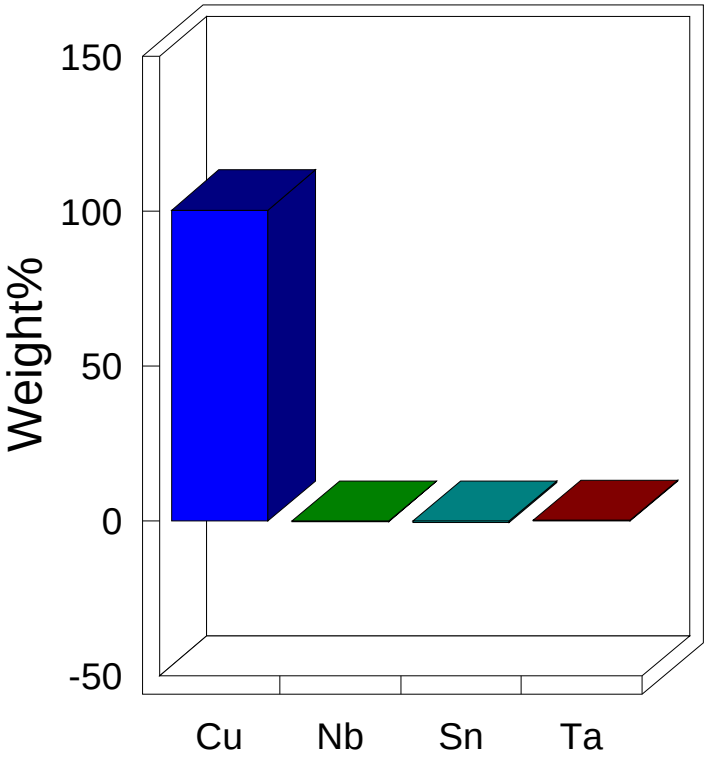
Quantitative results

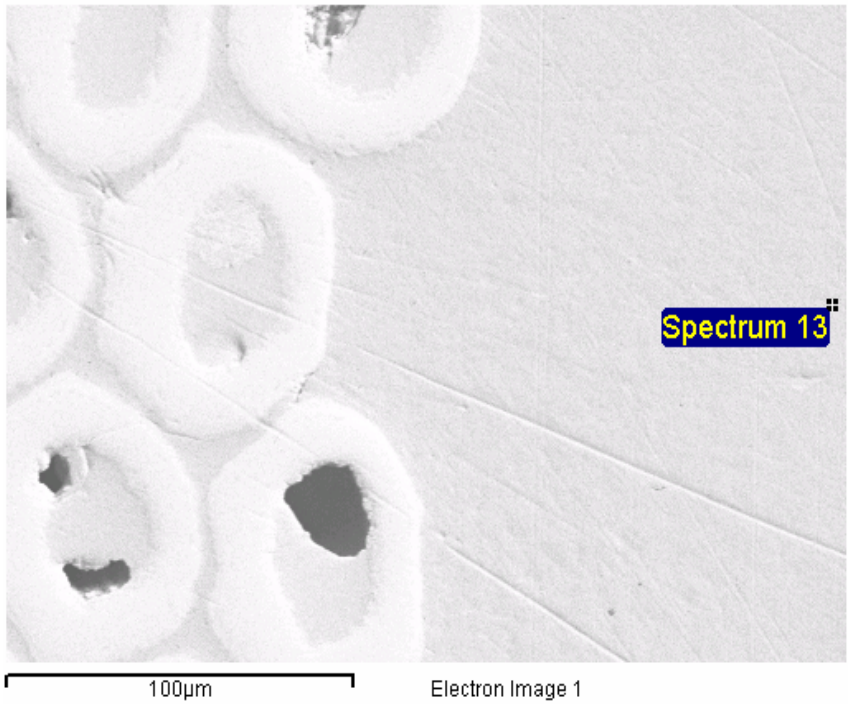


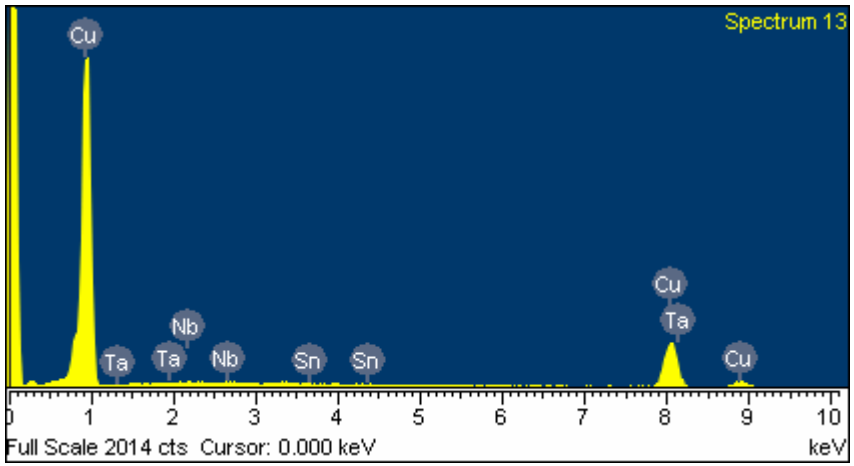




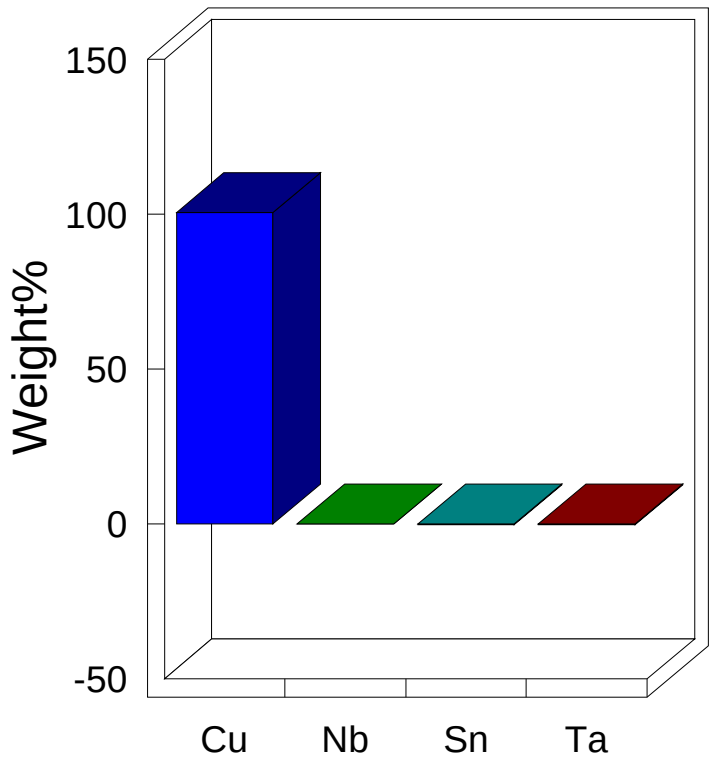
Quantitative results



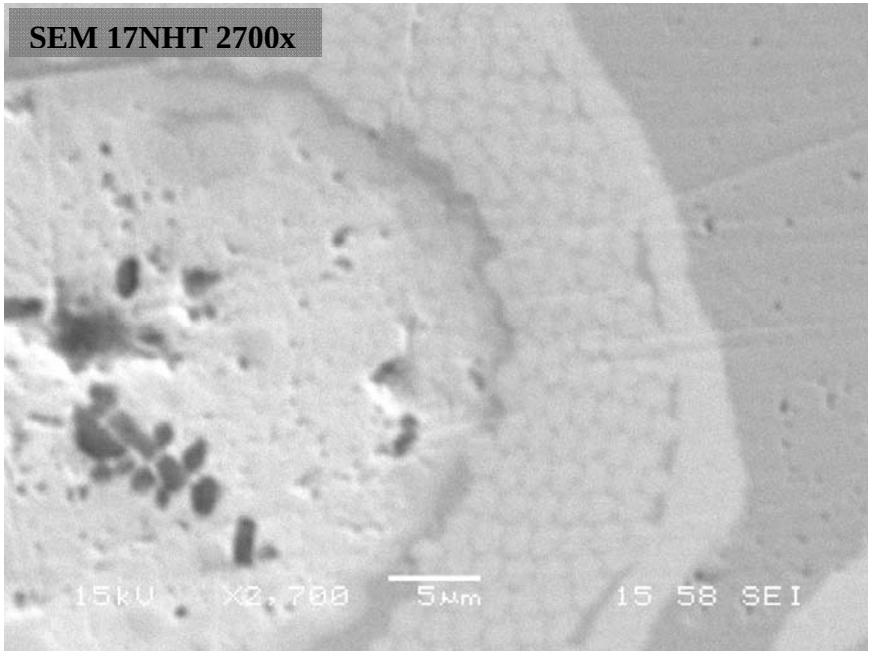


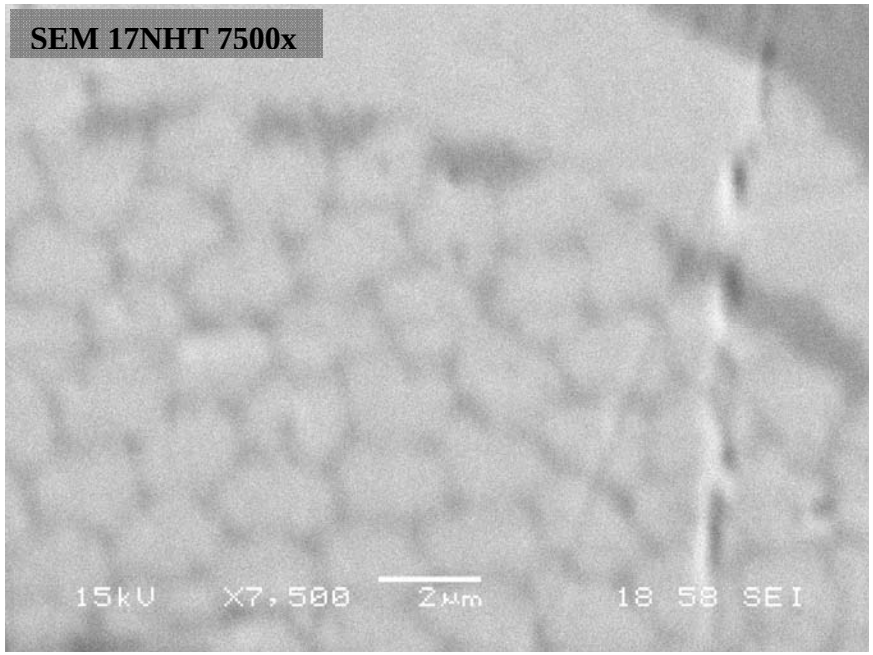


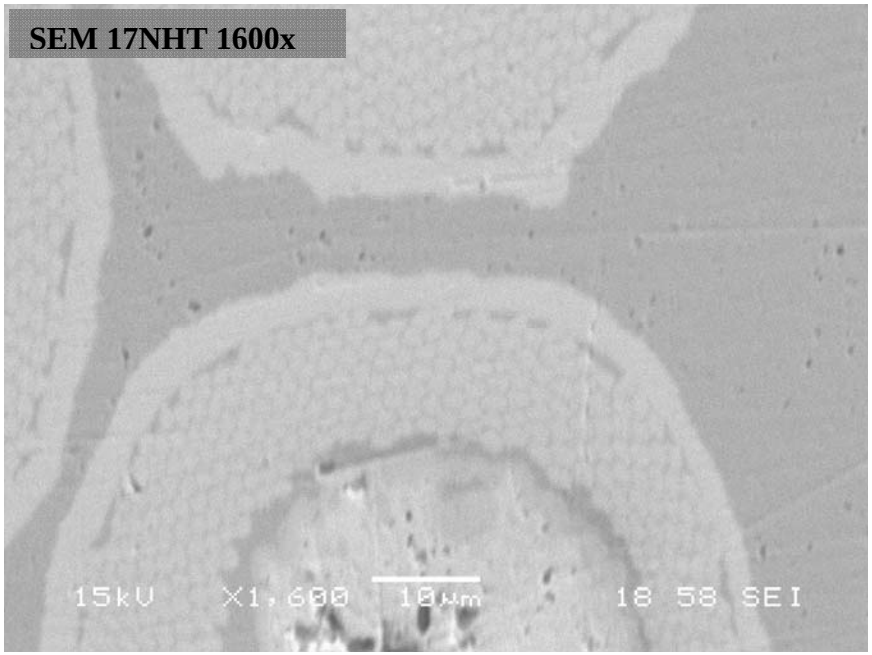
Quantitative results

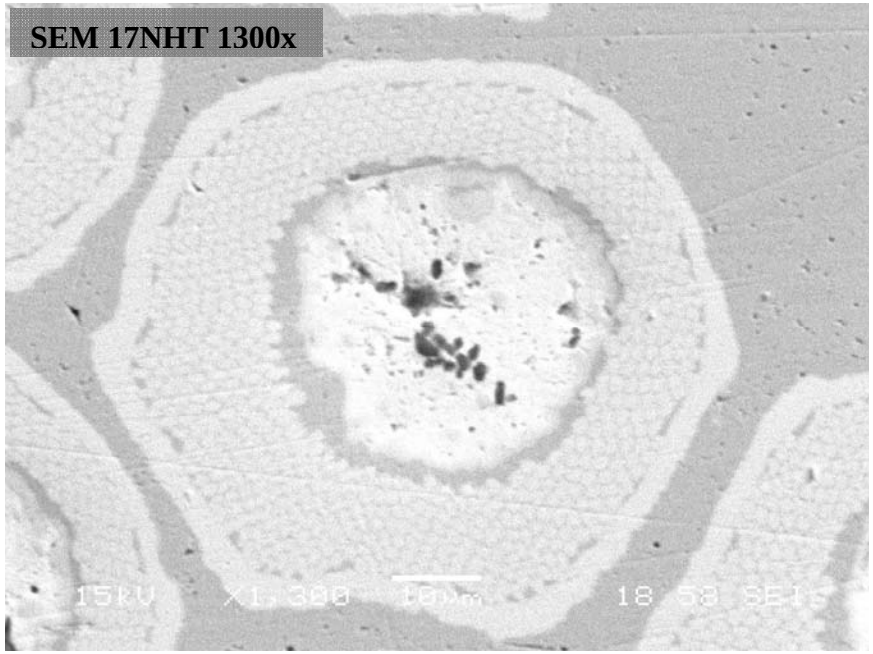


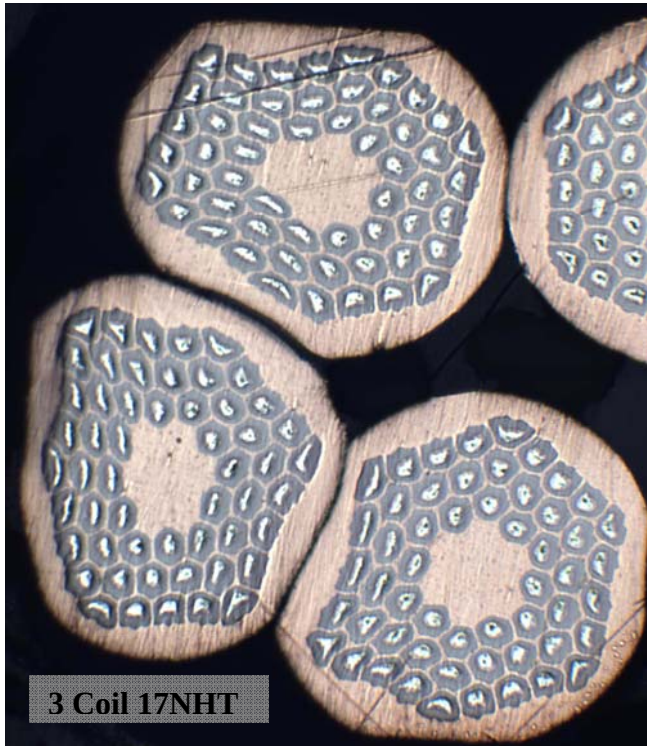
Appendix C
Coil 17 NHT

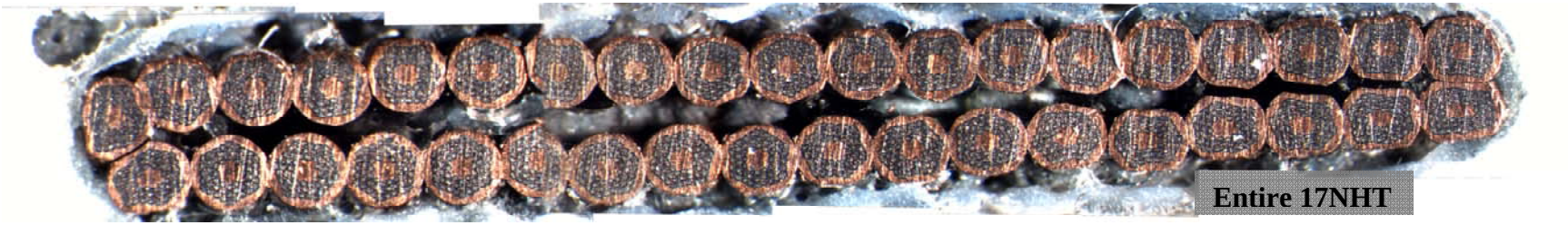







SEM 17NHT 1300x
15kV X1,300 10μm 18 53 SEI


3 Coil 17NHT


Entire 17NHT

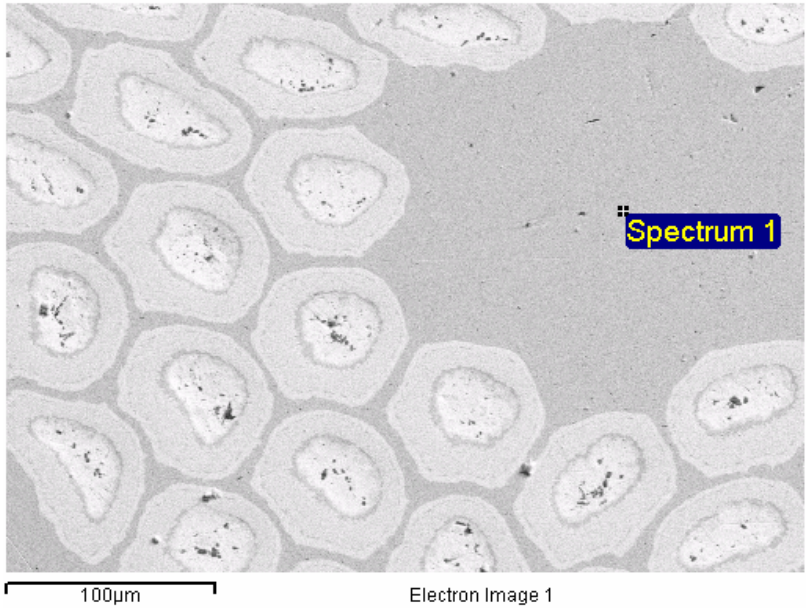
Coil 17 NHT

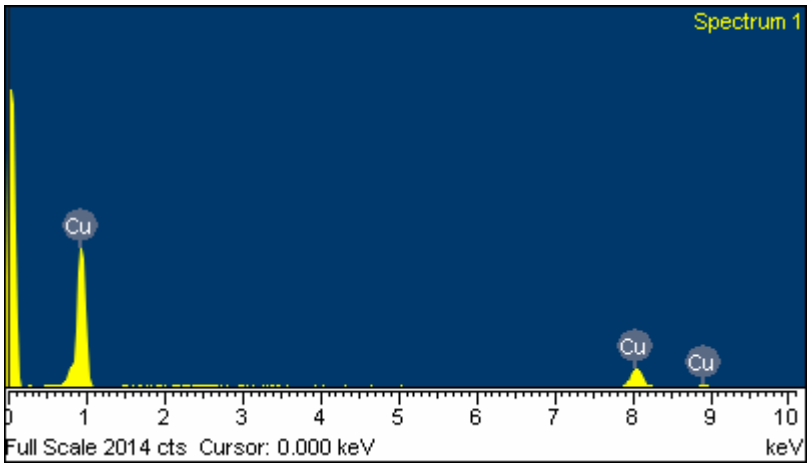
Spectrum processing :
Peak possibly omitted : 0.255 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	100.00	100.00
Totals	100.00	





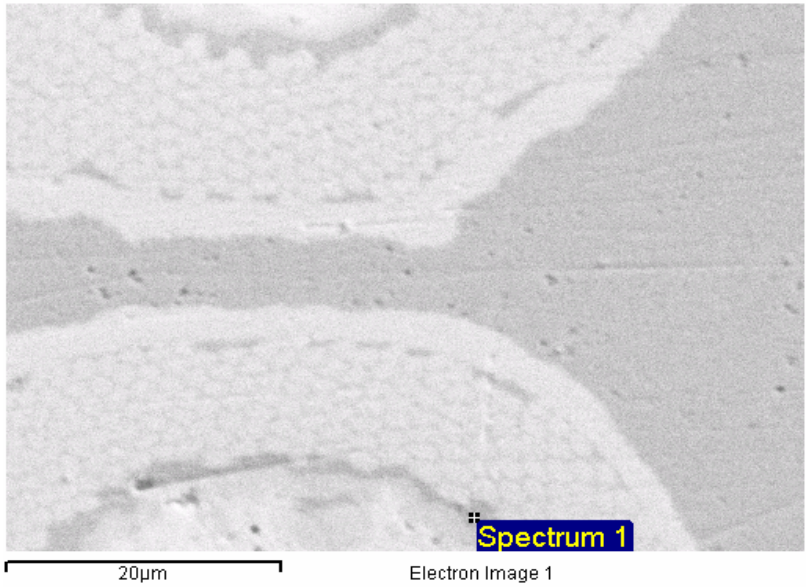
Coil 17 NHT

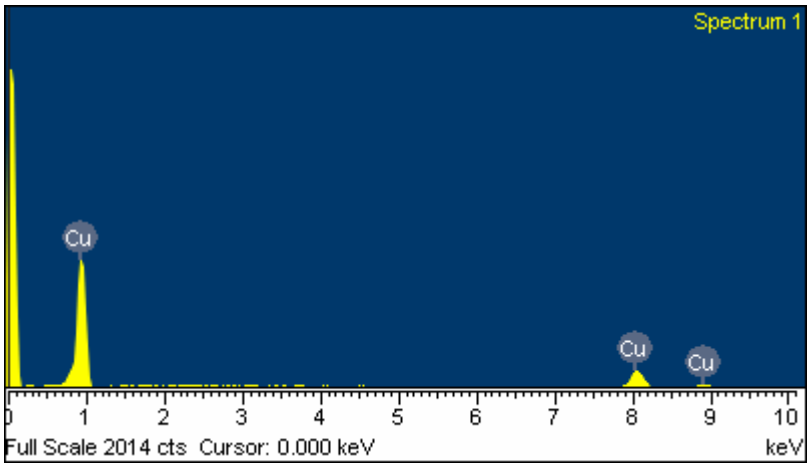
Spectrum processing :
Peak possibly omitted : 0.266 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 1

Standard :
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	100.00	100.00
Totals	100.00	





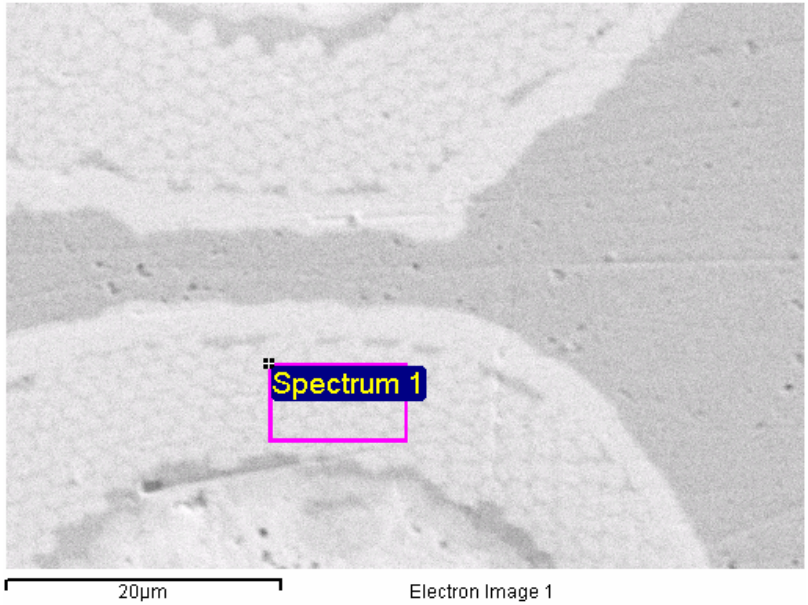
Coil 17 NHT

Spectrum processing :
No peaks omitted

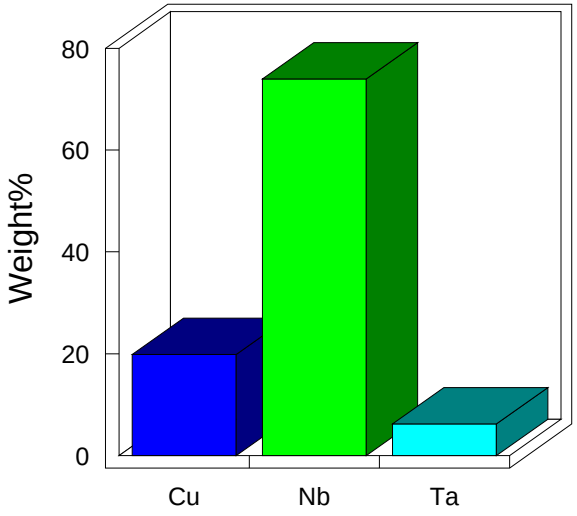
Processing option : All elements analyzed (Normalised)
Number of iterations = 3

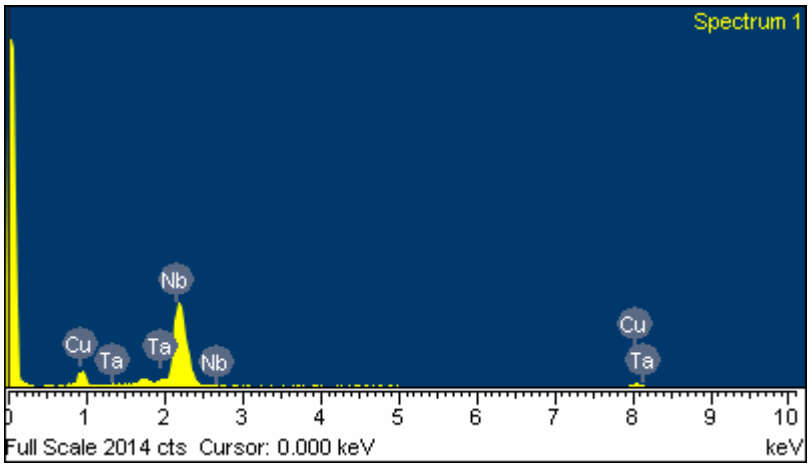
Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	19.87	27.36
Nb L	73.94	69.65
Ta M	6.19	2.99
Totals	100.00	



Quantitative results





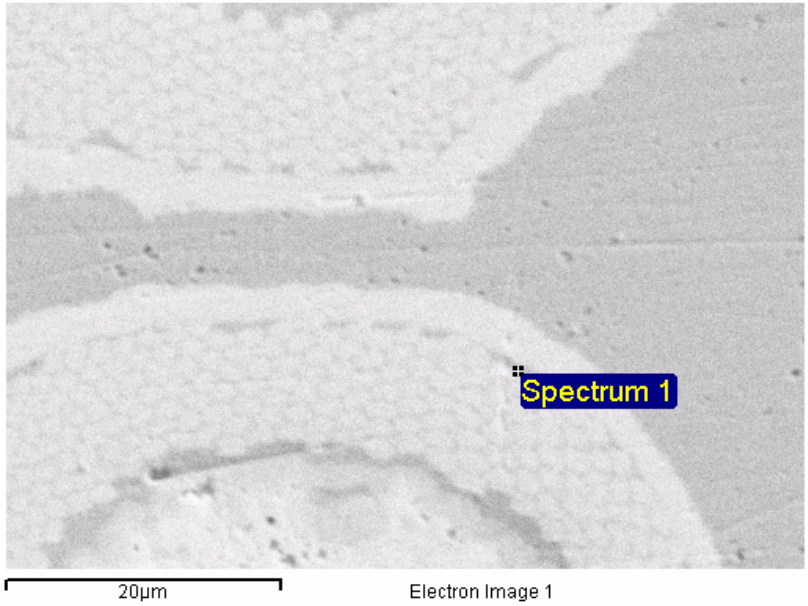
Coil 17 NHT

Spectrum processing :
No peaks omitted

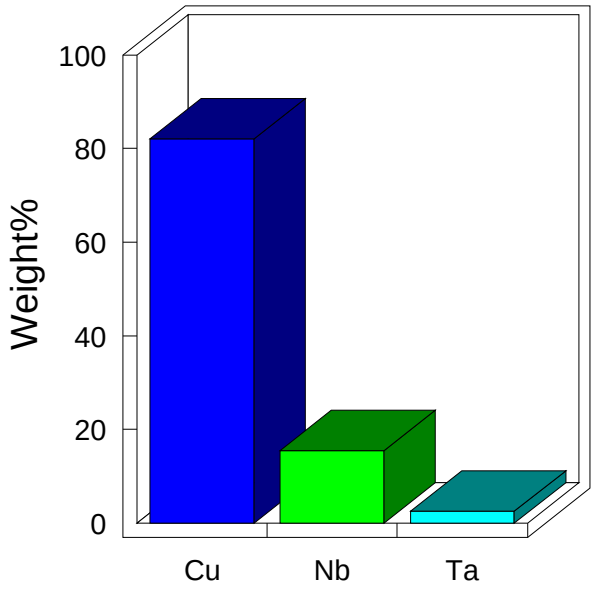
Processing option : All elements analyzed (Normalised)
Number of iterations = 3

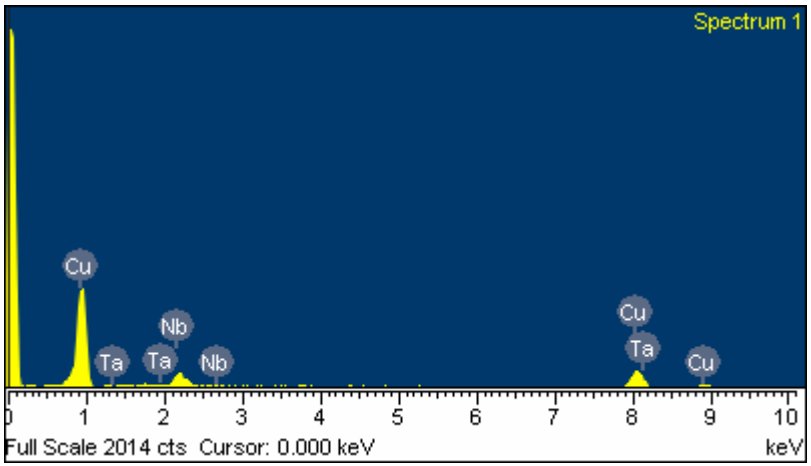
Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	82.05	87.76
Nb L	15.44	11.30
Ta M	2.50	0.94
Totals	100.00	



Quantitative results





Coil 17 NHT

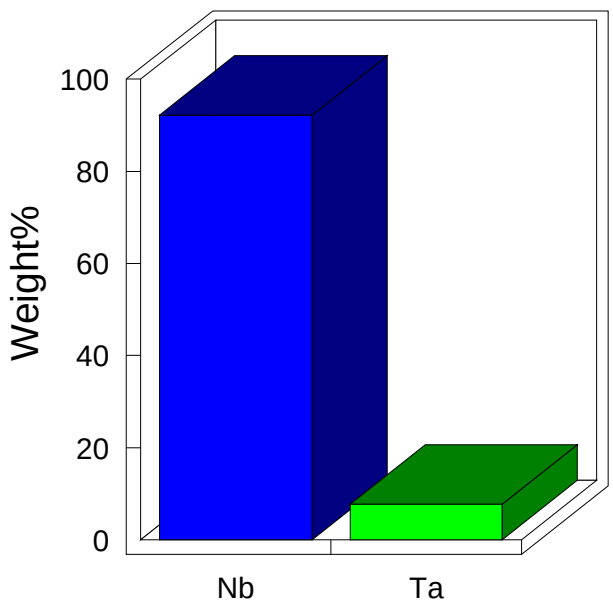
Spectrum processing :
No peaks omitted

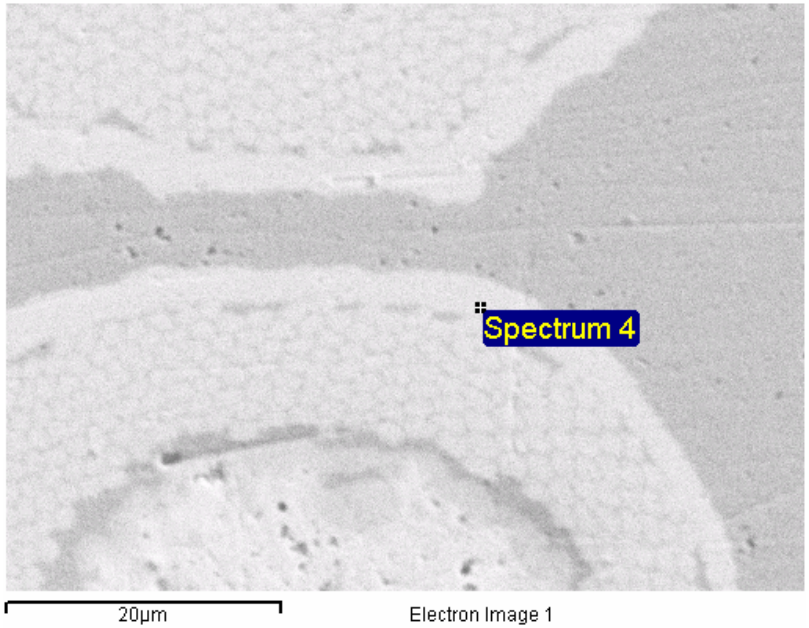
Processing option : All elements analyzed (Normalised)
Number of iterations = 2

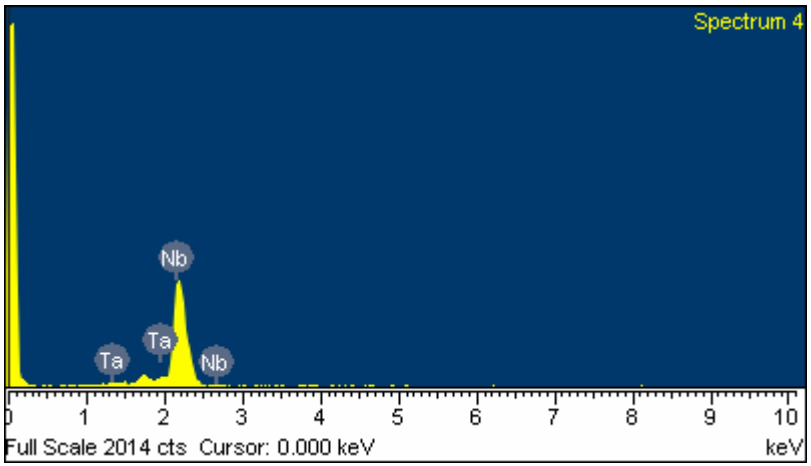
Standard :
Nb Nb 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Nb L	92.27	95.88
Ta M	7.73	4.12
Totals	100.00	

Quantitative results







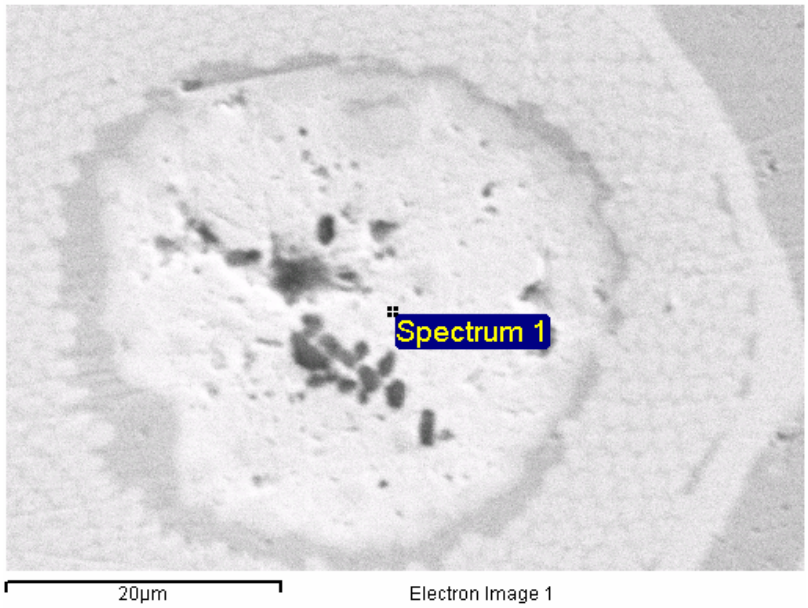
Coil 17 NHT

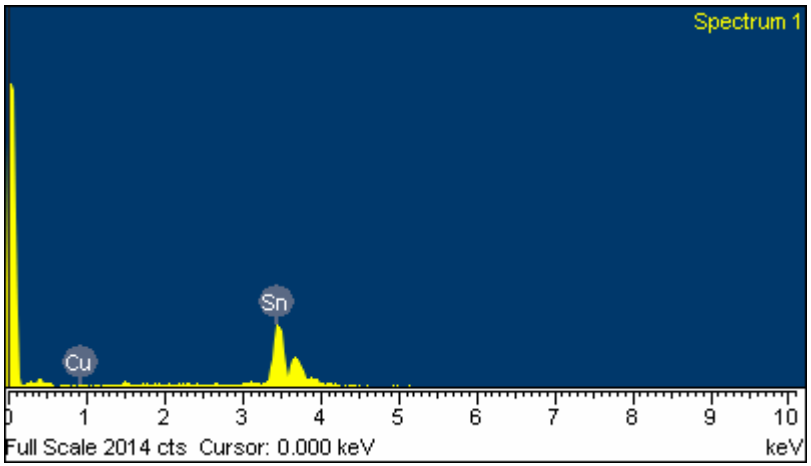
Spectrum processing :
Peak possibly omitted : 1.500 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 2

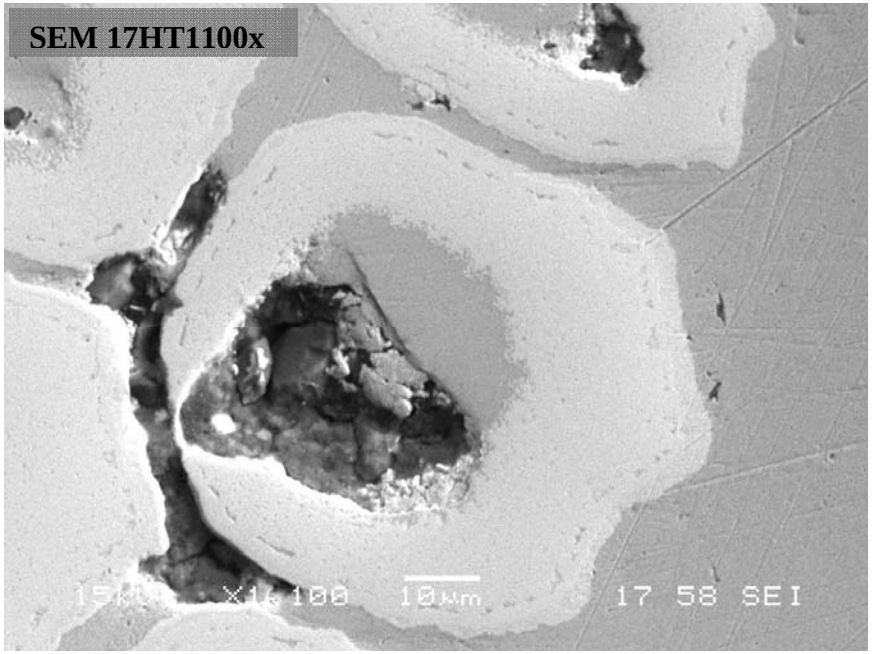
Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

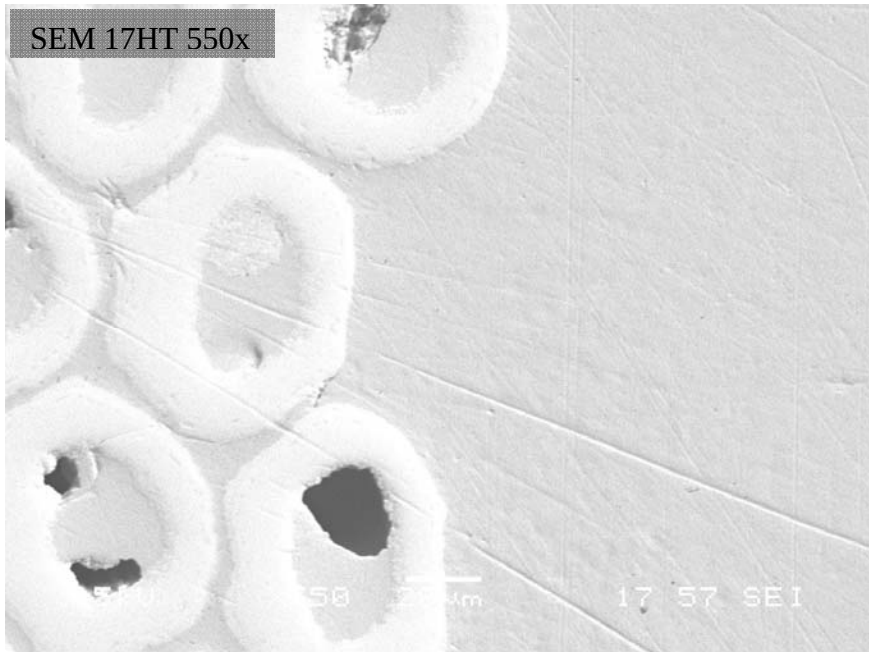
Element	Weight%	Atomic%
Cu L	3.06	5.57
Sn L	96.94	94.43
Totals	100.00	

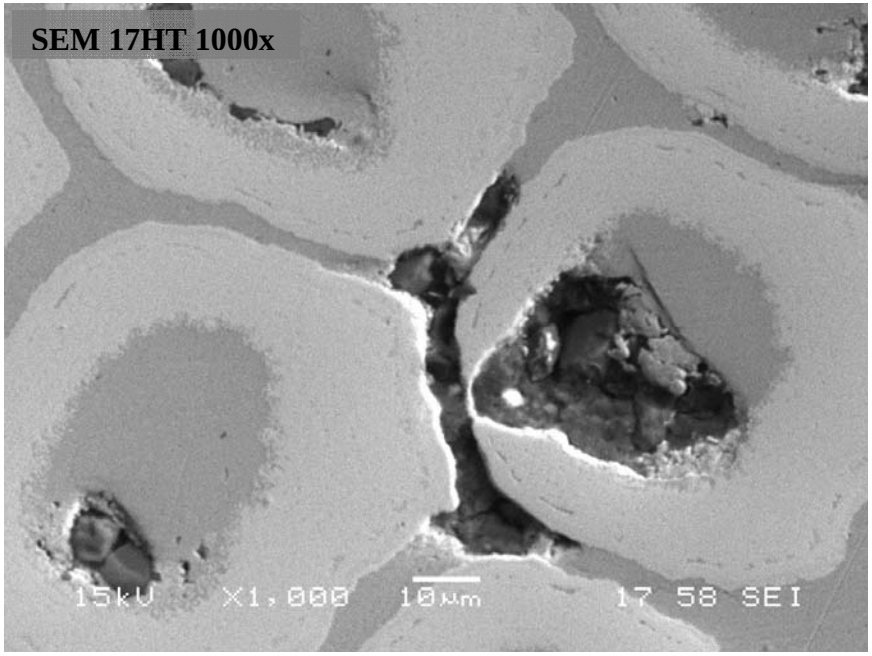


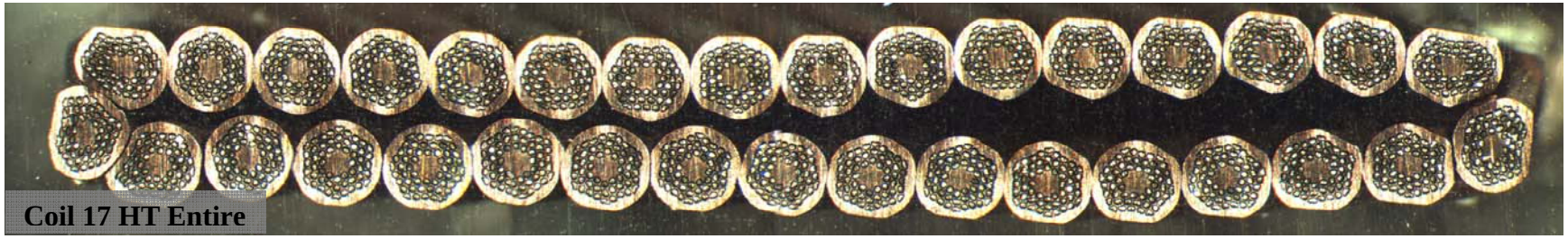


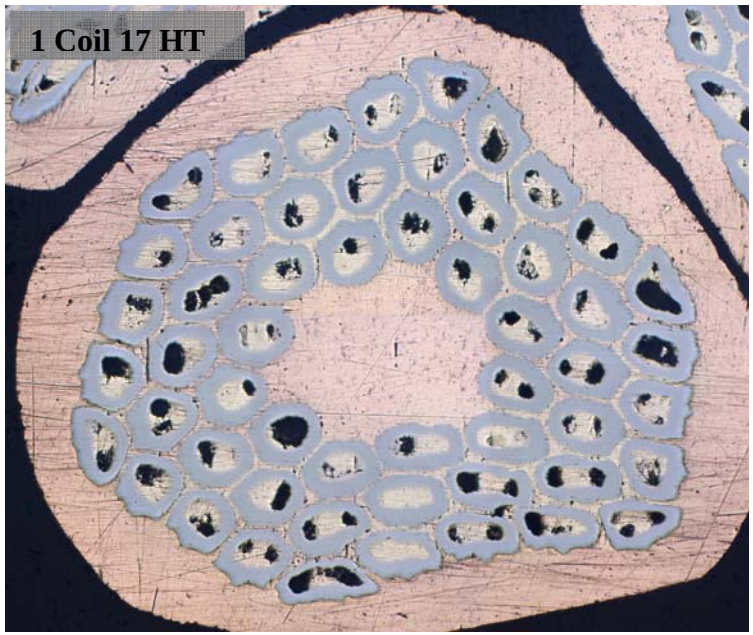
Appendix D
Coil 17 HT





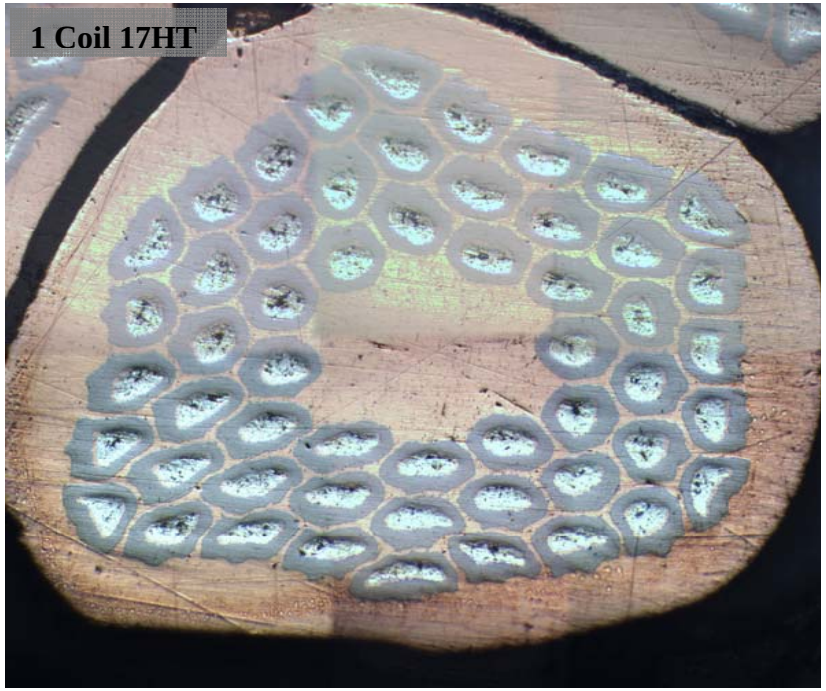


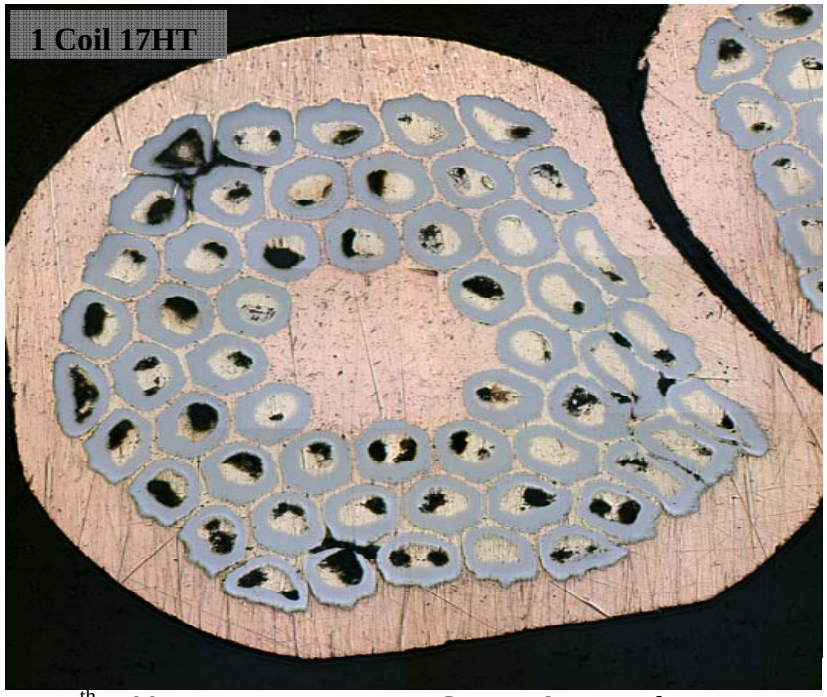

Coil 17 HT Entire


1 Coil 17 HT

1a Bad Coil 17 HT

1b Bad Coil 17HT


1 Coil 17HT


1 Coil 17HT

1c Bad Coil 17HT

Coil 17 HT

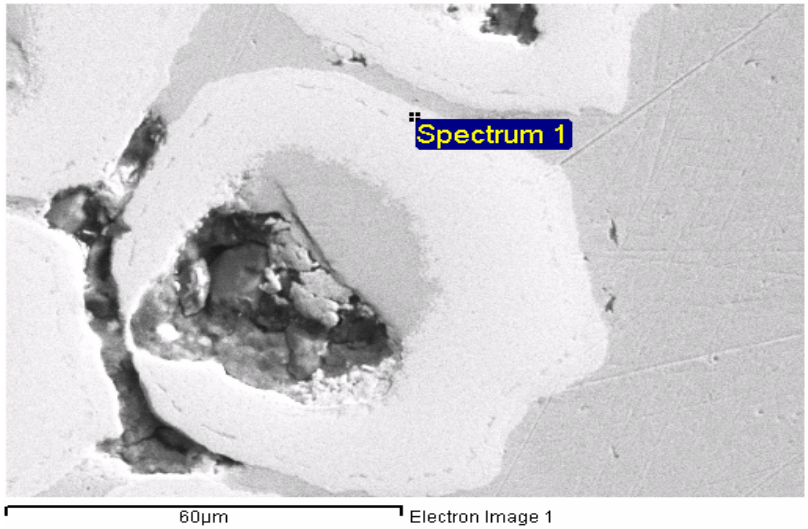
4/11/2005 4:51:40 PM

Spectrum processing :
No peaks omitted

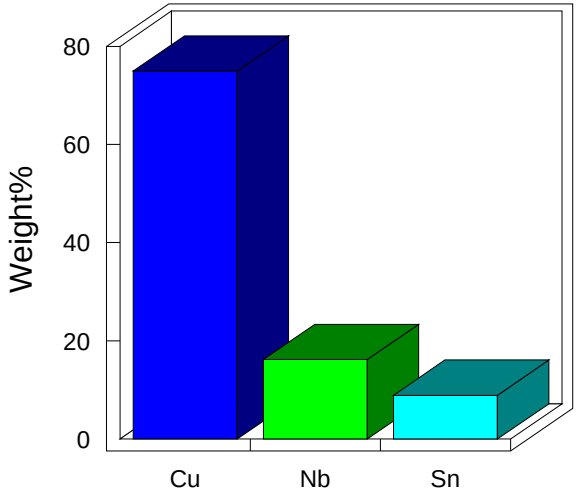
Processing option : All elements analyzed (Normalised)
Number of iterations = 3

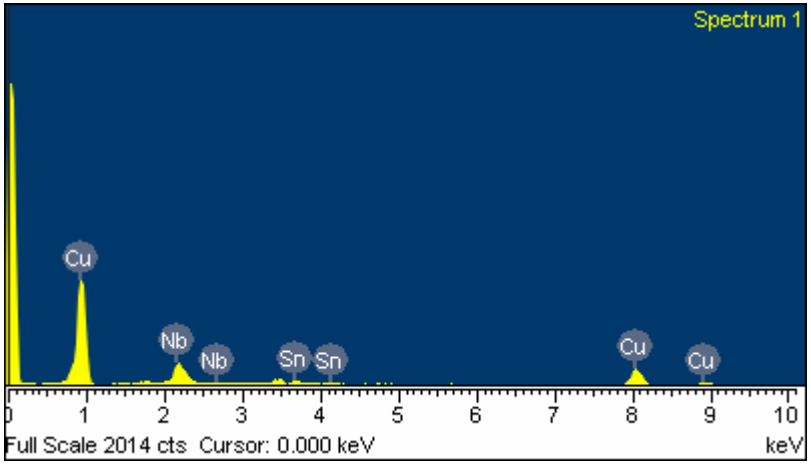
Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	74.95	82.58
Nb L	16.16	12.17
Sn L	8.90	5.25
Totals	100.00	



Quantitative results





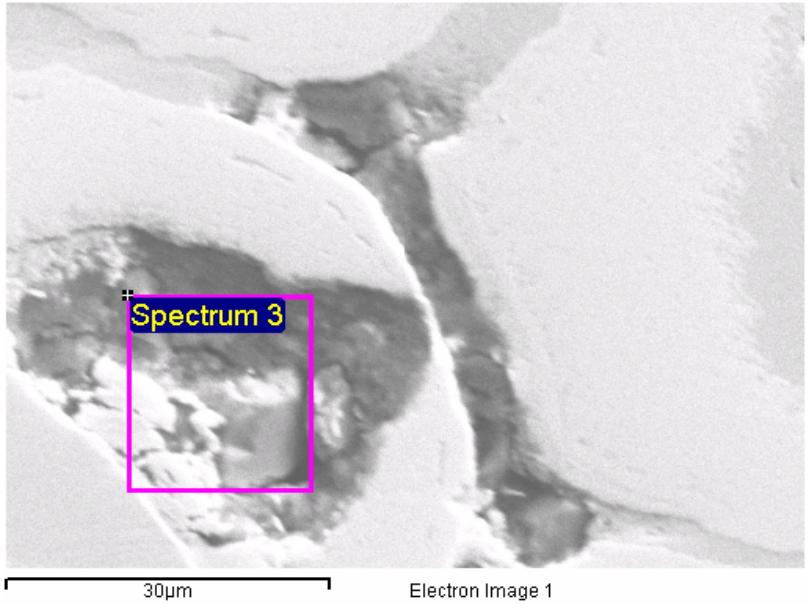
Coil 17 HT

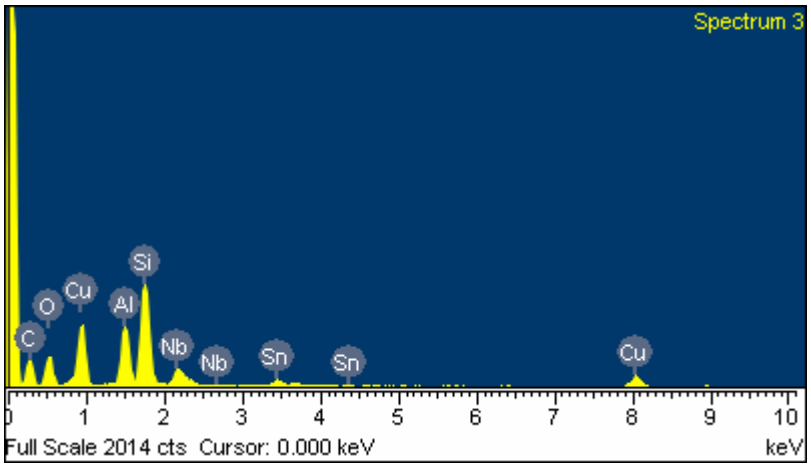
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 5

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Al Al2O3 1-Jun-1999 12:00 AM
Si SiO2 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
C K	28.37	50.13
O K	17.61	23.36
Al K	7.78	6.12
Si K	14.55	11.00
Cu L	22.13	7.39
Nb L	6.00	1.37
Sn L	3.56	0.64
Totals	100.00	





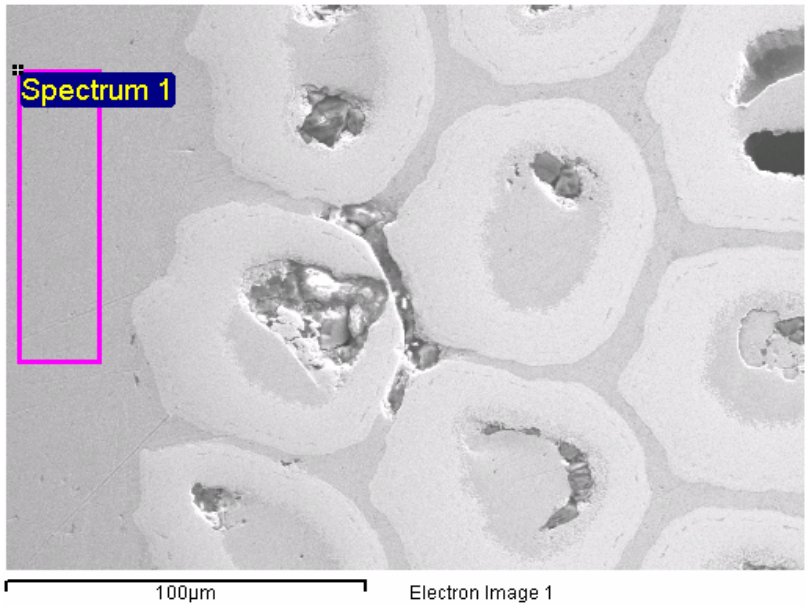
Coil 17 HT

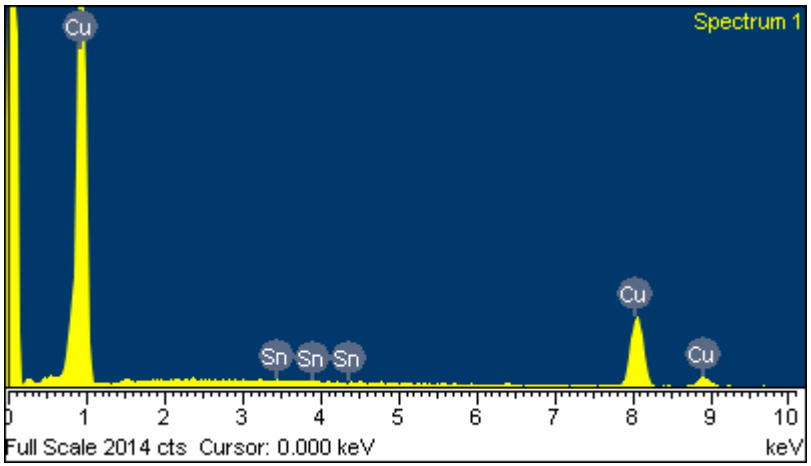
Spectrum processing :
Peaks possibly omitted : 1.505, 6.400 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	99.09	99.51
Sn L	0.91	0.49
Totals	100.00	





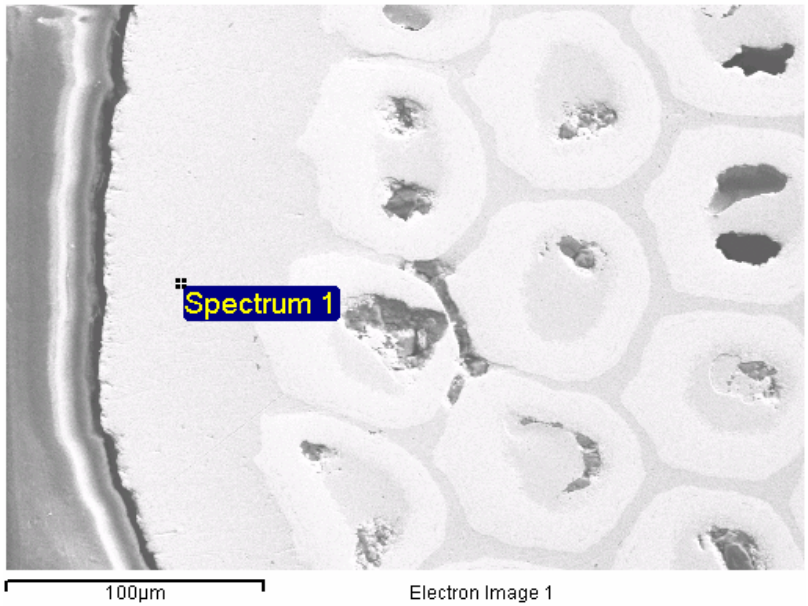
Coil 17 HT

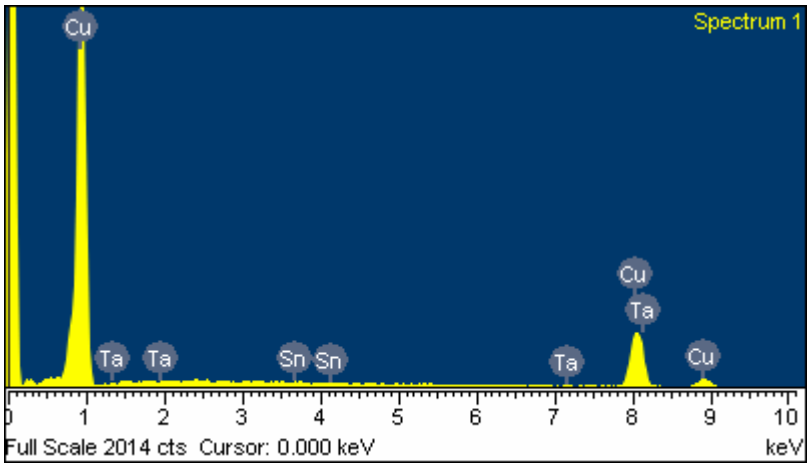
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 2

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	99.25	99.63
Sn L	0.60	0.32
Ta M	0.15	0.05
Totals	100.00	





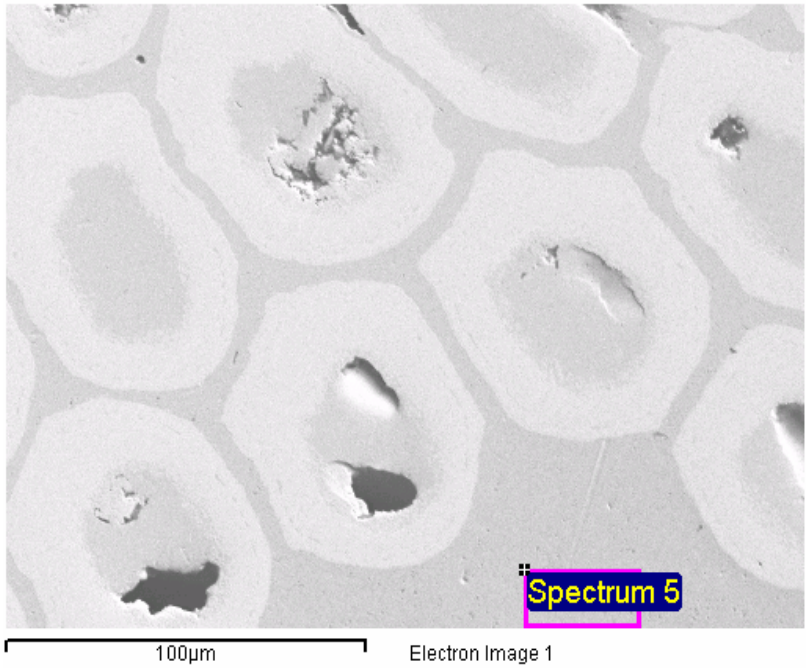
Coil 17 HT

Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	77.16	84.53
Nb L	16.13	12.09
Sn L	3.99	2.34
Ta M	2.72	1.04
Totals	100.00	



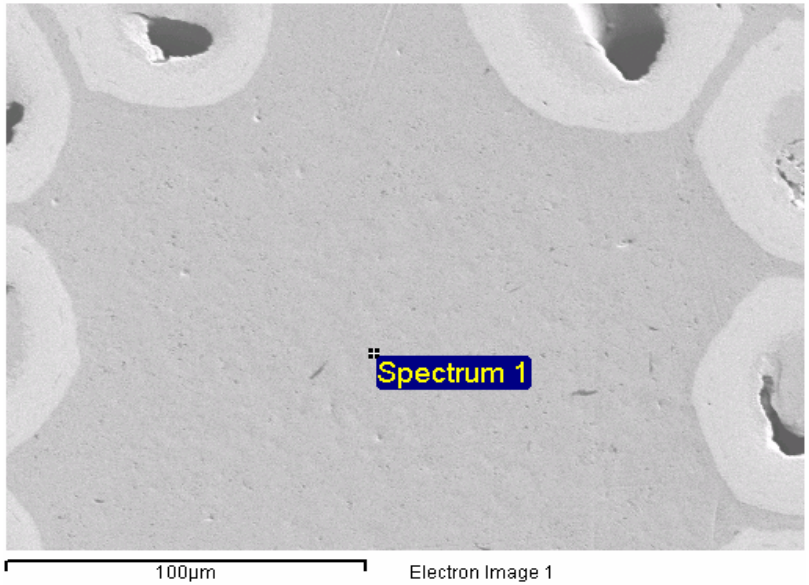
Coil 17 HT

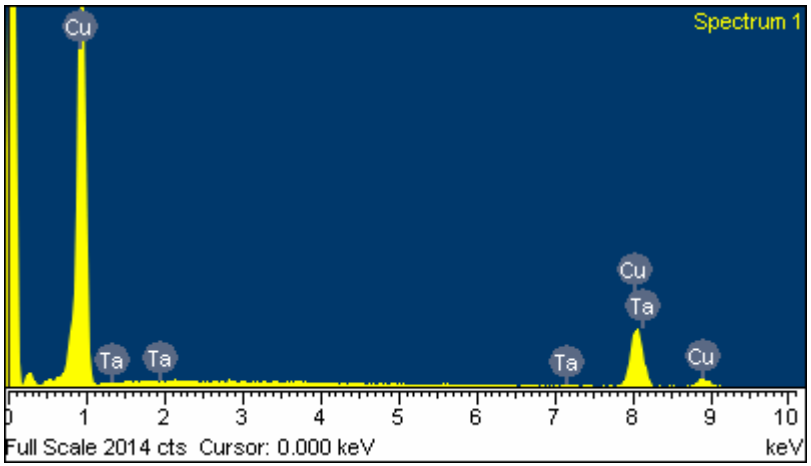
Spectrum processing :
Peak possibly omitted : 0.264 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	99.67	99.88
Ta M	0.33	0.12
Totals	100.00	





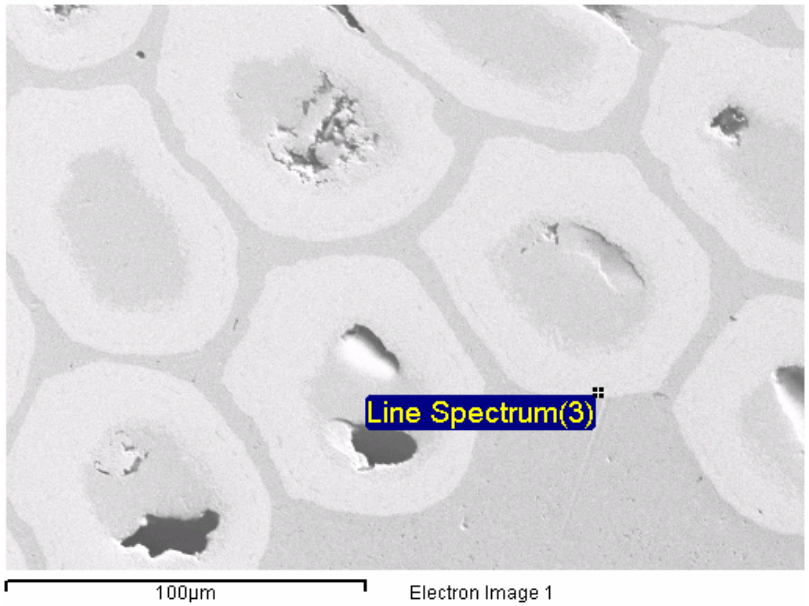
Coil 17 HT

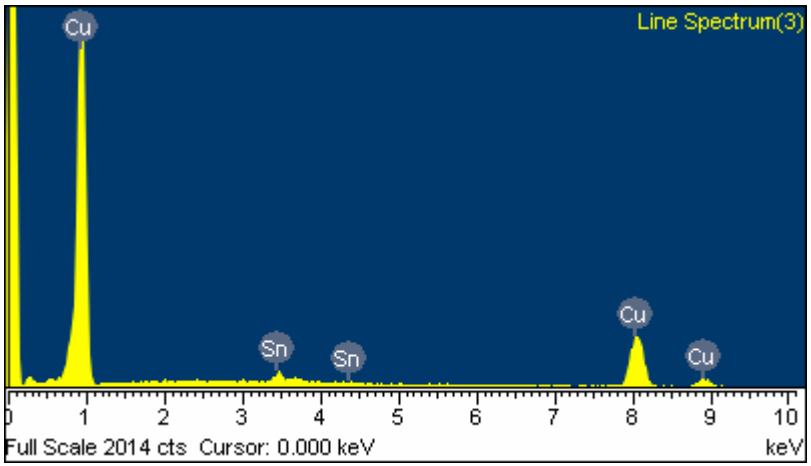
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	94.92	97.21
Sn L	5.08	2.79
Totals	100.00	





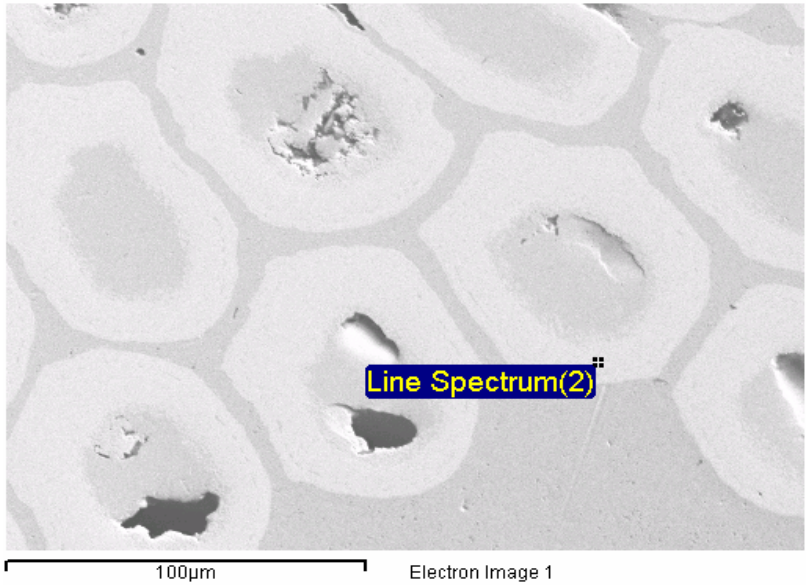
Coil 17 HT

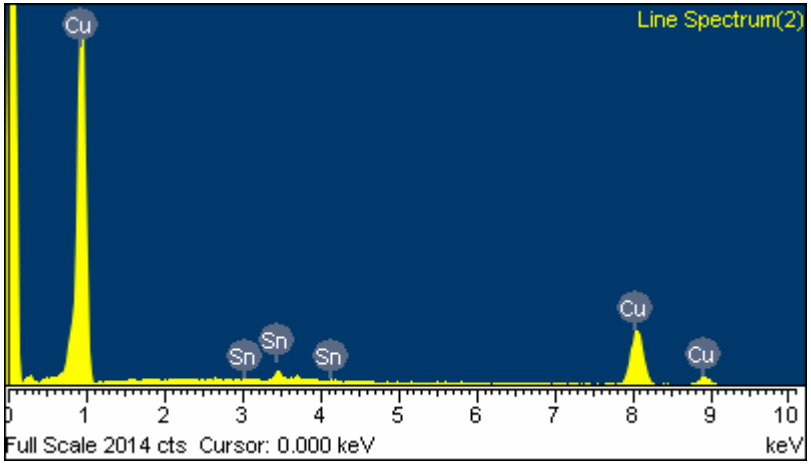
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	95.36	97.46
Sn L	4.64	2.54
Totals	100.00	





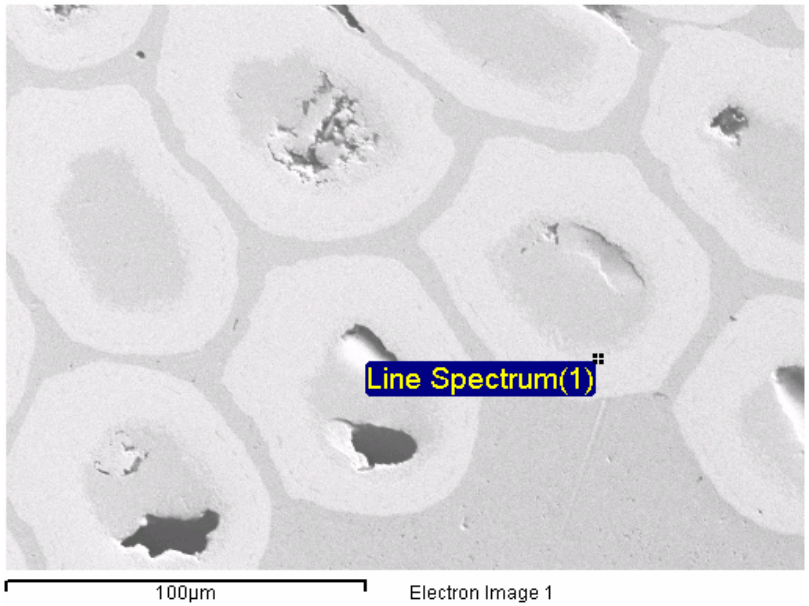
Coil 17 HT

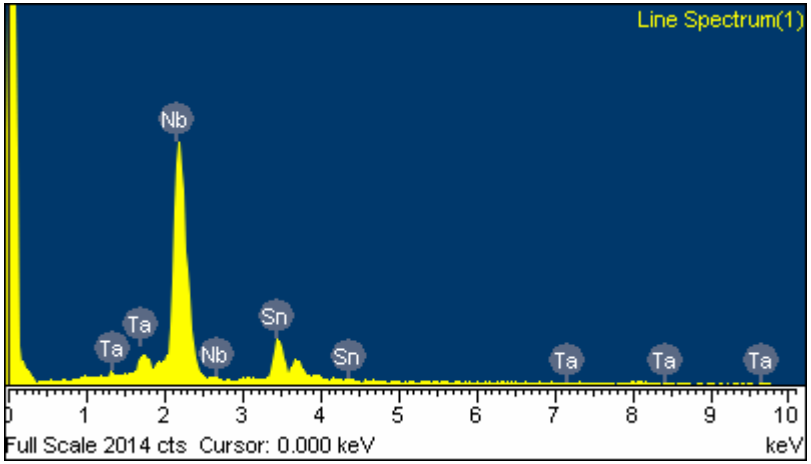
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 2

Standard :
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Nb L	67.35	73.86
Sn L	26.23	22.52
Ta M	6.42	3.61
Totals	100.00	





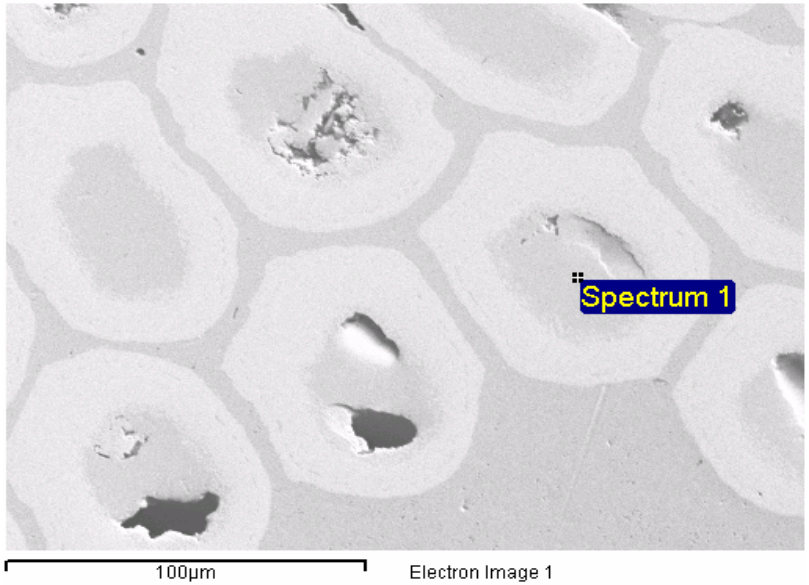
Coil 17 HT

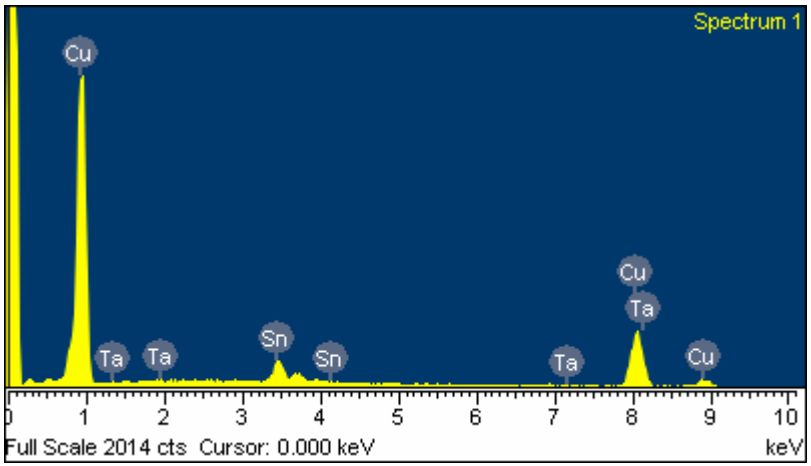
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 3

Standard :
Cu Cu 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

Element	Weight%	Atomic%
Cu L	88.17	93.45
Sn L	11.00	6.24
Ta M	0.83	0.31
Totals	100.00	





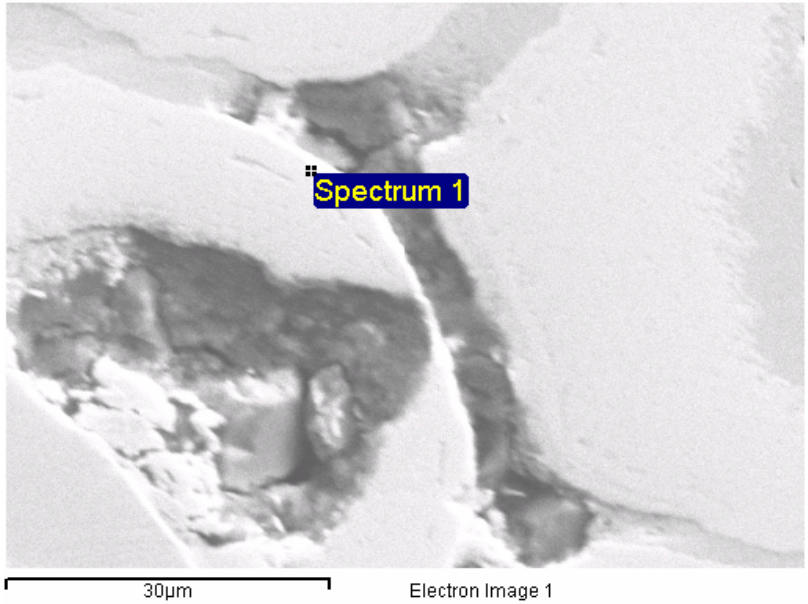
Coil 17 HT

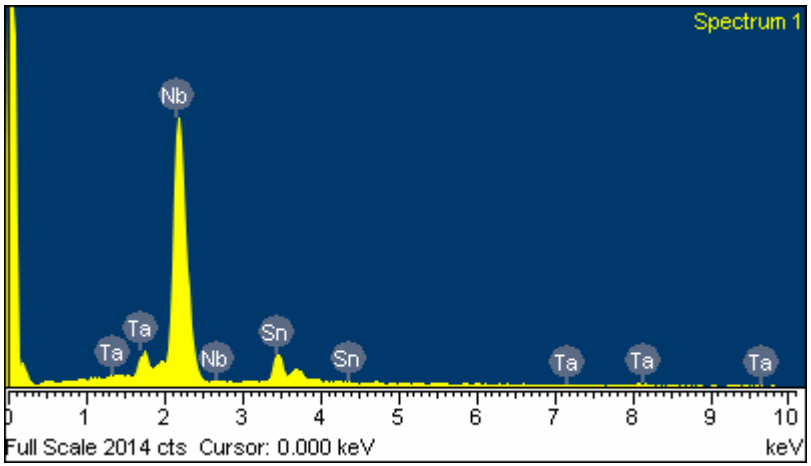
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 2

Standard :
Nb Nb 1-Jun-1999 12:00 AM
Sn Sn 1-Jun-1999 12:00 AM
Ta Ta 1-Jun-1999 12:00 AM

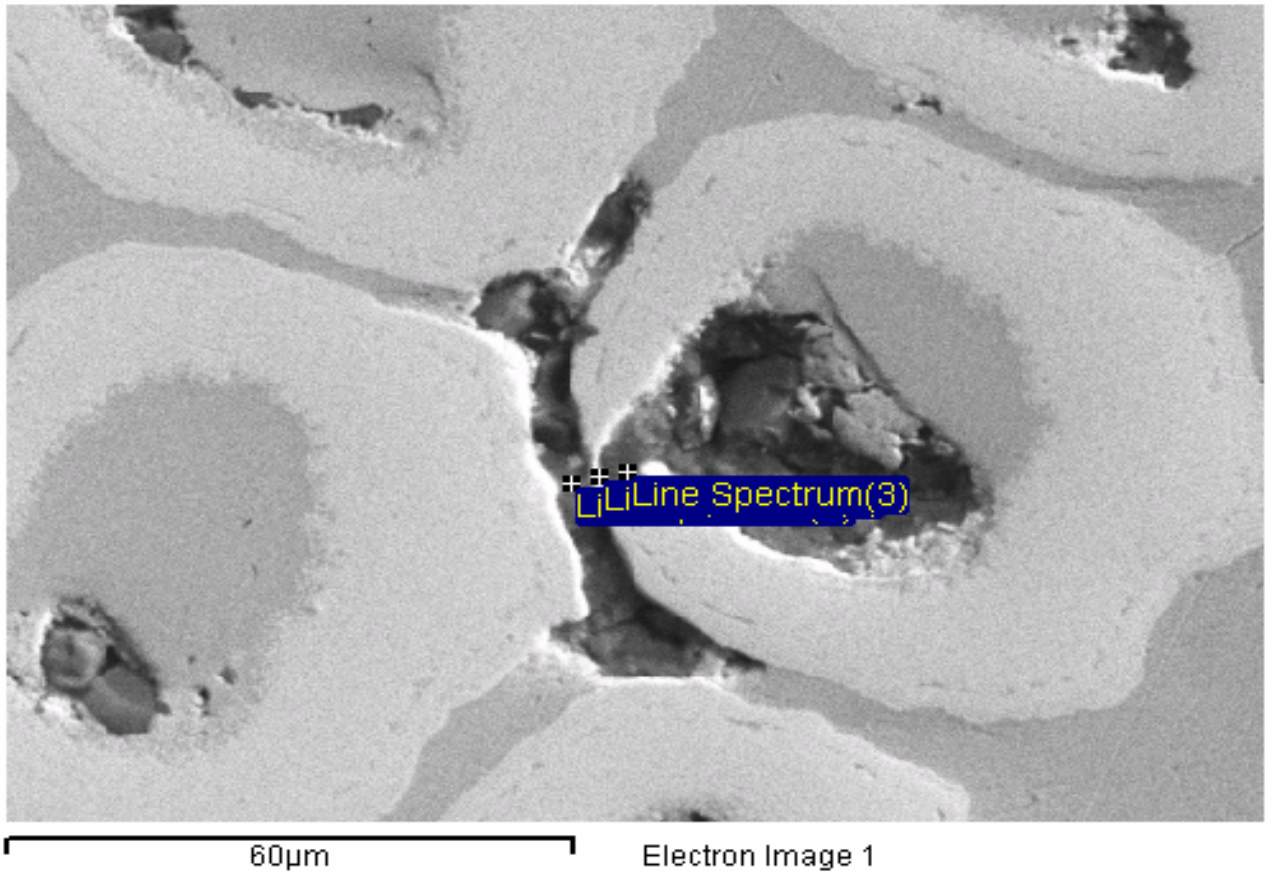
Element	Weight%	Atomic%
Nb L	74.94	80.84
Sn L	18.18	15.35
Ta M	6.88	3.81
Totals	100.00	





Coil 17 HT

4/11/2005 5:21:49 PM

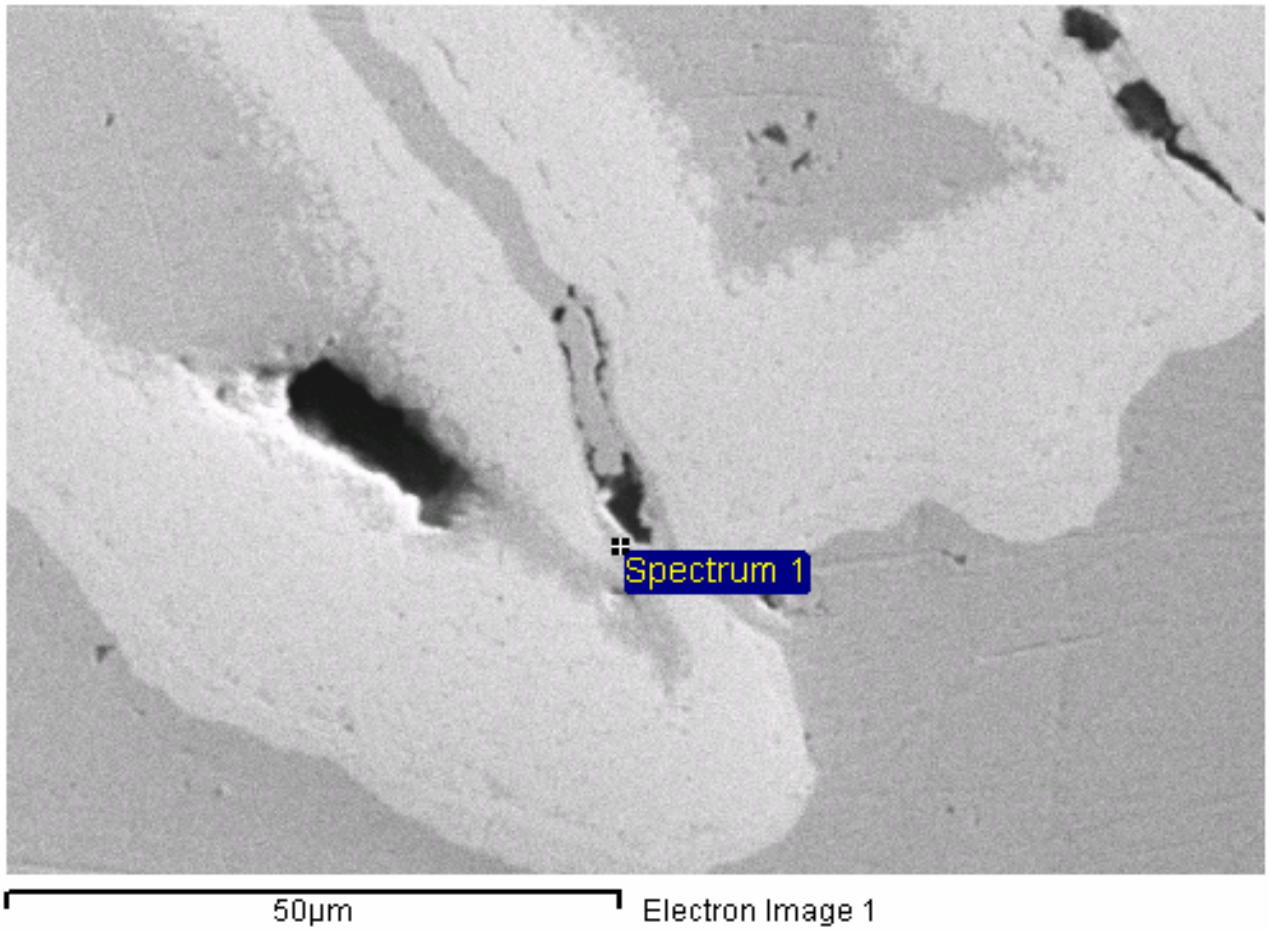


Processing option : All elements analysed (Normalised)

Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Line Spectrum(1)	Yes	9.18	60.42	20.35	10.06	100.00
Line Spectrum(2)	Yes	40.44	33.56	16.99	9.01	100.00
Line Spectrum(3)	Yes	41.66	7.21	-7.44	58.57	100.00
Mean		30.43	33.73	9.96	25.88	100.00
Std. deviation		18.41	26.60	15.17	28.31	
Max.		41.66	60.42	20.35	58.57	
Min.		9.18	7.21	-7.44	9.01	

All results in weight%

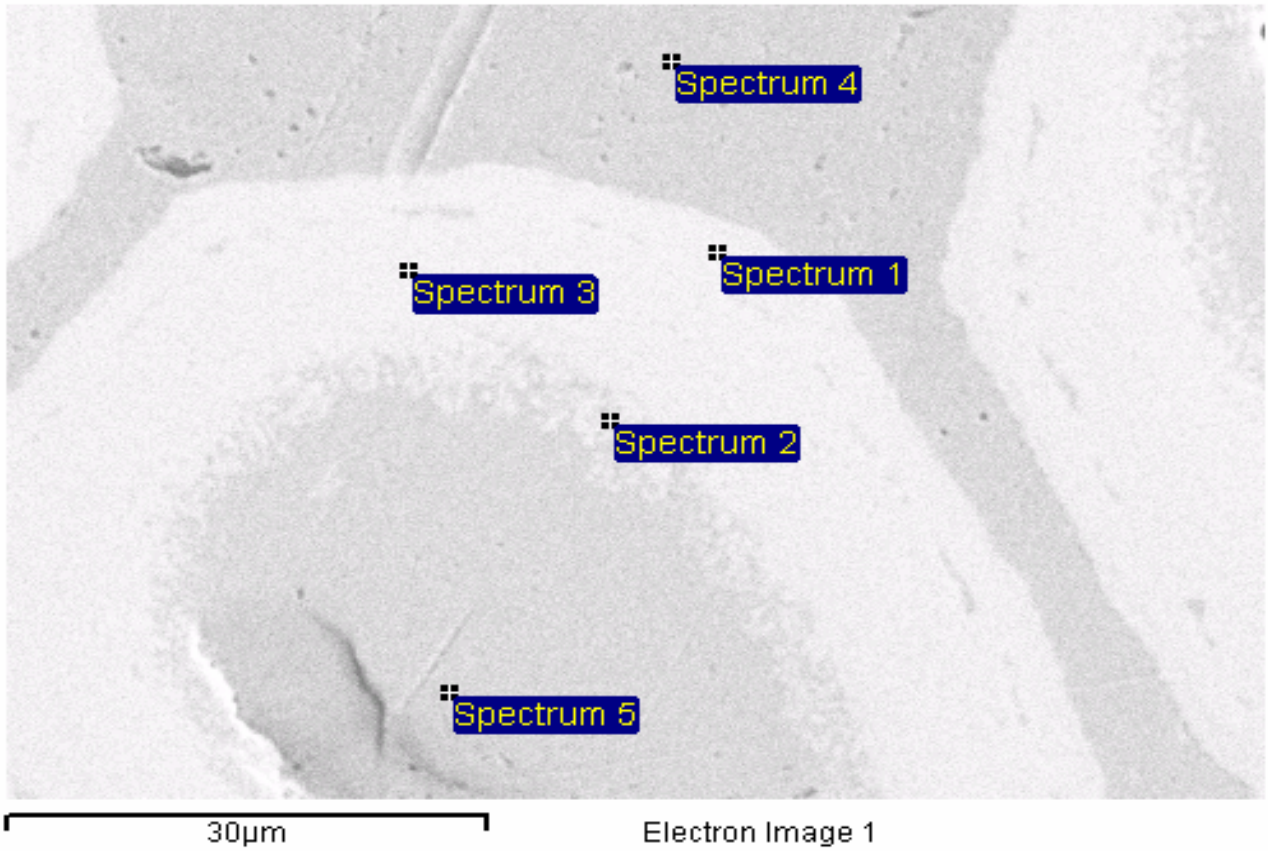
Coil 17 HT



Processing option : All elements analysed (Normalised)

Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Spectrum 1	Yes	55.72	35.73	6.00	2.55	100.00
Mean		55.72	35.73	6.00	2.55	100.00
Std. deviation		0.00	0.00	0.00	0.00	
Max.		55.72	35.73	6.00	2.55	
Min.		55.72	35.73	6.00	2.55	

All results in weight%

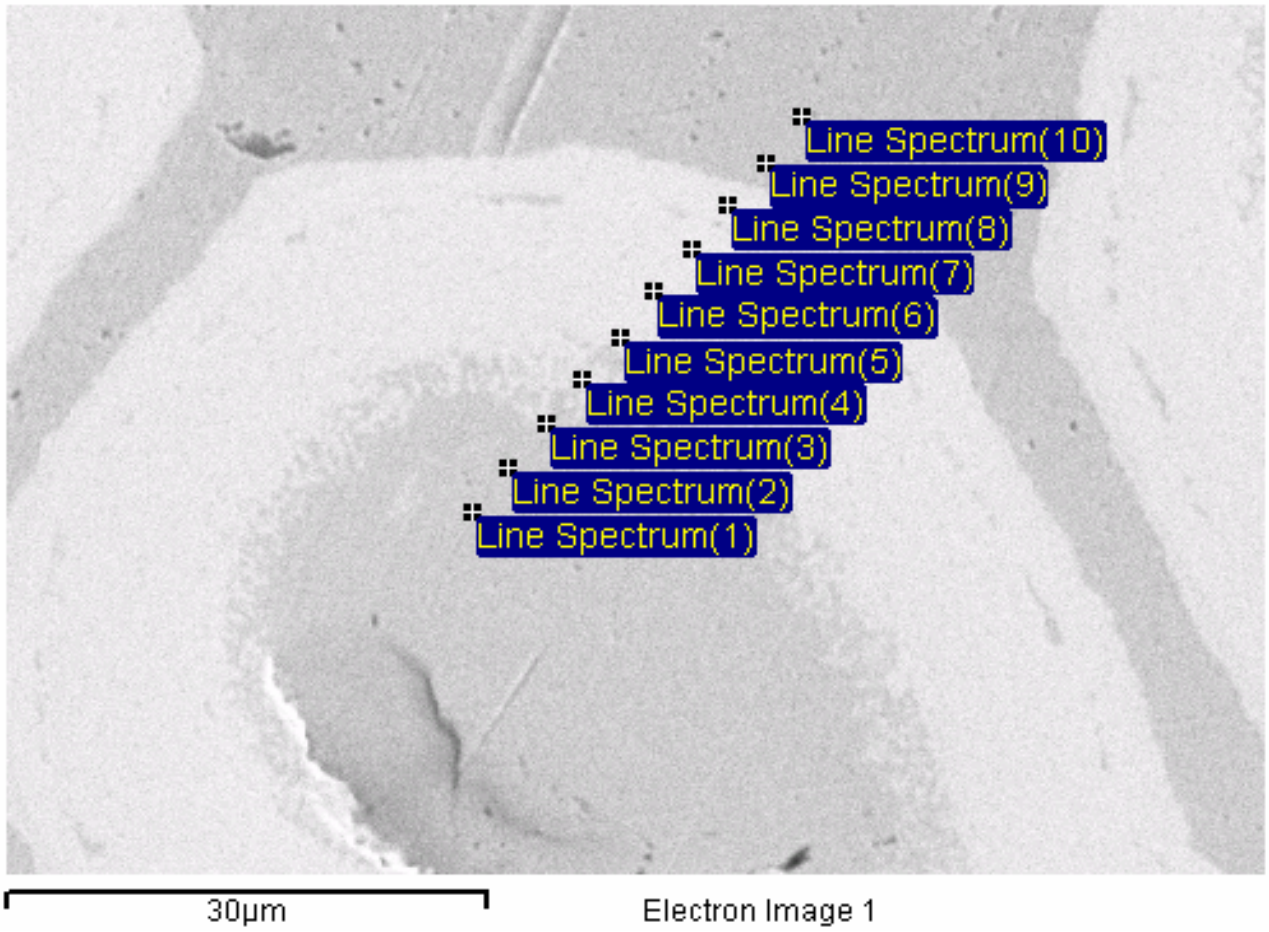


Processing option : All elements analysed (Normalised)

Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Spectrum 1	Yes	1.18	66.75	25.40	6.68	100.00
Spectrum 2	Yes	67.56	15.97	15.50	0.97	100.00
Spectrum 3	Yes	4.31	61.05	28.12	6.51	100.00
Spectrum 4	Yes	98.44	1.03	0.41	0.12	100.00
Spectrum 5	Yes	90.77	-0.15	10.03	-0.65	100.00
Mean		52.45	28.93	15.89	2.73	100.00
Std. deviation		46.79	32.61	11.34	3.58	
Max.		98.44	66.75	28.12	6.68	
Min.		1.18	-0.15	0.41	-0.65	

All results in weight%

Coil 17 HT

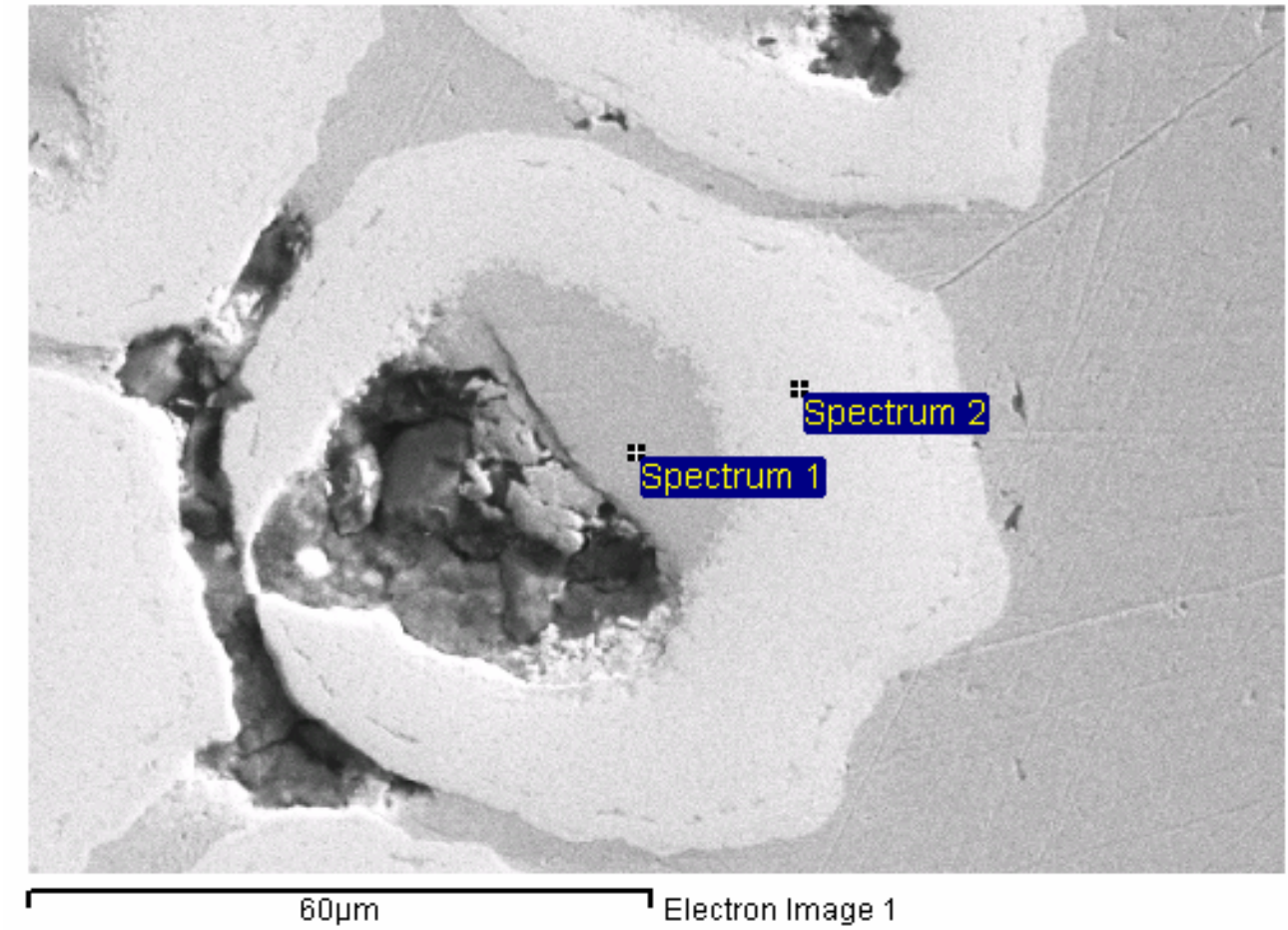


Processing option : All elements analysed (Normalised)

Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Line Spectrum(1)	Yes	89.13	0.48	10.90	-0.50	100.00
Line Spectrum(2)	Yes	88.28	0.09	11.10	0.53	100.00
Line Spectrum(3)	Yes	84.58	3.13	10.90	1.39	100.00
Line Spectrum(4)	Yes	18.23	51.63	25.41	4.73	100.00
Line Spectrum(5)	Yes	3.88	62.66	28.04	5.42	100.00
Line Spectrum(6)	Yes	0.86	66.05	26.78	6.31	100.00
Line Spectrum(7)	Yes	0.23	69.87	23.77	6.13	100.00
Line Spectrum(8)	Yes	97.28	0.42	1.98	0.31	100.00
Line Spectrum(9)	Yes	96.66	0.52	2.33	0.50	100.00
Line Spectrum(10)	Yes	97.98	0.12	2.02	-0.12	100.00
Mean		57.71	25.50	14.32	2.47	100.00
Std. deviation		45.14	32.23	10.73	2.81	
Max.		97.98	69.87	28.04	6.31	
Min.		0.23	0.09	1.98	-0.50	

All results in weight%

Coil 17 HT

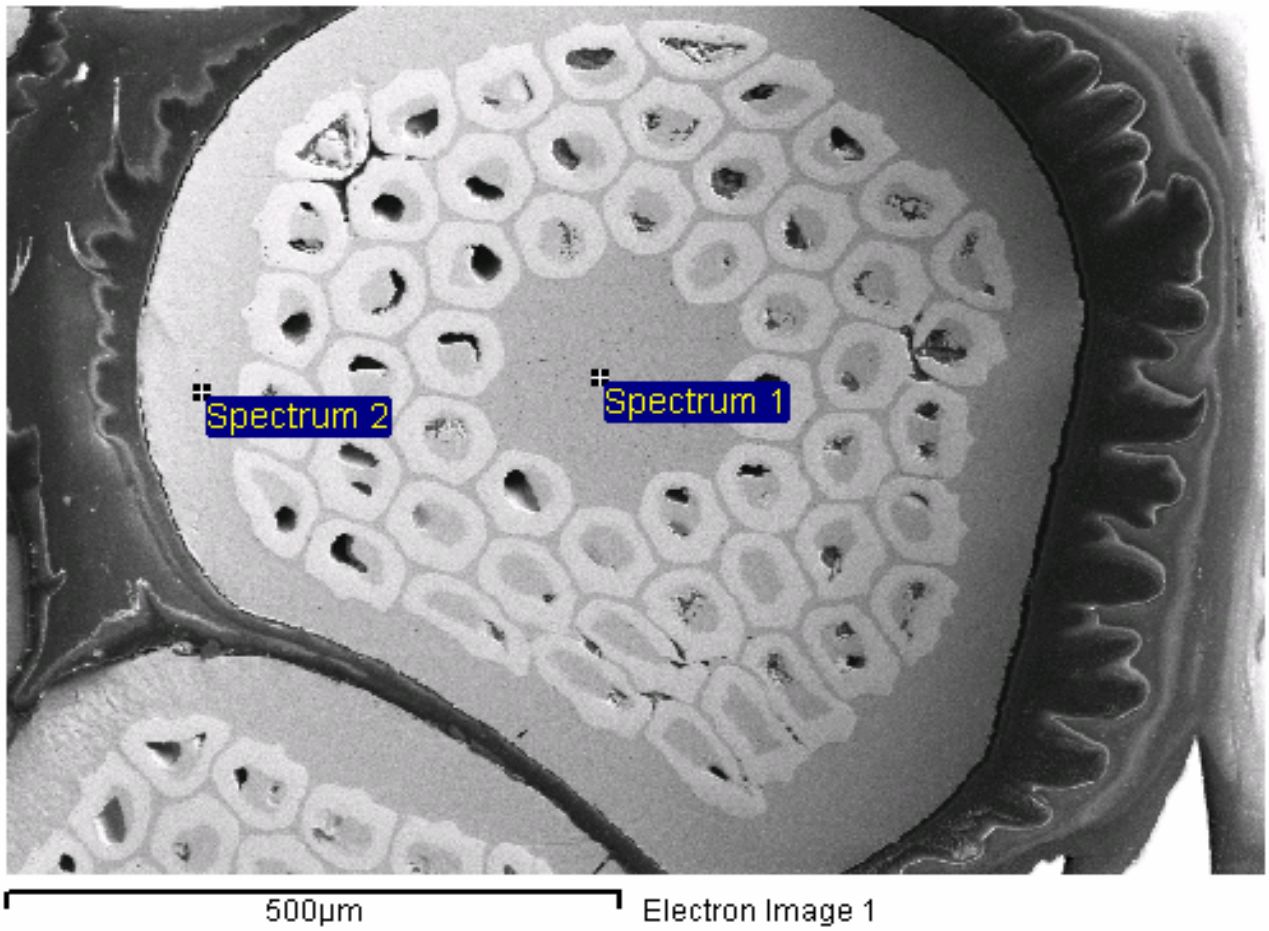


Processing option : All elements analysed (Normalised)

Spectrum	In stats.	Cu	Nb	Sn	Ta	Total
Spectrum 1	Yes	91.23		8.77		100.00
Spectrum 2	Yes		66.38	26.57	7.06	100.00
Max.		91.23	66.38	26.57	7.06	
Min.		0.00	0.00	8.77	0.00	

All results in weight%

Coil 17 HT



Processing option : All elements analysed (Normalised)

Spectrum	In stats.	Cu	Total
Spectrum 1	Yes	100.00	100.00
Spectrum 2	Yes	100.00	100.00
Mean		100.00	100.00
Std. deviation		0.00	
Max.		100.00	
Min.		100.00	

All results in weight%