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THICKNESS UNIFORMITY MEASUREMENTS OF THE COPPER FOILS USED FOR IRRADIATION PURPOSES OF E-631

V. Agoritsas

Two methods were used to measure the thickness of seven sample cuts (1, 2, 3, 4, 5, 6, 7) from 3 different copper foils, (A, B, C of 4 x 4 cm dimensions). The cuts were carefully machined in a lathe, as discs of $\sim$ 9 mm diameter. Two people independently applied the two methods (J.P. Bovigny and J. Haffner).

Method one :

The mean thickness of each sample was determined by dividing the weight of each sample by the product $\left[\text{surface} \times \left(\begin{smallmatrix}\text{copper}\\ \text{density}\end{smallmatrix}\right)\right]$
Copper density = 8.96 at 20°C.

$$\text{Thickness } [\mu m] = \frac{\text{Weight } [mg] \times 1000}{8.96 \times \text{Surface } [mm^2]}$$

Method two :

The thickness of the discs were directly measured using a commercial device called TESAMODUL (système électronique de mesure des longueurs) (electronic system for measuring thicknesses or lengths).

The thickness of each disc tabulated is the mean value of six thicknesses measured at six symmetric to center points. The standard deviation of the six thicknesses of each disc is also tabulated. This permits us to see thickness variations inside the disc.

RESULTS OF FIRST PERSON

.Copper foil A, Ø 9.00 mm

Sample	Weight [mg]	Surface [mm^2]	Method one thickness [µm]	Method two thickness [µm]
1	68.55	63.617	120.26	120.6
2	68.36	"	119.92	120.26
3	70.43	"	123.55	123.88
4	68.60	"	120.35	120.48
5	67.36	"	118.17	118.88
6	67.36	"	118.66	118.68
7	72.19	"	126.65	126.88
Mean ± SD,	69.02 ± 1.71		121.08 ± 3.00	121.38 ± 2.96
Copper foil B, Ø 9.00 mm				
1	70.81	63.617	124.22	124.56
2	73.60	"	129.12	128.83
3	73.53	"	128.99	128.98
4	74.05	"	129.90	129.46
5	70.58	"	123.82	123.50
6	74.17	"	130.12	130.18
7	71.83	"	126.07	126.30
Mean ± SD,	72.67 ± 1.54	"	127.45 ± 2.70	127.57 ± 2.71
Copper foil C, Ø 9.00 mm				
1	68.00	63.617	119.29	121.01
2	68.46	"	120.10	120.30
3	67.05	"	117.62	117.51
4	68.52	"	120.20	120.16
5	68.54	"	120.24	120.06
6	68.67	"	120.47	120.20
7	68.60	"	120.34	120.43
Mean ± SD,	68.26 ± .57	"	119.75 ± 1.01	119.95 ± 1.12

METHOD TWO

DETAILED RESULTS OF FIRST PERSON

COPPER FOIL (A)

Sample	Measurements	Mean	S.D.
1	121.0 / 120.3 / 121.0 / 120.2 / 120.3 / 120.8 →	120.6	± .37
2	119.9 / 120.4 / 120.3 / 120.6 / 120.3 / 120.1 →	120.26	± .24
3	124.1 / 123.5 / 123.8 / 123.9 / 124.1 / 123.9 →	123.88	± .22
4	120.1 / 120.8 / 120.8 / 120.4 / 120.1 / 120.7 →	120.48	± .33
5	119.0 / 119.5 / 119.6 / 119.9 / 117.8 / 117.5 →	118.88	± 1.00
6	119.4 / 118.3 / 117.7 / 118.8 / 119.2 / 118.7 →	118.68	± .61
7	127.2 / 127.0 / 126.4 / 126.8 / 126.9 / 127.0 →	126.88	± .27

COPPER FOIL (B)

1	124.0 / 124.9 / 125.2 / 125.2 / 124.5 / 123.6 →	124.56	± .66
2	129.3 / 128.3 / 128.5 / 128.7 / 129.1 / 129.1 →	128.83	± .39
3	128.6 / 128.7 / 128.7 / 129.3 / 129.4 / 129.2 →	128.98	± .35
4	129.5 / 129.9 / 129.4 / 129.0 / 129.4 / 129.6 →	129.46	± .29
5	124.7 / 124.0 / 122.9 / 123.1 / 123.6 / 122.7 →	123.5	± .76
6	129.8 / 130.1 / 129.5 / 130.4 / 130.7 / 130.6 →	130.18	± .42
7	126.5 / 126.4 / 126.3 / 125.8 / 126.3 / 126.5 →	126.3	± .26

COPPER FOIL (C)

1	120.6 / 121.3 / 121.3 / 121.5 / 121.0 / 120.4 →	121.01	± .44
2	120.8 / 120.2 / 120.0 / 120.1 / 120.2 / 120.5 →	120.3	± .30
3	118.7 / 118.4 / 118.1 / 116.6 / 116.8 / 116.5 →	117.51	± .99
4	120.4 / 119.6 / 120.3 / 120.3 / 119.9 / 120.5 →	120.16	± .34
5	120.1 / 119.8 / 120.1 / 120.6 / 119.9 / 119.9 →	120.06	± .29
6	120.8 / 120.2 / 119.9 / 120.1 / 119.8 / 120.4 →	120.2	± .36
7	119.3 / 121.3 / 120.1 / 120.6 / 121.0 / 120.3 →	120.43	± .71

RESULTS OF SECOND PERSON

COPPER FOIL (A) Ø 8.98 mm

Sample	Weight [mg]	Surface [mm^2]	Method one Thickness [µm]	Method two Thickness [µm]
1	68.56	63.334	120.81	120.56
2	68.34	"	120.43	120.80
3	70.40	"	124.06	123.67
4	68.54	"	120.78	120.40
5	67.40	"	118.77	119.05
6	67.62	"	119.16	118.72
7	72.25	"	127.31	126.60
Mean ± S.D,	69.01 ± 1.72		121.62 ± 3.03	121.4 ± 2.80

COPPER FOIL (B) Ø 8.98 mm

1	70.87	63.334	124.89	124.40
2	73.60	"	129.69	129.12
3	73.60	"	129.69	129.12
4	74.09	"	130.56	129.83
5	70.62	"	124.45	123.80
6	74.19	"	130.73	130.47
7	71.76	"	126.45	126.28
Mean ± S.D,	72.67 ± 1.54		128.06 ± 2.72	127.57 ± 2.71

COPPER FOIL (C) Ø 8.98 mm

1	68.02	63.334	119.86	120.78
2	68.38	"	120.50	120.30
3	67.05	"	118.15	117.80
4	68.61	"	120.90	120.23
5	68.58	"	120.85	120.02
6	68.71	"	121.08	120.40
7	68.60	"	120.88	120.47
Mean ± S.D,	67.28 ± .59		120.32 ± 1.03	120.00 ± 1.00

METHOD TWO

DETAILED RESULTS OF SECOND PERSON

COPPER FOIL (A)

Sample	Measurements	Mean	S.D.
1	120.8 / 120.9 / 120.7 / 119.9 / 120.8 / 120.3 →	120.56	± .40
2	120.9 / 120.9 / 120.5 / 120.7 / 120.8 / 121.0 →	120.80	± .18
3	123.9 / 123.6 / 123.1 / 123.3 / 123.9 / 124.2 →	123.67	± .41
4	120.4 / 120.3 / 120.2 / 120.9 / 120.2 / 120.3 →	120.40	± .26
5	120.2 / 118.7 / 120.4 / 118.2 / 118.0 / 118.8 →	119.05	± 1.01
6	119.2 / 118.0 / 117.7 / 118.1 / 120.0 / 119.3 →	118.72	± .91
7	127.0 / 126.9 / 126.3 / 126.2 / 126.2 / 127.0 →	126.60	± .40

COPPER FOIL (B)

1	124.4 / 124.1 / 124.0 / 124.2 / 125.3 / 124.4 →	124.40	± .47
2	129.3 / 129.0 / 129.4 / 129.0 / 129.1 / 128.9 →	129.12	± .20
3	129.0 / 128.8 / 128.9 / 129.5 / 129.2 / 129.1 →	129.12	± .19
4	129.3 / 129.6 / 130.1 / 129.9 / 130.0 / 130.1 →	129.83	± .32
5	124.6 / 124.1 / 124.0 / 123.8 / 122.9 / 123,4 →	123.80	± .59
6	130.3 / 130.6 / 130.5 / 130.4 / 130.3 / 130.7 →	130.47	± .16
7	126.0 / 126.5 / 126.4 / 126.2 / 126.0 / 126.6 →	126.28	± .26

COPPER FOIL (C)

1	121.2 / 121.0 / 120.2 / 120.4 / 121.1 / 120.8 →	120.78	± .48
2	120.6 / 120.2 / 120.7 / 120.2 / 120.6 / 119.5 →	120.30	± .45
3	118.4 / 117.3 / 117.8 / 117.9 / 118.1 / 117.3 →	117.80	± .44
4	120.5 / 120.6 / 120.5 / 119.9 / 119.8 / 120.1 →	120.23	± .34
5	120.2 / 119.8 / 119.7 / 119.8 / 120.5 / 120.1 →	120.02	± .31
6	120.0 / 120.5 / 120.6 / 120.9 / 120.2 / 120.1 →	120.40	± .35
7	120.0 / 120.7 / 120.5 / 121.0 / 120.6 / 120.0 →	120.47	± .40

Conclusions

1. The discrepancies between the results obtained by the two persons who made the thickness measurements using the two methods are very small.

2. The discrepancies between the measured mean thicknesses of the same copper foil, (A, B or C) using the two methods are also very small.

3. The standard deviation of the measured mean thicknesses of both methods and of both persons is $\pm$ 2.5% of the mean thickness $\sim$ 120 µm for copper foils A and B and $\pm$ 1% for copper foil C; however the standard deviation of the mean weight is exactly of the same order. As the weight and the diameter of each disc can be measured with good accuracy this implies that method two is as accurate as method one.

4. The standard deviation of the measured mean thickness by method two of individual discs of all three sampled copper foils is most of the time less than $\pm$ 1%. The area of the discs is comparable to the beam profile area on the irradiated foils. It implies therefore that the foil thickness cannot be known better than $\pm$ 1% if they are cut to discs of 9 mm in diameter. For bigger foil cuts (20, 30 mm in diameter the thickness of the irradiated foils is not known better than $\pm$ 2.5%.

5. More attention must be paid to determining the foil thickness of the irradiated area of the used or to be used copper foils.

6. Find a foil supplier with good uniformity or produce our own foils by evaporation techniques.

7. Use copper in other forms like powder or even in liquid solutions.