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August 22, 1996
Princeton/BaBar/TNDC-96-46

Drift Chamber Wire Quality Control: Preliminary Test Results

Introduction

Before we string the wire in the BaBar drift chamber it will be subjected to several quality inspection steps. Based on work done at the University of British Columbia and Princeton University the final inspection steps include measurements of the following for each spool of wire:

- Wire diameter,
- Linear density of the wire,
- Young's modulus,
- Yield tension,
- Creep,
- Surface quality,
- Straightness.

1 Wire Diameter

The BaBar drift chamber uses 20-μm-diameter gold-plated tungsten anode wires, 120-μm-diameter gold-plated aluminum cathode wires, and 80-μm-diameter gold-plated aluminum wires for those cathode wires not at ground potential. We desire both uniformity of wire diameter and of the gold plating. The latter is nominally 25 μinch = 0.6 μm, but comprises 12-17% of the mass of the wire.[1]

From measurements of both the diameter and the mass of the wire we can infer the thickness of the gold plating.

We measure the wire diameter with a Mitutoyo Model 293-701 digital micrometer whose resolution is 1 μm. The force from the micrometer spindle will deform the wire, resulting in a reading smaller than the true diameter. This spindle force is measured to be 5-10 N, which is applied along a diameter of the spindle, *i.e.*, 1/4 inch. A finite-element-analysis

[1] For the aluminum wire the gold is plated over layers of zinc and nickel of order 0.1 μm.

calculation shows the deformation for the 120-μm Al wire clmaped by the spindle will be 0.05-0.11 μm, which is negligible.

Table 1 lists the measured diameter for several wire samples. The results are repeatable and very close to their nominal value.

2 Linear Density

A Mettler AT1005 Mass Comparator (= balance) is employed to measure the mass of the wire. The readability of this balance is 0.01 mg, and most recently calibrated standard deviation of its sensitivity is 0.018 mg.

To ensure a standard length for test wire samples we have made a special wire cutting jig, shown in Fig. 1. The distance between two slots on two end blocks is 1000±0.1 mm. The width of the slots is just enough to insert a razor blade to cut the wire. Wire is threaded through the small holes on the two end blocks and then clamped at the right end; the left end of the wire is held straight by the operator.

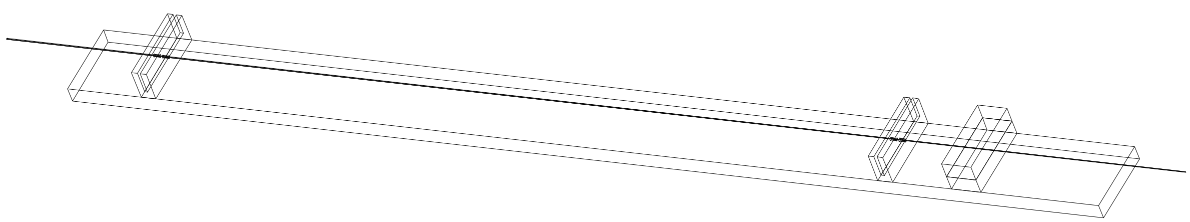

Figure 1: A jig to cut wire to a 1-m length.

An error in wire length will come from the variation of the wire tension, which is about 2 g. The smallest spring constant of our chambers wires is that of the 20-μm-tungsten anode wire, which is measured to be 23 g/mm. Therefore the variation of wire length due to the wire tension will be at most 0.1 mm.

Some test results for various wire samples are summarized in Table 1.

From the table we can see the linear density of CFW (California Fine Wire) Al wire is quite uniform. The observed variation of mass is consistent with the sensitivity of the balance, 10 μg, corresponding to linear mass density variation of less than one part per thousand.

The thickness t of the gold coating of the aluminum wire can be determined from the measured mass m, radius r and length l of the wire according to

$$t = \frac{m - \pi r^2 l \rho_{\mathrm{Al}}}{2\pi r l(\rho_{\mathrm{Au}} - \rho_{\mathrm{Al}})}.$$

[The density of tungsten and gold are so similar that this method doesn't work for the tungsten wire.] The error in the determination will be dominated by the ≈ 1 μm error in

Table 1: Linear density and diameter of various wire samples.

Material and Manufacture	Production Date	Spool #	Sample #	Weight (mg)	Diameter (μm)	Au/Ag thickness (μm)
Al 5056	4/17/96	1	1	33.86	119	
Au-coated			2	33.86	119	0.59
CFW			3	33.85	120	
Al 5056	4/2/96	2	1	16.61	81	
Au-coated			2	16.64	81	0.64
CFW			3	16.63	81	
Al 5056	6/18/96	1	1	15.84	80	
Ag-coated			2	15.83	81	1.03
CFW			3	15.85	81	
Al		1	1	33.43	124	
uncoated			2	33.43	124	
KEK			3	33.38	124	
Al 5056	7/96	1	1	16.43	81	0.60
Au-coated		3	1	16.43	81	0.60
CFW		4	1	16.41	81	0.59
		5	1	16.41	81	0.59
		7	1	16.41	81	0.59
		8	1	16.43	81	0.60
Tungsten Thermionic	4/2/96	1	1	6.72	21	
Tungsten Philips	4/20/80	1	1	6.72	21	

the measurement of the wire diameter, so can infer the thickness of the gold plating on the aluminum wires to about 1% relative accuracy.

Results of the calculation of the gold thickness are also shown in Table 1. They are quite close to the nominal thickness of 0.6 μm.

2.1 Young's Modulus and Yield Stress

The method we are using is based on tech-note TNDC-96-48 by W.P. Wong and C. Hearty. The apparatus is shown in Fig. 2. A Mettler PM5003 Comparator balance is used for this measurement. A 1-kg weight is put on the pan of the balance. The upper end of a wire is clamped to a horizontal bar, which is directly attached to the (nonrotating) spindle of a Mitutoyo model 406-721-30 digital micrometer with SPC readout. The lower end of a wire is clamped to a small tee with a hole on it. The 1-kg weight hooks to the tee through this hole. By rotating the thimble of the micrometer, a wire can be stretched to different lengths and the corresponding tension inferred from the reading of the balance.

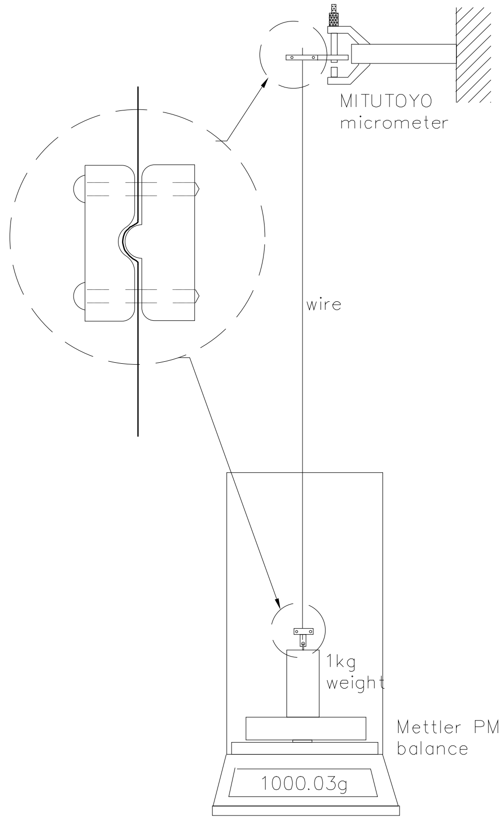

Figure 2: Set-up for measurement of the Young's modulus and yield tension.

The wire clamps are shown in the insert of Fig. 2. The wire is clamped around 1.5-mm-radius pin, producing sufficient friction to hold a weight up to 800 g. Since the wire is highly deformed at the clamp it somethimes breaks there before the nominal breaking stress is achieved.

By reading the balance and micrometer as the latter is adjusted, a load *vs.* stretch curve can be recorded. The data are entered semi-automatically into a Windows statistical spreadsheet package (StatMost) via RS-232 control using a TSR communication program (Software Wedge). A small correction is needed for the variation of the balance pan's displacement with load. We have measured the correction directly with a dial indicator with graduations of 0.0005 inch. The displacement of the pan is $\Delta x(\text{mm}) = 0.0001 \times \text{Load(g)}$, a very small correction.

Typical load *vs.* displacement curves for 81-μm-diameter aluminum wires with Au or Ag coating are shown in Fig. 3.

The 'yield strength' of the wire is defined as the tension that produces a 0.2% deviation from a linear stress *vs.* strain relation. See Fig. 3, where the yield point corresponds to an extra elongation of 1.2 mm of the 587-mm-long wire.

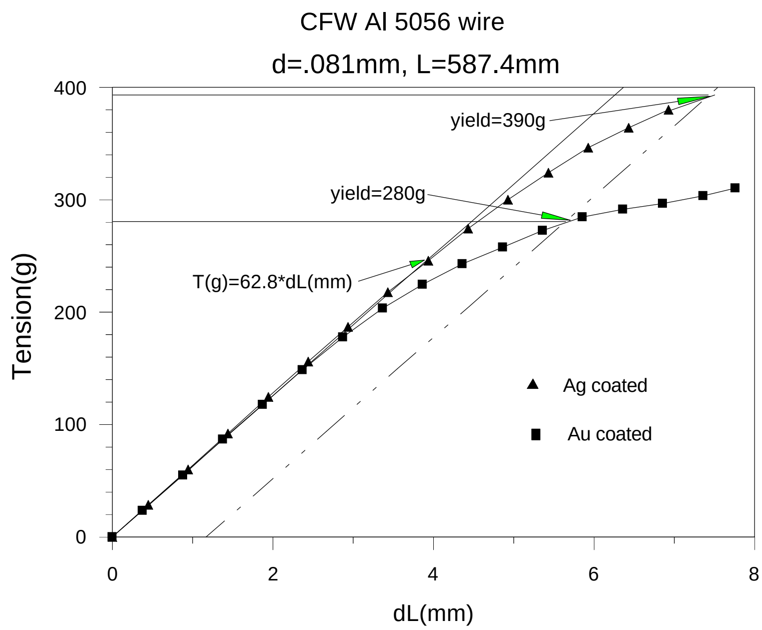

Figure 3: Wire tension vs. displacement curves for Au/Ag-coated Al wires.

In Table 2 we summarize the Young's modulus, yield tension, and breaking tension for various wire samples.

It is notable that the KEK aluminum wire sample has very different behavior from the CFW wire. In Fig. 4 we show tension *vs.* displacement curves for KEK and CFW Al wire. Both have the same Young's modulus over the linear portion of the curve, but the KEK wire shows a rather low yield tension. At around 280 g tension the 124-μm-diameter KEK wire passes its elastic limit and goes into extensive plastic deformation. The 56-cm-long wire sample could be stretched by $\sim$ 3 cm without appreciable increase in tension, during which time the diameter of the wire was reduced to 121 μm.

We loosened the KEK wire, reclamped the permanently stretched wire at 56 cm distance, and repeated the tension *vs.* displacement measurement. The linear portion of the curve was unchanged, but yield tension was higher than first time, being now $\sim$ 340 g. It stretched by another $\sim$ 3cm and the diameter decreased to 118 μm.

We repeated the same procedure a third time, and found a still higher yield tension, $\sim$ 380 g. Finally the wire broke at 400 g tension.

In comparison, a 120-μm-diameter CFW wire achieves a much higher yield tension, and there is no sharp turning point from elastic to plastic region. Just slightly above the yield tension of 751 g it broke.

It may that the process of gold plating that has changed the yield behavior. We found significantly different yield tensions for the 80-μm-diameter Al 5056 wire with different coatings: Au coating showed $\sim$ 280 g yield tension, but Ag coating (KLOE wire) showed a much higher yield tension, 390 g.

Table 2: Summary of measured Young's modulus and yield tension for various wire samples.

Material and Manufacture	Production Date	Diameter (μm)	Spool #	Young's Modulus (GPa)	Yield Tension (g)	Breaking Tension (g)
Al 5056 Au-coated CFW	7/96	81	1	70.2	280	310
	7/96	81	3	69.5	284	290
	7/96	81	4	69.2	280	300
	7/96	81	5	69.4	278	300
	7/96	81	7	70.0	280	310
	7/96	81	8	69.3	280	290
Al 5056 Au-coated CFW	4/17/96	119.3	1	69.6	700	700
Al 5056 Ag-coated CFW	6/18/96	81	1	69.3	390	380
Al uncoated KEK		124		70.8	280	400
Tungsten Au-coated Thermionic	4/2/96	21	375.6	108	105	

3 Creep Test Results

A 1-m-long straw-tube prototype chamber (from BNL E-787) was used for the wire creep test. A layer of 24 straw tubes were mounted in an aluminum frame. The test wires were strung inside of straw tubes and fixed at both ends by pushing copper pins into plastic feedthroughs. To prevent the wire from slipping between the feedthrough and pin, a plastic collar was tightly placed outside of the tapered feedthrough.

We tested several types of wires:

1. Au-coated tungsten wire of 21 μm diameter. Seven tungsten wires under different tensions show no sign of creep after 45 days.

2. CFW Au-coated aluminum wires of 81 μm and 120 μm diameter (purchased in 1995 by SLAC, provided to us by Daivd Warner of CSU), These wire samples were just strung 7 days ago and already we see 4-5% decrease in wire tension (Fig. 6). This is reasonably consistent with measurements by C. Hearty on wire purchased in 1995.

3. CFW Au-coated aluminum wires of 81 μm and 120 μm diameter (purchased in March 1996 by Princeton). The first 45 days results of the 1996 CFW aluminum wires are

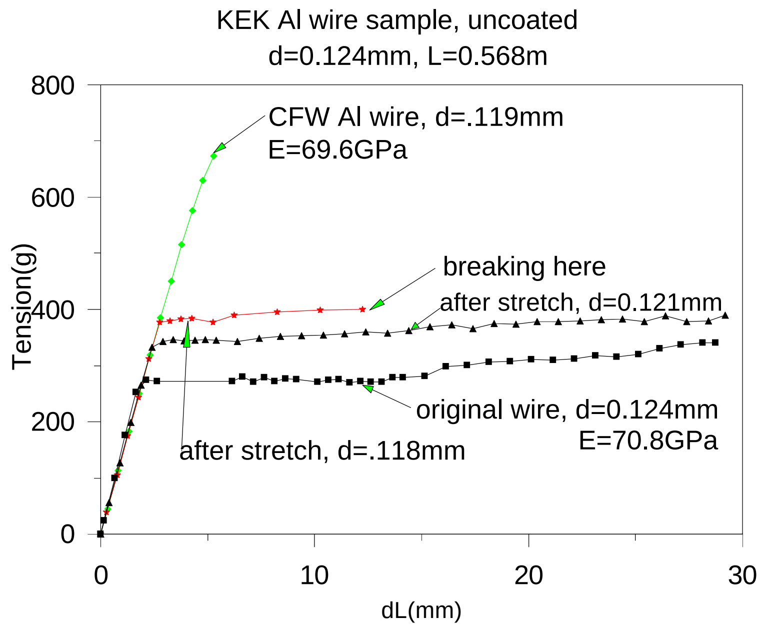

Figure 4: Comparison of KEK uncoated Al wire and CFW Au-coated Al wire.

shown in Fig. 5. We didn't see a sharp decrease of the wire tension during the first week. A slow decrease in tension has been observed, amounting to 2-8% after 45 days and loosely correlated to the wire tension. [C. Hearty reports that CFW Al wire purchased in August 1996 shows creep after a few days similar to that of the 1995 wire. We will test samples of this wire in the near future.]

4. Uncoated KEK aluminum wire of 124 μm diamter. No creep in this wire has been observed over 45 days to the accuracy of our test: about 1% in the tension.

4 Wire Surface Quality

Wire surface quality is difficult to specify and to inspect. Currently we are considering two means: microscopic and macroscopic.

4.1 Microscopic

We can use our scanning electron microscope to check a small sample from each spool. Our Amray 1200B SEM prdouces sharp and clear pictures up to 5000X magnification. The surface topographical detail can be revealed down to sub-micron range. That performance, although far from state of the art, should be sufficient for our purpose.

In Fig. 7 we show a picture taken from 81-μm-diameter CFW Al wire with Au coating (purchased in March 1996). The surface of Au-coated wire is never perfect. Extensive cratering with on the few-micron scale can be clearly seen. But there are no projections,

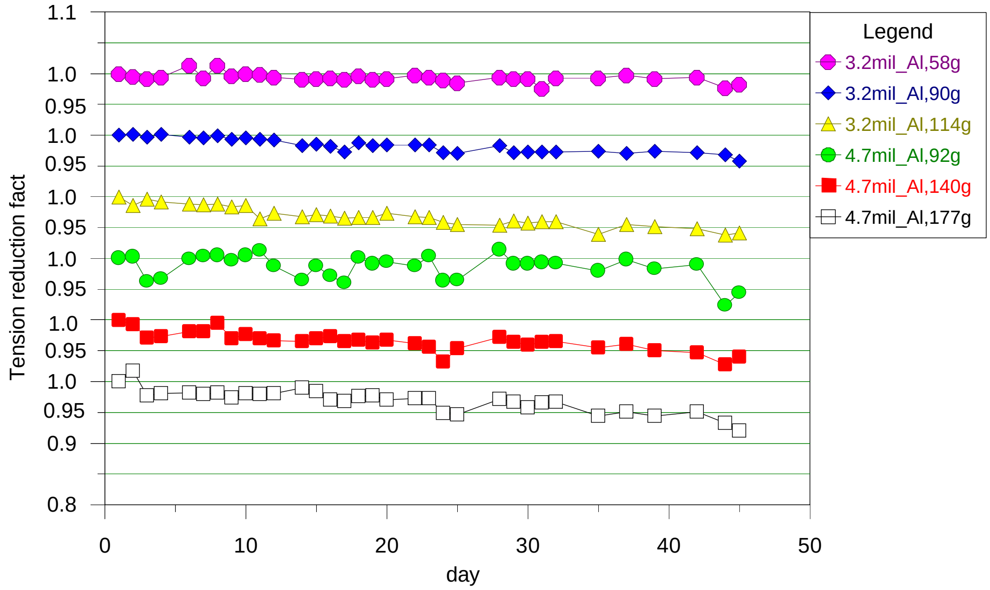

Figure 5: Creep test results.

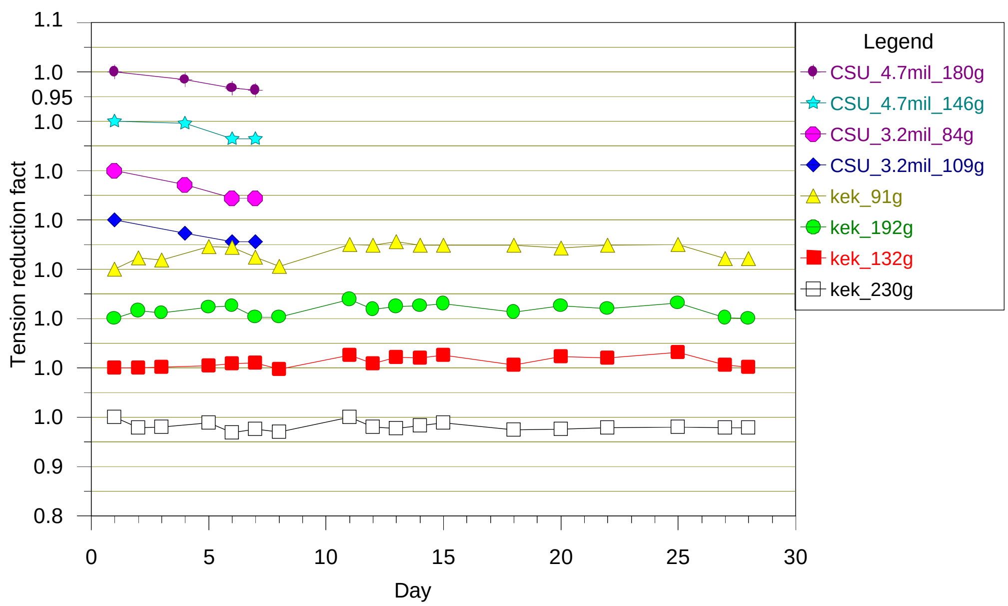

Figure 6: Creep test results for KEK Al wire and CSU wire.

only seen are pits. Hence the surface structure should not greatly aggravate field emission and is believed to be acceptable for drift-chamber opertion.

Figures 8 and 9 show two other samples of Al wire. All show evidence of surface pitting, although perhaps somewhat less than in Fig. 7.

On other hand, the Au-coated tungsten anode wire itself only 20 μm in diameter, so

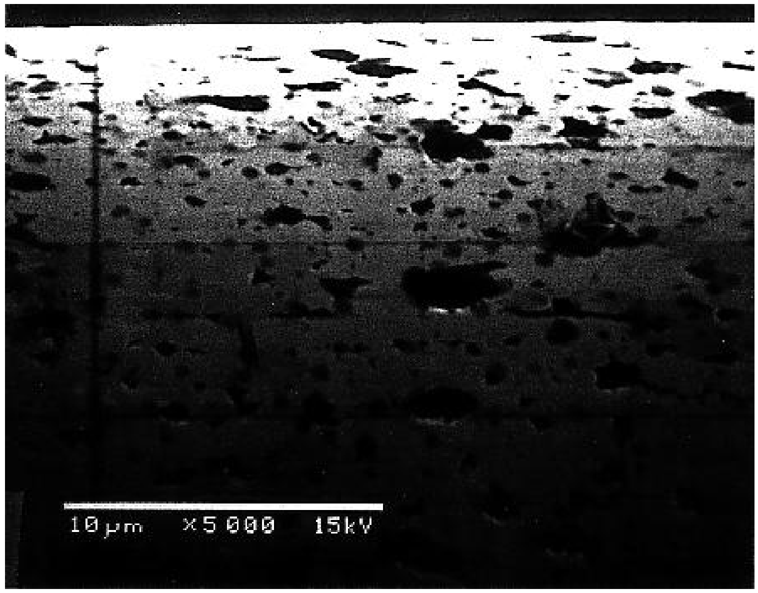

Figure 7: SEM picture of 81-μm-diameter Au-coated aluminum wire from CFW.

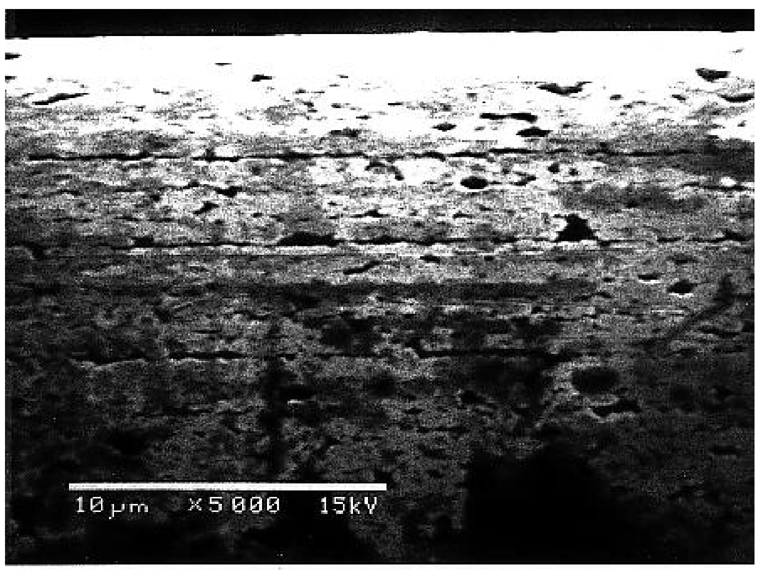

Figure 8: SEM picture of 81-μm-diameter Ag-coated aluminum wire from CFW.

micron scale surface structure can have a greater effect In Fig. 10 to 13 we show samples from four vendors. The different surface qualities are clear. The wire in Figs. 11 and 12 led to poor performance in chambers built years ago at Princeton University.

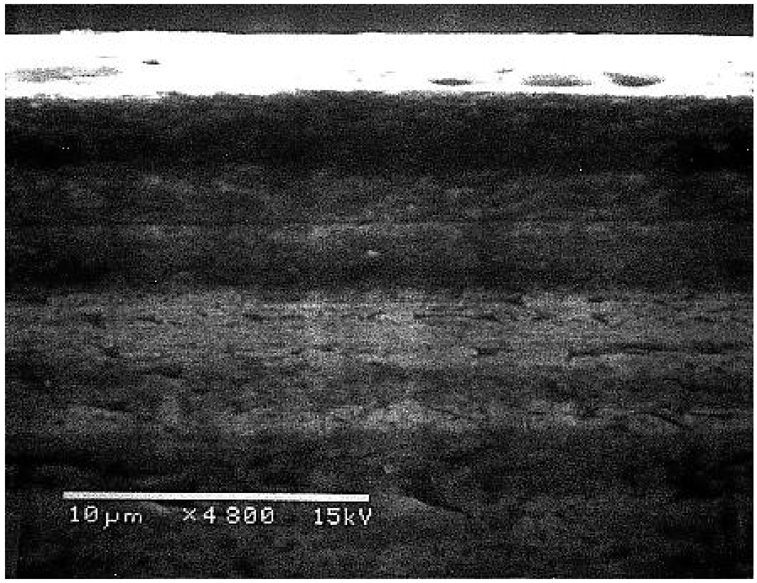

Figure 9: SEM picture of 124-μm-diameter uncoated aluminum wire from KEK.

4.2 Macroscopic

The SEM can give a clear wire-surface topographic picture, but it is restricted to a very small portion of each spool. Maybe a more quantitative criteria based on a macroscopic usage of the wire would be better. We are presently exploring the merits of high-voltage tests of centimeter lengths of wire in small cylindrical chambers.

5 Straightness of the Wire

Highly curled wire is difficult to thread through the tiny hole of a pin or chamber feedthrough. According to a phone conversation with Mike Hagen of SAES, Luma and CEBAF settled on a certain criterion regarding the straightness of 20-μm-diamter tungsten wire. For a 1-m-long wire sample hung vertically with a 1-g weight at lower end, the maximum acceptable deviation from a straight line is 1 cm (straightness grade 1). We will explore whether this criterion is suitable for the BaBar drift chamber stringing technique.

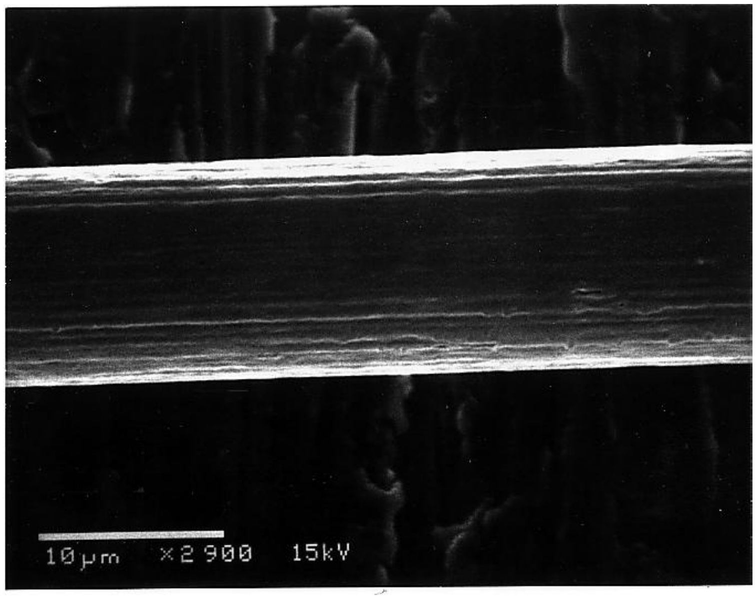

Figure 10: SEM picture of 20-μm-diameter Au-coated tungsten wire from Luma.

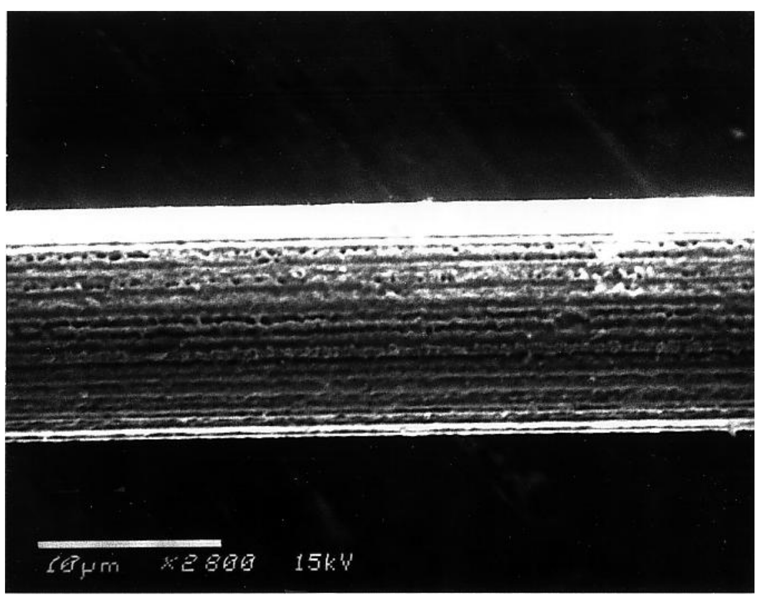

Figure 11: 20-μm-diameter Au-coated tungsten wire from GE.

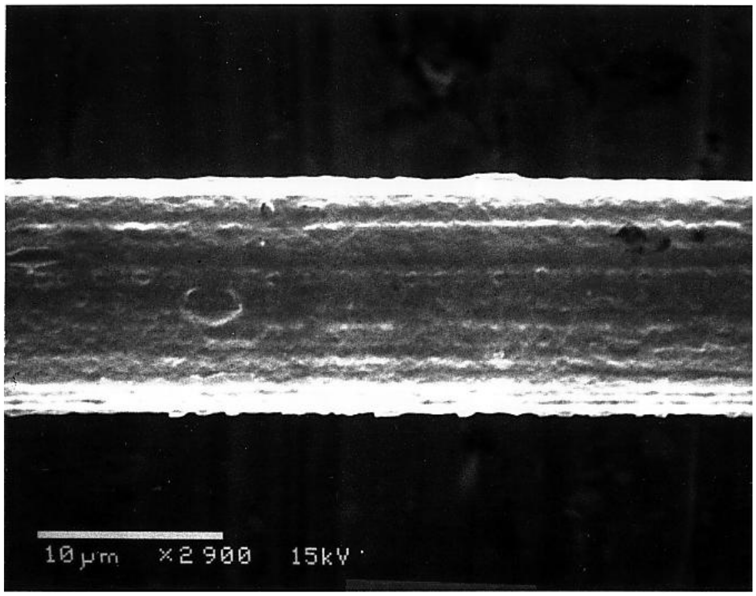

Figure 12: 20-μm-diameeter Au-coated tungsten wire from Philips Elmet.

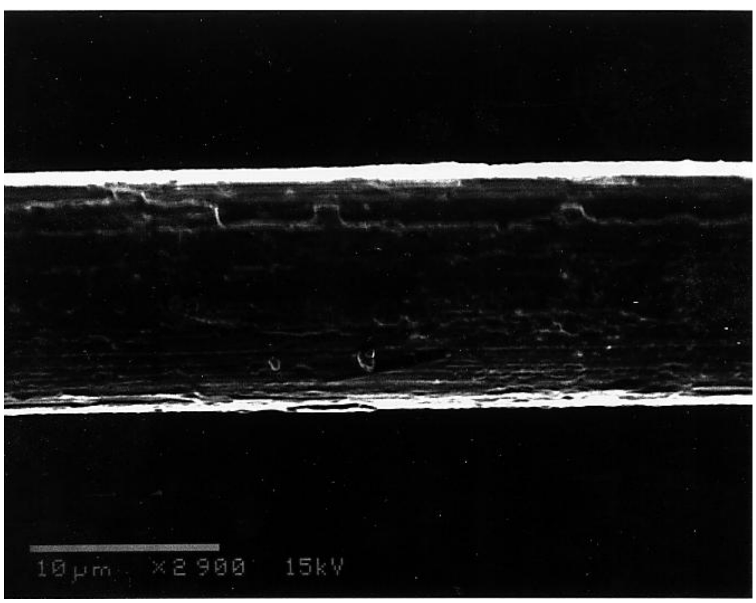

Figure 13: 20-μm-diameter Au-coated tungsten wire from Thermionic Products.