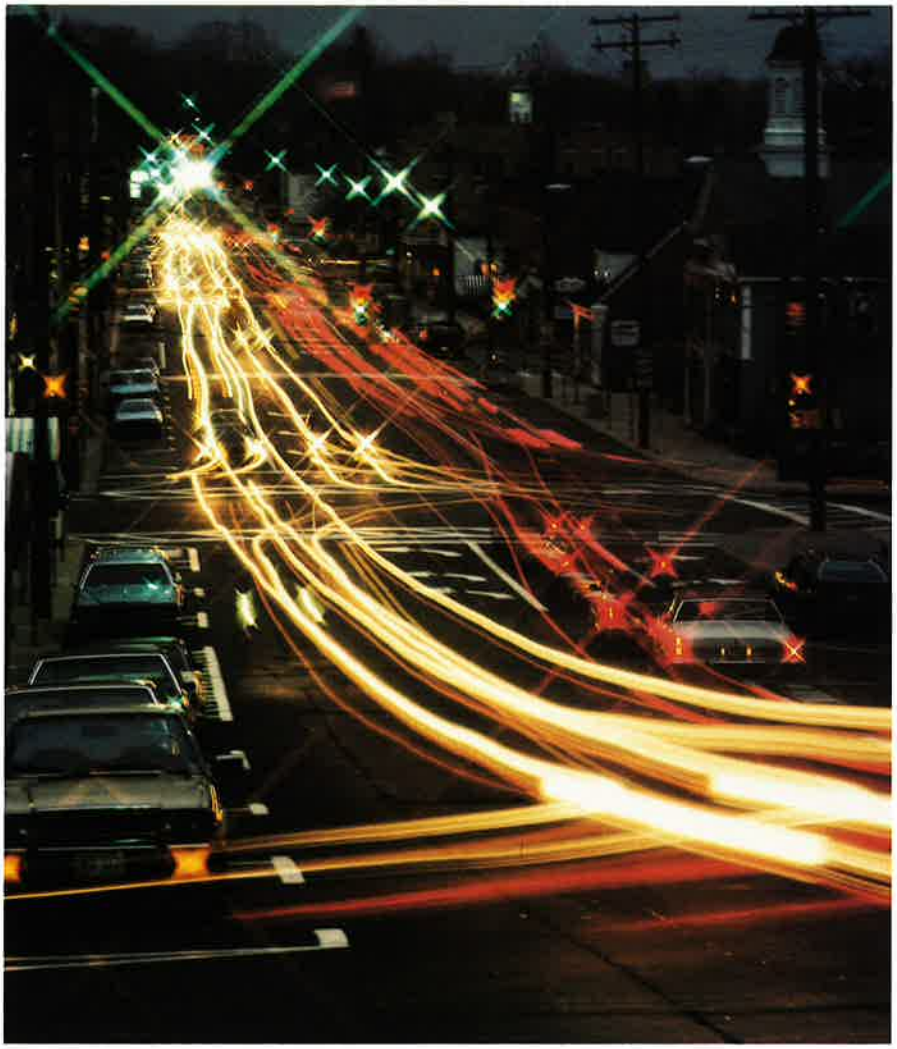
Tungsten Wire

GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY
Lamp Components & Technical Products Division

Introduction

GENERAL ELECTRIC TUNGSTEN WIRE



The high temperature strength and stability of tungsten wire help to provide reliable lighting even in such vibration-prone applications as automotive lamps.

Tungsten... A Unique Engineering Material

Of all the materials that have emerged in America's space age, few can match the strength and high temperature characteristics of tungsten.

At General Electric Company, we've harnessed the tremendous potential of this material. By making it available in wire forms, GE combines the engineering properties, the design latitude, and the production versatility that makes tungsten wire useful in a variety of demanding applications.

Tungsten wire is a material born of the lamp industry. With its strength at high temperatures, it developed into the prime material for lamp filaments, capable of burning brightly, cycle after cycle, without failing.

Today, these high temperature attributes are being put to work in applications far afield from lighting.

Contributing to the growing use of tungsten wire is its availability in an almost infinite variety of sizes, properties and finishes. Using conventional manufacturing techniques, tungsten wire is readily coiled, formed, cut, rolled, joined and etched to meet exacting dimensional requirements.

With the excellent capabilities that General Electric has for the production of tungsten wire, we are much more than just another source. GE offers the staff and facilities to provide valuable design and manufacturing assistance to users. Our engineers are constantly improving the properties and performance of tungsten products, and our laboratories are specially equipped to support this effort.

If you'll tell us how you expect to use our material, we'll help you select the product that is most appropriate for your application, and give you guidelines on handling it in your process.

A Part of GE's Past

The development of tungsten wire dates back to the beginning of General Electric Company. At the turn of the century, lamp filaments were rather short-lived. This was a major concern to Thomas Edison and other pioneers of the lighting industry. It was the legendary Charles Steinmetz who spurred his small but growing group of researchers to overcome this major obstacle to the lamp industry's growth.

By 1907, GE had lamps with sintered tungsten filaments on the market, offering twice the light efficiency of tantalum filament lamps then available.

Lamp filaments made from the first ductile tungsten wire, developed in the laboratory of Dr. William D. Coolidge, another of GE's pioneering scientists in the lamp industry, were introduced in 1910.

In 1916, Irving Langmuir of GE patented a lamp with a coiled tungsten filament that again doubled lamp efficiency. GE produced a nonsag tungsten wire that extended lamp life even further the following year.

Thoriated tungsten filaments for electron tubes were introduced in 1925, and they were up to 50 times better as electron emitters than pure tungsten.

The double coiled (or coiled coil) tungsten wire lamp filament, similar to that used to this day, was introduced in incandescent lamps by GE in 1936. This proved to be a superior design for lamp filaments, one that provided longer hours of illumination and improved efficiency.

The work of the laboratory continues to this day. A more recent development is tungsten rhenium wire (3D), an alloy with improved high temperature structure and higher resistivity offering improved ductility and reliability for demanding applications. GE is constantly looking for new ways to improve the performance of tungsten wire, and to use its properties more effectively.

Many of the lighting products we take for granted...the high intensity discharge lamp, halogen headlamps, and long-life lamps...benefited from GE's vast store of knowledge about this versatile material.

Coolidge, Langmuir, Steinmetz

Growing Applications for Tungsten Wire

Tungsten wire lamp filaments produced by GE provide reliable, low cost illumination.

Nothing surpasses tungsten wire for brightness and length of service in incandescent lamp filaments, an application which did more than anything else to spur development of this remarkable metal.

Tungsten filaments are used in lamps for general lighting, automotive and aircraft lighting, photographic and studio lighting, and specialty applications from business copiers to indicator lamps.

Because of its compatibility with other lamp materials, tungsten wire is also used in lead wires for glass-to-metal seals, and as filament supports.

General Electric produces tungsten wire with a variety of properties and compositions for lighting and other industries. For instance, a 1% thoriated 99% tungsten wire (NF) is made to provide maximum vibration strength for filaments used in transportation vehicles, and a 3% rhenium-97% tungsten wire (3D) offers improved performance in miniature lamps and cathode ray tube heater coils. Type 320 wire was developed to enhance the coiling properties of wire used in difficult automotive headlamp applications, and Type 710 was engineered to meet the specific requirements of quartz-halogen lamps.

Although lamp manufacturers still dominate the market for tungsten wire, many other uses are emerging as designers recognize the superior properties of this material.

Outside the lighting industry, tungsten wire is being put to work in applications that demand high strength combined with an ability to tolerate elevated temperatures. One of these is fiber composites, made in the form of tape and sheet for use on aircraft, helicopters, spacecraft, turbine engines, and specialized industrial components.

These composites are as strong as steel, twice as stiff, and as light as aluminum. They are produced by chemical vapor deposition of boron onto a thin tungsten wire heated to 1200° C. Tungsten wire's strength, its availability in fine sizes, as well as its ability to react in a controlled fashion with boron, are the major considerations in this application.

The excellent mechanical characteristics of tungsten wire are also utilized in high temperature springs, microsyringe plungers, high speed matrix printhead wires, and microneurological needles.

The electronics industry is another important user of tungsten wire for highly technical applications. Uses include heaters and grids in radio and TV picture tubes, radio transmitting tube filaments and pins, traveling wave helices, and semiconductor test probes.

For these applications, tungsten wire provides high temperature stability, strength, electron emissivity, hot-cold shock strength, and high resistivity.

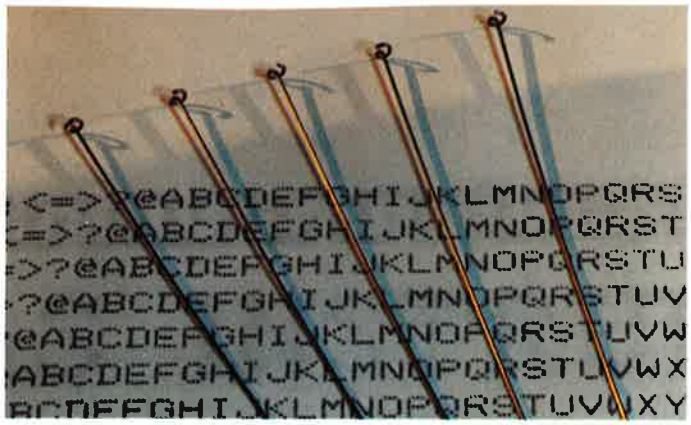
Another important application for tungsten wire is in vacuum metallizing, a production operation which creates a shiny, chrome-like finish on plastic, glass or metallic parts.

In a vacuum chamber, tungsten coils and aluminum are placed in contact. When the coils are energized, the aluminum vaporizes and deposits on the parts to be coated. Metallized parts have replaced chrome-plated automotive dashboard components at a fraction of the cost, but with no sacrifice in appearance or utility. The method is also used for coating TV screens and mirrors, plastic toys and hobby kit pieces, and many other decorative parts. Other metals such as chromium and silver are also routinely metallized using tungsten filaments.

Tungsten wire is used as a heating element in electric furnaces, either as a winding around ceramics or as a mesh basket. The properties utilized here are high temperature strength, good electrical and thermal conductivity, and the ability to withstand thermal cycling stresses.

There are a number of specialty applications for tungsten wire, among them radiation counter tubes, electro discharge machining tools, fuse and igniter wires, corona wire in business copiers, thermocouple wire, and air cleaners for electrostatic precipitators.

Tungsten matrix printhead wires for dot matrix printers.



An array of tungsten metallizing coils.

Tungsten wire is the substrate material used in producing boron filaments. Boron fiber reinforced composite materials are used for skin components on high performance fighter aircraft as well as for such sporting applications as fishing rods, golf clubs and tennis rackets.

Some of the decorative pieces created with vacuum metallizing.

Fluorescent lamp cathodes.

Types of Tungsten Wire

A variety of different types of tungsten wire, each with its own distinctive properties, have been developed by General Electric Company to meet the needs of industry. There is a wire size, type, finish or process variation that will provide optimum performance for each application. All types exhibit, with minor differences, properties that are vital to coiling and forming of close tolerance products.

Formability characteristics are important considerations, second only to high temperature properties in determining the proper wire type for reliable performance under service conditions.

The Product Selection Guide below should be utilized when selecting a wire type and finish for your specific applications.

When a special grade is required, highly qualified application engineers, supported by experienced metallurgical and chemical personnel, are available to assist users.

PRODUCT SELECTION GUIDE

	WIRE TYPE	NON-SAG QUALITY	HOT SHOCK STRENGTH	VIBRATION STRENGTH	FORMABILITY	THERMIONIC EMISSION	SURFACE QUALITY	ROOM TEMP. SERVICE	RECOMMENDED SIZE RANGE mm-DIA (mils-DIA)	AVAILABLE FINISHES	APPLICATIONS
		ATTRIBUTES								AVAILABILITY	
HIGH TEMP. SERVICE	218	●	◐	◐	●	○	◐	●	.008 - .012 (0.3 - 0.5)	EE, EES	FILAMENT, GRID, FUSE
									.012 - .500 (0.5 - 20)	B, BS, C, CS, EE, EES, EP, EPS	LAMP, ELECTRONIC, MISC.
	710	●	◐	◐	●	○	●	●	.063 - .500 (2.5 - 20)	B, BS, C, CS, EE, EES, EP, EPS	QUARTZ HALOGEN LAMP
	320	●	◐	◐	●	○	◐	●	.165 - .270 (6.5 - 10.6)	BS, CS, EES, EPS	RETRACTABLE MANDREL AUTO LAMP FILAMENT
	310	●	◐	◐	◐	○	◐	●	.500 - 1.500 (20 - 60)	B, C, BS, CS, EE, EES, EP, EPS	HIGH WATTAGE STD. AND Q/H FILAMENT
MEDIUM TEMP. SERVICE	MWG	●	○	◐	◐	○	◐	●	.500 - 1.500 (20 - 60)	B, C, BS, CS	VAC. METALLIZING AND FURNACE WINDINGS
	NF	○	●	●	○	●	◐	×	.015 - 1.500 (0.6 - 60)	B, C, BS, CS, EE, EES, EP, EPS	SHOCK AND VIBRATION SERVICE • FILAMENTS
	2TH	○	◐	◐	○	●	◐	×	.760 - 1.500 (30 - 60)	B, C, BS, CS	DISCHARGE LAMP ELECTRODES
	3D	◐	◐	●	◐	○	◐	◐	.010 - 1.500 (0.4 - 60)	B, C, BS, CS, CLS, EE, EES, EP, EPS	VIBRATION SERVICE FILAMENT, CATHODES

ATTRIBUTE CODE

- ● HIGHEST
- ◐ ADEQUATE
- ○ LOWEST
- × NOT RECOMMENDED

FINISH CODE

B..... BLACK
BS.... BLACK STRAIGHTENED
C..... CLEANED
CS.... CLEANED AND STRAIGHTENED
CLS... CLEANED, ANNEALED AND STRAIGHTENED
EE.... ELECTRO ETCHED
EES .. ELECTRO ETCHED AND STRAIGHTENED
EP.... ELECTRO POLISHED
EPS .. ELECTRO POLISHED AND STRAIGHTENED

218

For almost 60 years, GE Type 218 wire has been the foremost filament wire in the lighting industry. Type 218 is an essentially pure metal at 99.95+ percent tungsten, although it is lightly doped to achieve specific metallurgical properties. Its superior quality has earned it a worldwide reputation, and today it remains the outstanding choice for general purpose lamp and specialty applications.

The most outstanding attribute of this wire is the character of its microstructure after recrystallization. Proper "flashing" of 218 wire produces a large, elongated and interlocking grain structure which promotes high temperature strength and the wire's excellent non-sag quality.

Type 218 tungsten wire performs well in extremely difficult forming applications, especially if a low level of heat is applied at the point of coiling or forming.

310

Type 310 is a non-sag doped tungsten wire designed to supplement 218 in the larger wire sizes. Similar in purity and other properties to 218 wire, it's especially recommended for high wattage lamps. In sizes 0.5mm diameter and larger, 310 is more ductile than 218 wire in equivalent sizes due to the higher level of retained cold work resulting from processing variations. Type 310 should be worked with the aid of heat during forming. When properly recrystallized, it provides an excellent non-sag microstructure.

320

This wire was developed specifically for sealed-beam headlamp filaments, an application which imposes the most severe coiling conditions for tungsten wire. This wire has a 218 base that has been specially processed to provide a lower yield point and higher elongation for improved coilability. It is generally supplied in the cleaned and straightened condition in sizes ranging from 80 to 225mg/200mm.

710

A premium wire processed from 218 stock, Type 710 wire is designed for use in demanding quartz halogen lamp filaments. The highest purity wire is required for this application to avoid possible interference with the halogen cycle during lamp operation.

The superior high temperature properties of 218 wire are fully retained and the manufacturing process for 710 virtually eliminates minute surface defects that might trap impurities from either wire drawing or the coiling processes. This improved surface assures more complete removal of surface contaminants during coil cleaning and reduces breakage at coiling.

NF

Type NF is a thoriated tungsten wire that provides improved performance over pure tungsten in specialty lamps and electronic vacuum tubes. Approximately 1% thoria is dispersed uniformly in the metal and contributes in two useful ways: First, it controls recrystallized grain size and shape for enhanced vibration damping properties. Second, it lowers the thermionic work function so that when NF is used as an emission source it is a better electron emitter than pure tungsten.

NF is somewhat more difficult to work than 218 tungten, so heat at forming is usually required. NF's fine, equiaxed recrystallized grain structure, desired for shock and vibration resistance, causes concomitant lower sag resistance. Therefore, NF is not recommended for filament service above the 2200°C range.

2TH

Type 2TH is a tungsten wire containing 2% thoria used primarily for electrodes in discharge lamps. Due to its higher thoria content, 2TH has a low work function, and thus improved electronic emission properties. This wire is generally available only in sizes above 0.76mm diameter.

3D

An alloy of 218 tungsten with 3% rhenium made by the powder metallurgy process, developed by General Electric, Type 3D's primary attribute is enhanced ductility in the partially recrystallized state. This ductility is associated with a fine grained microstructure when properly heat treated, and contributes to improved hot strength, cold strength, and vibration resistance characteristics over 218 wire at temperatures above 2200°C. The intrinsically higher resistivity that rhenium imparts to 3D permits the alloy to be used at larger wire diameters than 218 or NF, a factor which is frequently advantageous for strength considerations.

MWG

General Electric MWG tungsten wire is made with a closely controlled chemistry expressly for use in the vacuum metallizing industry. The high degree of purity and cleanliness of this wire provides wettability and consistent results in metallizing. Potassium is controlled to a lower level than in lamp grade wire, and overall purity is typically 99.95 percent tungsten based on trace analysis and calculated on a gas-free basis. Used in the form of single or multiple-strand configurations, MWG offers excellent forming characteristics, superior resistance to embrittlement, and longer life.

Further information about MWG tungsten wire or coils for vacuum metallizing can be found in the catalog entitled "GE Metallizing Products," available upon request.

Properties of Tungsten Wire

The variety of applications of tungsten wire demonstrates the wide range of properties of this material. Tungsten wire combines low vapor pressures at elevated temperatures, excellent room temperature strength, good electrical and thermal conductivity, high elastic modulus and hardness, and inertness to chemical reactions with many materials.

Tungsten is one of the refractory metals, a family of materials which exhibit very high strength at elevated temperatures. Tungsten's melting point is 3417°C. It is stronger than any other metal at 1900°C, and retains usable strength at 3000°C, making it unique and irreplaceable in many applications.

Tungsten can be doped or alloyed to further improve some of its properties, including its high temperature strength, creep resistance, mechanical stability, recrystallized ductility, vibration damping, and thermionic emissivity.

Tungsten is sometimes considered difficult to fabricate, but technology developed over 70 years ago by General Electric Company makes it possible to produce tungsten in a vast array of wire sizes and properties.

Although sintered tungsten is brittle at room temperature, the material is ductile at elevated temperatures and can be extensively worked.

Like most materials, tungsten develops additional strength as it is worked into smaller diameters. Successive draw passes of the wire create the fibrous grain structure needed for ductility in coiling and other fabrication processes. As the wire is drawn, the ductile-to-brittle transition temperature is progressively suppressed to values well below room temperature. Because tungsten wire is processed below its recrystallization temperature, it work-hardens and must be softened by stress-relieving anneals to allow further processing to smaller diameters.

Applications of tungsten at temperatures greater than 400°C are normally limited to vacuum, inert, or reducing atmospheres to prevent oxidation.

To take full advantage of the outstanding properties of tungsten wire, especially for new applications, a consultation with General Electric's engineering staff may be advisable. Based on experience, they can provide guidelines for the most effective and cost-efficient use of the material.

TABLE I
PHYSICAL PROPERTIES OF TUNGSTEN (W)

Melting Point		3417°C
Boiling Point		5930°C
Vapor Pressure (mm Hg):		
1527°C (2780°F)		1.93×10^{-15}
2127°C (3860°F)		7.90×10^{-9}
2727°C (4940°F)		6.50×10^{-5}
3227°C (5840°F)		4.68×10^{-3}
Specific Heat at 20°C (68°F) (Cal/gram-atom)		6.25
Thermal conductivity (cal/sq cm/cm/sec/°C):		
20°C (68°F)		0.310
927°C (1701°F)		0.275
1127°C (2061°F)		0.268
1327°C (2421°F)		0.260
1527°C (2781°F)		0.253
1727°C (3141°F)		0.245
Density (g/cc):		
ASTM Wire		19.17
Coefficient of Linear Expansion, mean value 0° – 500°C (32° – 932°F):		
Worked		4.98×10^{-6}
Annealed		4.45×10^{-6}
Heat of Fusion (cal/g)		44
Thermionic Data:		
Apparent electron work function (eV)		4.55
Apparent positive ion emission (eV)		11.93
Radiation emission coefficient		0.43
First ionization potential		7.60
Elastic Properties: (at 25°C)		
Young's Modulus	41×10^3 kg/mm^2	(58.3×10^6 psi)
Shear Modulus	16×10^3 kg/mm^2	(22.8×10^6 psi)
Poisson's Ratio		0.27
Electrical Resistivity (micro-ohm-cm):		
24°C (75°F)		5.89
100°C (212°F)		7.28
700°C (1292°F)		22.43
1100°C (2012°F)		34.65
1500°C (2732°F)		49.66
1800°C (3272°F)		57.52
2100°C (3812°F)		69.61

Manufacturing & Quality Control

To provide 99.95% purity in the finished product, only the most contaminant-free starting materials are used in the manufacture of General Electric's tungsten wire. The high purity level is maintained throughout manufacture, from production of tungsten powders to drawn wire that can be finer than a human hair.

Tungsten wire is a highly engineered material with properties specifically tailored for its various applications. General Electric has developed a comprehensive quality assurance system to characterize, control, and trace wire properties through all stages of processing—from the mining of ore to finished wire products. Frequent audits of process temperatures, lubrication conditions, reduction drafts, and lineal speeds are conducted to assure uniformity of properties.

Product traceability throughout General Electric's process establishes a reliable wire pedigree.

A highly skilled staff working with state-of-the-art equipment supports this total commitment to quality assurance and customer satisfaction.

Coordination of the quality control program is the responsibility of several special laboratories at GE's Tungsten Products Plant.

In our Analytical Chemistry Laboratory, purity standards are established and maintained as an integral part of the quality assurance system. Dopant additions used to create the unique structures and properties of General Electric tungsten wire are controlled within a few parts-per-million. Once a product chemistry has been established in powder and ingots, further processing is monitored to prevent contamination. Special attention is given to the presence of embrittling elements, specifically iron and nickel.

Tungsten ingots are heated in a furnace and quickly inserted into rolling mills for processing into smaller diameters.

Multiple die equipment in which temperature, drawing speed, and die geometry are carefully controlled, is used to produce very small diameter tungten wire.

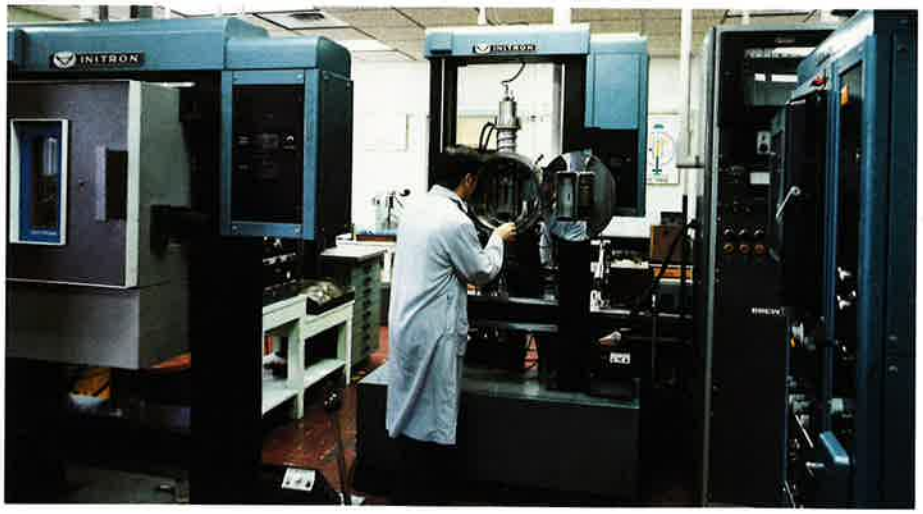
Manufacturing & Quality Control (cont'd.)

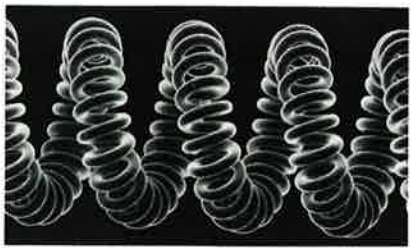
GE recognizes that it is the total metallurgical system that determines the ultimate performance of tungsten wire. The microstructure of wire products is carefully monitored with advanced metallographic techniques in the Structure and Properties Laboratory. Since the metallurgical structure controls the mechanical properties of tungsten wire, the results from these analyses are closely coordinated with physical testing. In addition to the conventional types of mechanical measurements familiar to material engineers, special testing techniques have been developed in the Physical Testing Laboratory to assure product performance in the most demanding applications.

Requests for samples with novel properties are encouraged and generally serviced from our Piloting Laboratory. Advanced research equipment is used in this laboratory to develop new and improved products, processes and measurement techniques.

Atomic absorption spectrophotometry is used to check impurities, especially those that influence sag characteristics. In this test, samples are dissolved and aspirated into a high temperature flame; radiant energy from a lamp is absorbed in proportion to the impurity atom concentration.

The elevated temperature strength properties are measured to better understand the response of wire to varying application conditions. Wire is normally tested in hydrogen although it can be measured in either vacuum or inert atmospheres.





The inset shows a greatly magnified view of a coiled coil tungsten lamp filament.

The scanning electron microscope (SEM) is a versatile and indispensable aid in structure analyses. The SEM in use here not only produces micrographs but is coupled with energy dispersive x-ray analysis to simultaneously provide semi-quantitative chemical analysis.

The needs and concerns of customers are attended to by an experienced engineering staff. In its many uses, tungsten wire is subjected to heat treatments, mechanical deformation, and surface conditioning. Since these operations can significantly affect wire performance, GE is constantly striving for ways to assist customers in their applications of tungsten wire. In many cases the sophisticated analyses GE uses for the internal quality assurance programs depicted on these pages have been used to help solve customer problems.

In our quality control lab on the manufacturing floor, samples taken from actual production runs are tested for tensile strength, electrical resistance, camber, roundness, diameter and other characteristics to assure process control.

On the direct coupled plasma spectrometer (DCP), up to 19 elements in solution can be identified and measured simultaneously.

The electron microprobe x-ray analyzer is a device in which extremely small samples can be studied. It is especially valuable for analyzing the homogeneity of two additives, thoria and rhenium.

This high vacuum heat treating bell jar determines the effect of atmosphere and temperature during the annealing of different grades of tungsten wire as well as evaluating its thermal stability and recrystallized structures.

Size Range Determination

For most tungsten wire applications, the success of the end product depends upon very close control of wire diameter.

Wire diameters above 0.51mm are measured with standard micrometers and reported in mils. For wire diameters below 0.51mm, none of the common methods of direct measurement can approach the degree of precision required. Therefore, an indirect method, called rating, is used. A precise 200mm length of wire is cut and weighed on an accurate electronic balance. The weight of the sample is recorded in milligrams to three decimal places, for sizes below 1.02 mg/200mm. Above 1.02 mg/200mm, the weight is rounded and recorded to two decimal places.

RATING AND WEIGHING

Rating and weighing of tungsten wire is performed with precision by experienced operators specifically trained for this important function. Constant checks are made to maintain accuracy of the system. Balances used for this operation are of the most accurate and dependable type available, and are carefully maintained. Balances are always calibrated at the nearest point to the wire size being weighed, and the working calibration weights are frequently checked against standards traceable to the National Bureau of Standards. Each balance is used only for a small portion of the total size range.

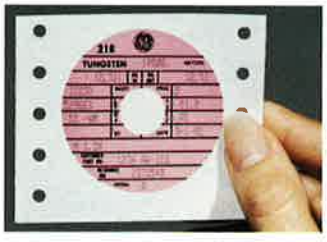
Cutting blocks are designed to cut wire precisely to a 200 millimeter length.

TABLE II
SIZE-WEIGHT RELATIONSHIP OF TUNGSTEN WIRE

$$\text{Diameter (d)} = K\sqrt{\text{mg/200mm}}$$

$$\text{mg/200mm} = C \times d^2$$

Wire Type / Units	GE 218, MWG, 3D etc. based on 19.17 gm/cm³		For GE NF (1% Th), based on 18.80 gm/cm³		For GE 2TH (2% Th), based on 18.50 gm/cm³	
	K	C	K	C	K	C
μm	18.223	3011.18×10^{-6}	18.402	2953×10^{-6}	18.550	2906×10^{-6}
mm	.018223	3011.18	.018402	2953	.01855	2906
mils	.71745	1.9427	.72452	1.905	.73029	1.875



Tungsten wire is rated and weighed on this electronic equipment to make certain customer specifications are being met. The wire is weighed and gauged by the operator and the data is displayed on the readout. Simultaneously, the data is cross checked through the specifications in the computer memory, and a label is printed containing all critical information for that particular order.

Product Specifications

CLEANED WIRE

Clean tungsten wire will show no visible evidence of drawing lubricant residues, oxides, or other foreign matter such as dirt, oil, etc. when viewed without magnification.

Depending on the final cleaning, or cleaning/anneal process, tungsten wire will have different surface textures. This can result in variable degrees of luster ranging from dull-matte-gray through bright-shiny. This difference in luster is not related to cleanliness.

STRAIGHTNESS

Straightness is determined by the amount of camber exhibited by the wire. For tungsten wire, camber is expressed as the maximum deviation of the wire from a straight line over a fixed span. For sizes below 1.25 mg/200mm, degree of curl specifications are used.

EDDY CURRENT TESTING

Splits in tungsten wire are longitudinal defects of variable length and depth which can be internal or exposed to the wire surface. For most applications, the infrequent, short random occurrence of these phenomena are of no importance.

However, in applications where splits could be detrimental to the wire forming process or to end product use, eddy current testing should be specified. This procedure detects where splits are located within a single length of wire, and logs the cumulative total split length as a percent of the total wire length.

The designation "M" following the letters identifying the various finishes of tungsten wire indicates eddy current testing has been specified and performed.

ROUNDNESS

This is expressed as % out-of-round (OOR) for wire ranging in size from 0.17 mg/200mm to 1.27mm (.050") diameter. Percent OOR is calculated using the formula:

$$\% \text{ OOR} = \frac{\text{Max. Dia.} - \text{Min. Dia.}}{\text{Max. Diameter}} \times 100$$

TABLE III
WIRE TOLERANCES

Wire Size	Standard Tolerance	Special Tolerances Available
≤1.02mg/200mm	± 0.03 mg/200mm	±0.025, ±0.02, ±0.015, ±0.01, ±0.005mg/200mm
1.03 thru 777.19 mg/200mm	± 3% by weight	±2½%, ±2%, ±1½%, ±1%, ±½%
≥0.51mm (0.020")	± 1.5% by diameter	±1¼%, ±1%, ±¾%

TABLE IV
WIRE STRAIGHTNESS

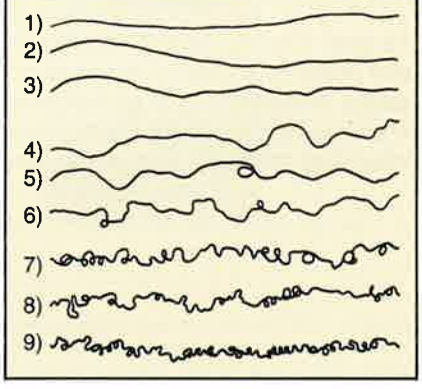
Size Range	Process	Maximum Curl or Camber/ Wire Length
* < 1.25mg/200mm	BS, CS, CLS, EES, EPS	#4 curl
1.25 to 2.5mg/200mm	BS, CS, CLS, EES, EPS	16mm/76mm
2.6 to 4.0mg/200mm	BS, CS, CLS, EES, EPS	12mm/76mm
4.01 to 8.0mg/200mm	BS, CS, CLS, EES, EPS	8mm/76mm
8.01 to 777mg/200mm	BS, CS, EES, EPS	32mm/200mm
8.01 to 50mg/200mm	CLS ONLY	20mm/200mm

*For sizes below 1.25mg/200mm, "curl" values are used to determine the relative straightness.

TABLE V
OUT-OF-ROUND LIMITS FOR MATERIAL TYPES 218, 310, 320, 710, 3D, NF

Size Range	Maximum OOR
0.17 - 2.39mg/200mm	5%
2.40 - 79.99mg/200mm	4%
80.00 - 777mg/200mm	3%
0.51mm - 1.27mm	3%

DEGREE OF CURL



In determining degree of curl, a two-foot length of wire is allowed to hang in a 1" catenary. It is then compared to this chart and rated accordingly.

Product Options

Tungsten wire that is specified "black" or "as drawn" has a graphite coating over a layer of surface oxide. The oxide results from drawing the wire at high temperature, and the graphite is the lubricant that is applied to improve wire drawing performance and inhibit oxidation of the wire.

For many users, the graphite and oxide coating is desirable, especially since it protects the wire from further oxidation during storage and acts as a lubricant during coiling. But, there are many applications which require a product with characteristics other than "as drawn". For these, General Electric has tungsten wire available with a cleaned surface, with an etched finish, straightened, or with special tensile strength or other non-standard characteristics.

Each standard type of tungsten wire has distinctive physical characteristics. The *Product Selection Guide* on Page 6 indicates the characteristics and sizes available in each type; the available finishes shown in column 10 refer to process designations defined in the box at right. Standard minimum lengths of tungsten wire available from GE are shown in Table VI, by their process designations.

General Electric invites inquiries for wire types to suit special needs. It is helpful if inquiries are accompanied by an explanation of the desired properties and intended use of the wire.

AVAILABLE FINISHES (PRODUCT DESIGNATIONS)

B	Black wire, as drawn
BS	Black wire, as drawn, which has been given a straightening treatment
C	Process "B" wire which has been electrochemically cleaned
CS	Process "BS" wire which has been electrochemically cleaned
CLS	Process "CS" wire which has been annealed for lower tensile strength and maximum straightness
EE	Process "B" wire which has been electrolytically etched to reduce size and improve surface texture
EES	Process "EE" wire which has been given a straightening treatment
EP	Process "B" wire which has been electrolytically processed to polish and improve the surface
EPS	Process "EP" wire which has been given a straightening treatment

TABLE VI
STANDARD MINIMUM LENGTHS (METERS)

SIZE (mg/200mm)	PROCESS						
	B	C	BS	CS	EE/EP	EES/EPS	CLS
.15 - .29	—	—	—	—	100	50	—
.30 - .49	400	200	300	200	200	100	200
.50 - 1.00	400	400	400	400	200	200	400
1.01 - 2.00	400	400	400	400	300	300	400
2.01 - 4.00	400	400	300	300	300	300	400
4.01 - 10.00	400	300	300	300	300	300	300
10.01 - 20.00	400	300	250	250	250	250	250
20.01 - 40.00	300	200	200	200	200	200	200
40.01 - 100.00	150	150	150	150	150	150	150
Above 100.00mg/200mm	50 grams of wire - all processes						

Shipping Containers and Coils

General Electric tungsten wire is packaged for shipping either in self-contained coils or wound upon standard spools or bands. The material is shipped in one continuous length per container or coil, as indicated in the chart below. Any deposit charge made for shipping containers is refunded when containers are returned prepaid, in good condition.

Designation of Container Dimensions

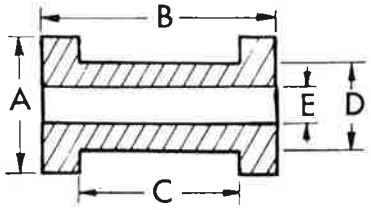


TABLE VII

	Name	Material	GE Drawing No.	Approx. Weight In Grams	CONTAINER DIMENSIONS						Wire Size Range, Standard Processes	Approx. Container Capacity (grams)
					Units	Flange Diameter (A)	Width (B)	Traverse (C)	Barrel (D)	Hole (E)		
	Bobbin	Alum.	B-10504	4.4	mm	18.26	14.94	10.97	14.91	11.11	0.08 - .40 mg/200mm Black or Clean	8
					in.	.719	.588	.432	.587	.438		
	Small Plastic Spool	ABS	C-10749	22	mm	53.98	26.16	19.81	37.16	10.29	0.20-60.0 mg/200 mm Black Wire and 0.20-50.0 mg/200 mm Clean Wire	250
					in.	2.125	1.030	.780	1.463	.405		
	Small Spool	Alum.	C-396	68	mm	55.50	25.35	20.12	40.51	8.64		280
					in.	2.185	.998	.792	1.595	.340		
	Large Plastic Spool	ABS	C-10905	63	mm	63.50	35.00	28.55	41.22	10.29		500
					in.	2.500	1.378	1.124	1.623	.405		
	Large Spool	Alum.	C-9669	110	mm	63.50	35.00	28.55	41.22	7.950		560
					in.	2.500	1.378	1.124	1.623	.313		
	Blue Special Band	Lexan®	A-8165	73	mm	119.86	27.00	20.63	105.18	96.04	20.0-150.0 mg/200 mm Clean Wire	650
					in.	4.719	1.063	.813	4.141	3.781		
	Orange Regular Band	Lexan®	A-8166	100	mm	126.21	33.34	25.40	108.36	98.43	41.0 mg/200 mm— 23 mils (.584 mm) Black or Clean	1050
					in.	4.969	1.313	1.000	4.266	3.875		
	10" Band	Nylon	C-10857	95	mm	254.00	34.29	30.73	219.58	216.03	0.254 mm - .762mm 10 mils - 30 mils	3000
					in.	10.000	1.350	1.210	8.645	8.505		
	3" CI Reel	Cast Iron	A-6461	2085	mm	133.30	90.53	76.23	98.37	82.83	15.0 mg/200 mm— 30.0 mils (.762 mm) Black or Clean	3500
					in.	5.248	3.564	3.001	3.873	3.261		
	203.2mm / 8" Diameter Self-Contained Coil, Black or Clean										0.508 mm - .838 mm 20 mils - 33 mils	N/A
	406.4mm / 16" Diameter Self-Contained Coil, Black or Clean										0.838 mm - 1.525 mm 33.0 mils - 62.0 mils	N/A

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PACKAGE IDENTIFICATION

The following identification and descriptive information, where applicable, is put on each label: type of wire, standard process designation, quantity of meters or kilograms, size in milligrams per 200 millimeters or in mils, metal lot number, designation of ingot from which wire was drawn, date of packaging, and code number of operator who packaged wire. Information such as this is backed by records of a rigid quality control system and makes possible positive identification of every piece of wire made by GE.

It is recommended that labels and tags be kept with the wire so that identification can be made at any time.

Small corks are used to secure wire to spools or bands. A red cork signifies the outer end.

Technical Assistance

The facilities and staff of General Electric Company are available to assist users in their particular applications for tungsten wire. Application engineering assistance is available to aid customers in selecting and specifying the optimum material and finish for their requirements. GE also offers assistance in tailoring properties, consultation on quality control procedures, and trouble-shooting.

If you have a potential use for tungsten wire, or feel your present application may be improved, please let us know.

An excellent aid to specifying tungsten wire is the GE conversion slide chart pictured here. It provides data on wire types and finishes, diameter to weight ratios, and other information. It is available in English, Japanese, German and Spanish languages with data in both English and metric values. Data for GE molybdenum wire is available on the reverse side of the pictured slide chart. For your free copy, write to the Sales Operation headquarters (address below).

Ordering Information

For further information or to order tungsten wire, contact your Sales Operation representative, Sales headquarters, or the Tungsten Products Plant customer service representative.

General Electric Company
Lamp Components & Technical Products Division
Sales Operation
21800 Tungsten Road
Cleveland, Ohio 44117
Phone:
Domestic — (216) 266-2451
International — (216) 266-3295
Telex: 985569 (GECOLCS EUCD)

General Electric Company
Tungsten Products Plant
Customer Service–Tungsten Wire
21800 Tungsten Road
Cleveland, OH 44117
Phone: (216) 266-3600

General Electric's Lamp Components & Technical Products Division is the source for tungsten, molybdenum, glass, fused quartz, Lucalox® ceramic, phosphors, chemicals, Dumet and Cumet wire, leads, bases and other components used by the lamp, electronics, cemented carbide and other industries. Technical and engineering assistance is available on all products.

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