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Vacuum Science and Technology for Accelerator Vacuum Systems

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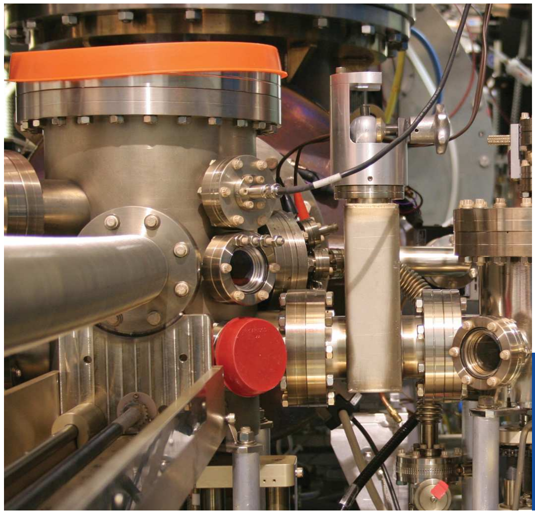

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SESSION 4.1: VACUUM MATERIALS

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  → Other metals

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  → Ceramics and Glasses
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Stainless Steels – Classifications

- *Stainless steel is a steel alloy with at least 11% chromium content by weight. It is also called corrosion-resistant steel.*

- *Austenitic stainless steel (300 series): These are generally non-magnetic steel alloys. They contain a maximum of 0.15% carbon, a minimum of 16% chromium and sufficient nickel and/or manganese to retain an austenitic structure at all temperatures from the cryogenic region to the melting point of the alloy. The low carbon (-L) grades are used when welding is involved. In UHV applications, especially accelerators, 300 stainless steels are commonly used.*

- *Other less used types of stainless steel alloys are: Martensitic stainless steels (400 series), precipitation-hardening martensitic stainless steels (most common used 17-4PH) and ferritic stainless steels . Martensitic stainless steels are much more machinable, and are magnetic. Those are much less used for accelerators, mainly due to the magnetism.*

Austenitic Stainless Steels

- High strength, moderate formability, excellent weldability.
- Can be extruded in simple shapes
- 304L SS, most commonly used in vacuum, but may become magnetized from machining and welding.
- 316L SS, with Mo added, more expensive, resistant to chemical attack, welds are non-magnetic
  316LN SS, a nitrogen-enhanced 316L steel, much more expensive, but excellent strength at very elevated temperatures (as high as 1000°C)
- Wide variety of circular tubes and pipes available (seamless & welded)
- Outgassing rates can be decreased by employing good machining techniques, chemical cleaning and baking (up to 900°C)
- Poor thermal and electrical conductivity

Mechanical Properties for Stainless Steels

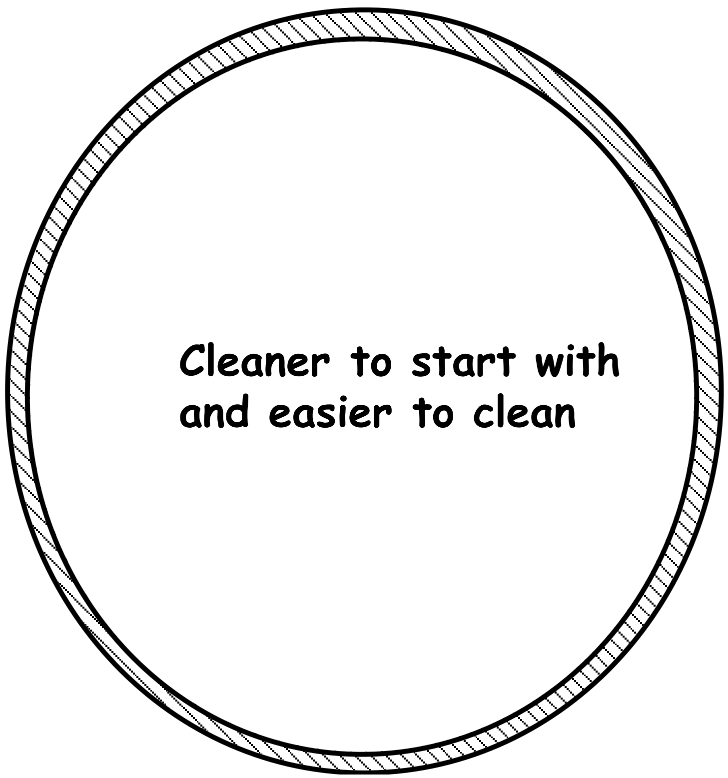
Property	304L	316L	316LN	OFE Cu
Ultimate Tensile Strength (MPa)	564	560	637	338
Tensile Strength (ksi)	81.8	81.2	92.4	49.0
Yield Strength (Mpa)	210	290	>280	217
Yield Strength (ksi)	30.5	42.1	>41.6	31.5
Elongation at Break (%)	58	50	58	55
Modulus of Elasticity (Mpa)	197	193	200	115
Modulus of Elasticity (ksi)	28.6	28.0	29.0	16.7

Ref. www.matweb.com

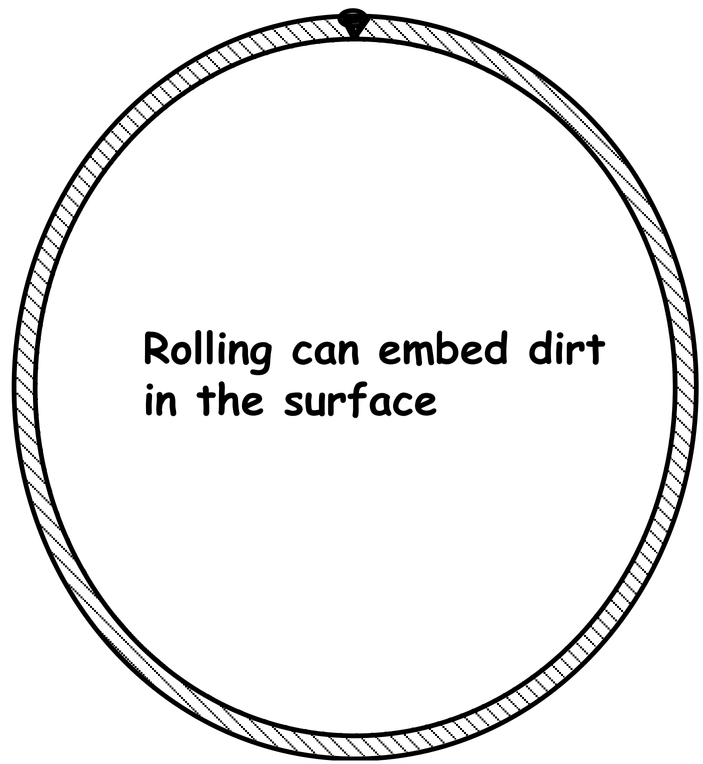
Physical Properties for Stainless Steels

Property	304L	316L	316LN	OFE Cu
Composition:	C 0.03% Cr 18-20% Mn 2% *Fe Balance* Ni 8-12% P 0.045% S 0.03% Si 1%	C <0.03% Cr 17.9% Mn 2.0% Mo 2.5% Fe Balance Ni 11-14% S 0.03% Si 1%	C <0.03% Cr 17.9% Mn 2.0% Mo 2.5% Fe Balance Ni 10.8% N 0.16% S 0.03% Si 1%	Cu 100%
Melting Point (°C)	1427	1385	1400	1083
Density (g/cc)	8.0	8.0	8.0	8.92
Electrical Resistivity (Ω-cm)	7.2×10^{-5}	7.2×10^{-5}	7.4×10^{-5}	1.71×10^{-6}
Elect. Conduct. (% IACS*)				101
Therm. Conduct. (W/m-K)	16.2	16.3	16.0	391
Coeff. Of Therm. Exp. ($°C^{-1}$)	17.2×10^{-6}	16.0×10^{-6}	16.0×10^{-6}	17.5×10^{-6}

Tubing - Seamless and Welded



Seamless (extruded)



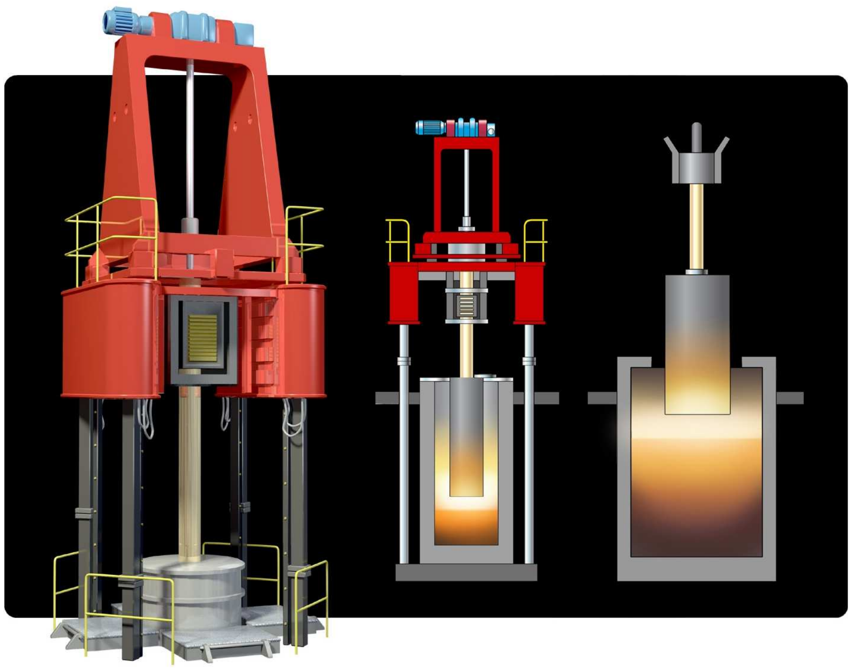
Welded (rolled & welded)

Plate/Rod – ESR or Cross-Forged

- *Stainless steels are the most common material for making knife-edge sealing flanges*

- *For making knife-edge seal flanges, either ESR or cross-forged stainless steels should be used to avoid costly defects on the knife-edge tip*

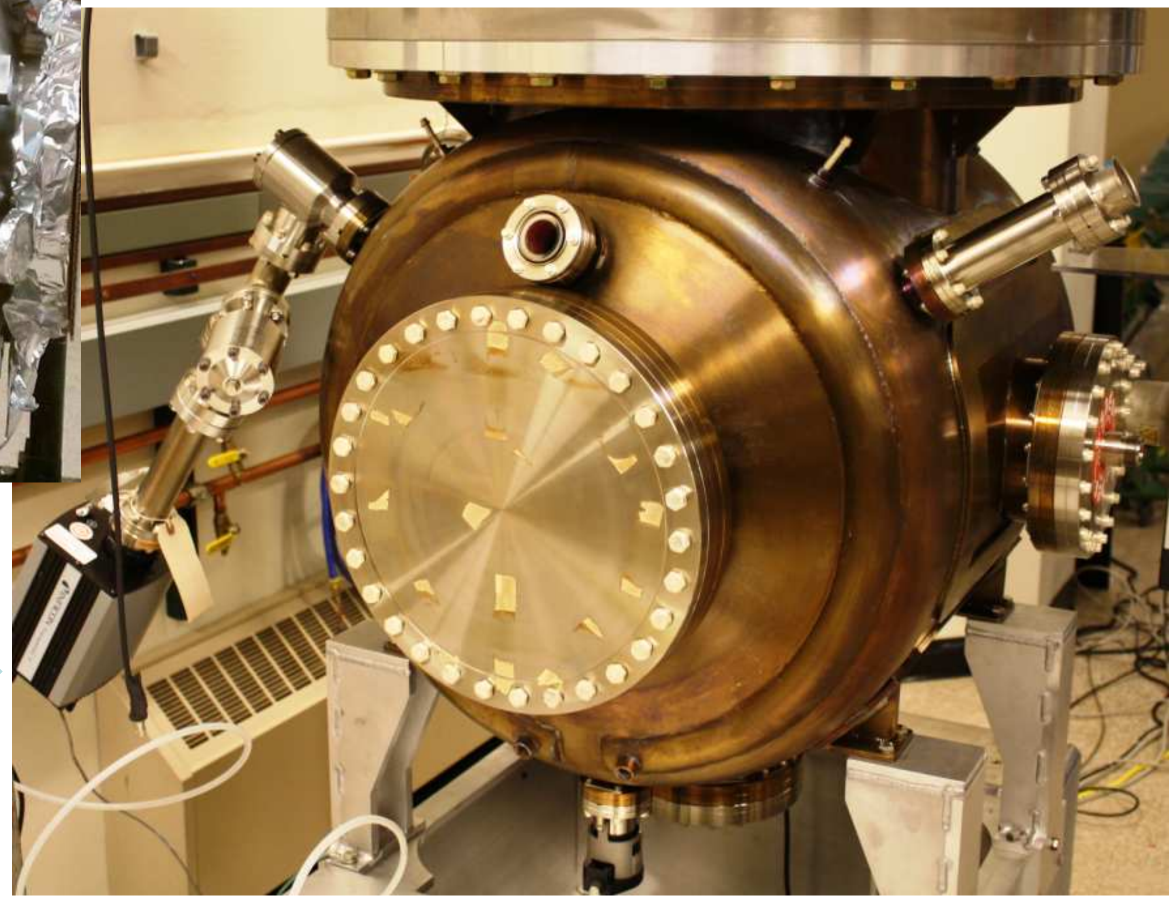
THE ELECTROSLAG REMELTING (ESR) PROCESS IS USED TO REMELT AND REFINE STEELS AND VARIOUS SUPER-ALLOYS, RESULTING IN HIGH-QUALITY INGOTS.



Cornell DC Photo-Cathode Electron Gun Chamber

As received stainless steel gun chamber

Air-baked, and assembled to the gun, w/ pumps and gauges



Aluminum and Alloys

Alloy Number	Major Alloy Element(s)	Characteristics and Sample Applications
1xxx	None	Good electric and thermal conductivities, corrosion resistance. Typical applications: electric conductor wires and bus
2xxx	Copper	High strength, at room and elevated temperatures, Alloys 2011, 2017, and 2117 are widely used for fasteners and screw-machine stock
3xxx	Manganese	Similar property as 1100, slightly higher strength. Good for sheet works.
4xxx	Silicon	Excellent flow characteristics. Alloy 4032 for forging, 4043 used for GMAW and TIG 6xxx alloys.
5xxx	Magnesium	Mostly for structural applications, matching 6xxx extrusions well. 5083 alloy suitable for cryogenic applications.
6xxx	Magnesium + Silicon	6061-T6 is one of the most commonly used, 6063 is mostly used in extruded shapes
7xxx	Zinc	Mostly for structural, supporting frames. 7075-T6 is one of the most used 7000 series aluminum, and strongest one.
8xxx	Sn, Li, etc.	Specialty alloys not cover by other series.

Aluminum and Alloys – Tempers

- *Besides alloy designations (with Nxxx), there are standard temper designations for aluminum alloys, with one letter and a numeral.*
- *For strain-hardened (cold-worked), there are hardness designations.*

  -F *as fabricated;*
  -H1 *Strain hardened without thermal treatment*
  -H2 *Strain hardened and partially annealed*
  -H3 *Strain hardened and stabilized by low temperature heating*

- *For alloys can be heat treated to produce stable tempers (partial list)*

-O *Full soft (annealed);*
-T2 *Cooled from hot working, cold-worked, and naturally aged*
-T4 *Solution heat treated and naturally aged*
-T5 *Cooled from hot working and artificially aged (at elevated temperature)*
  -T51 *Stress relieved by stretching*
    -T511 *Minor straightening after stretching*
-T6 *Solution heat treated and artificially aged*

Aluminum and Alloys – General Characteristics

- *Moderate strength, good formability, easy to machine*
- *6063-T4 can be extruded in complicated shapes*
- *6061-T6 is the most common aluminum alloy for vacuum components*
- *5083 is a good alloy for welding*
- *Aluminum is much cheaper to machine than stainless steel (2x to 3x cheaper)*
- *Aluminum is much less likely been radiactivated.*
- *Special care must be taken in the design of welds and the techniques used due to higher thermal conductivity and thermal expansion (30% > SS)*
- *Surface anodizing degrades outgassing characteristics, but improves chemical resistance*

Typical Mechanical Properties for Aluminum

Property	1100-0	5083-H34	6061-T6	OFE Cu
Tensile Strength (MPa)	165	345	310	338
Tensile Strength (ksi)	23.9	50.0	45.0	49.0
Yield Strength (Mpa)	150	280	275	217
Yield Strength (ksi)	21.8	40.6	39.9	31.5
Elongation (%)	5	9	12	55
Modulus of Elasticity (Mpa)	69	70.3	69	115
Modulus of Elasticity (ksi)	10.0	10.2	10.0	16.7

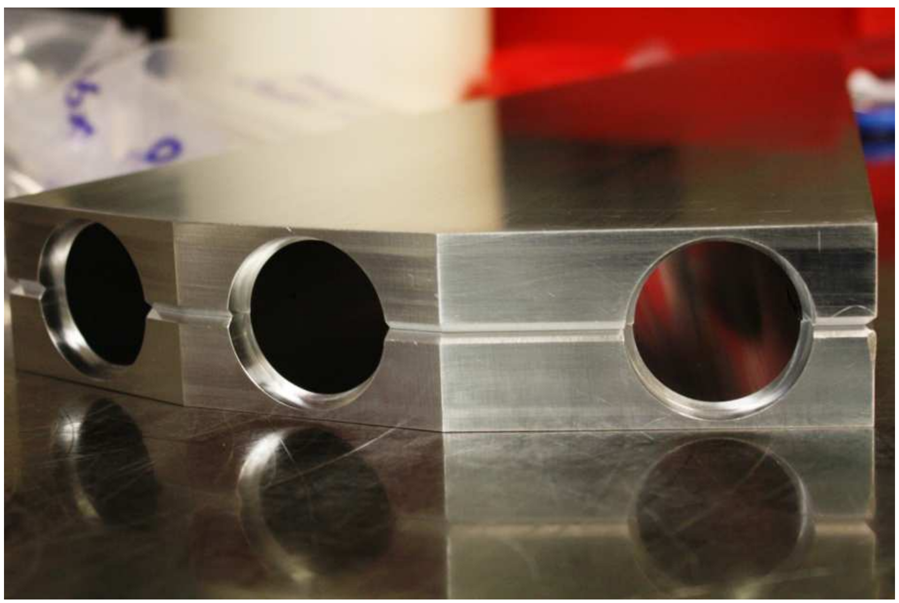
Ref. www.matls.com

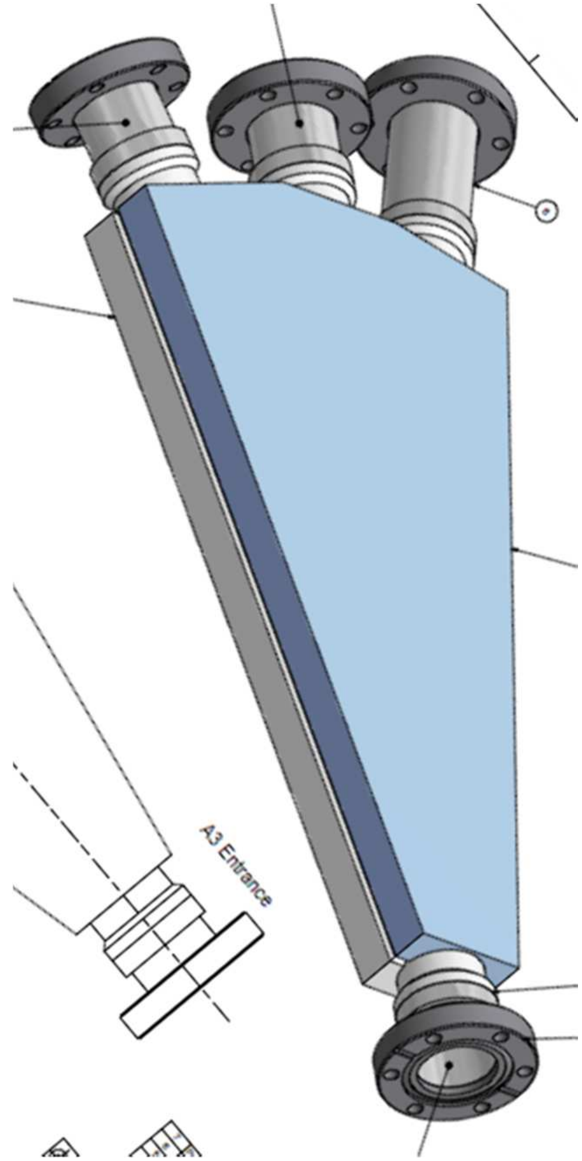
Typical Physical Properties for Aluminum

Property	1100-0	5083-H34	6061-T6	OFE Cu
Composition:	Al 99% Cu 0.05-0.2% Mn 0.05% Si+Fe 0.95% Zn 0.1%	Al 94.8% Cu 0.1% Cr 0.05-0.25% Mg 4-4.9% Mn 0.4-1% Fe 0.4% Si 0.4% Ti 0.15% Zn 0.25%	Al 98% Cu 0.15-0.4% Cr 0.04-0.35% Mg 0.8-1.2% Mn 0.15% Fe 0.7% Si 0.4-0.8% Ti 0.15% Zn 0.25%	Cu 100%
Melting Point (^oC)	643	591	582	1083
Density (g/cc)	2.71	2.66	2.7	8.92
Electrical Resistivity (Ω-cm)	3×10^{-6}	5.9×10^{-6}	3×10^{-6}	1.7×10^{-6}
Heat Capacity (J/g-^oC)	0.904	0.9	0.896	0.385
Therm. Conduct. (W/m-K)	218	117	167	391
Coeff. Of Therm. Exp. ($^oC^{-1}$)	25.5×10^{-6}	26×10^{-6}	25.2×10^{-6}	17.5×10^{-6}

Ref. www.matls.com

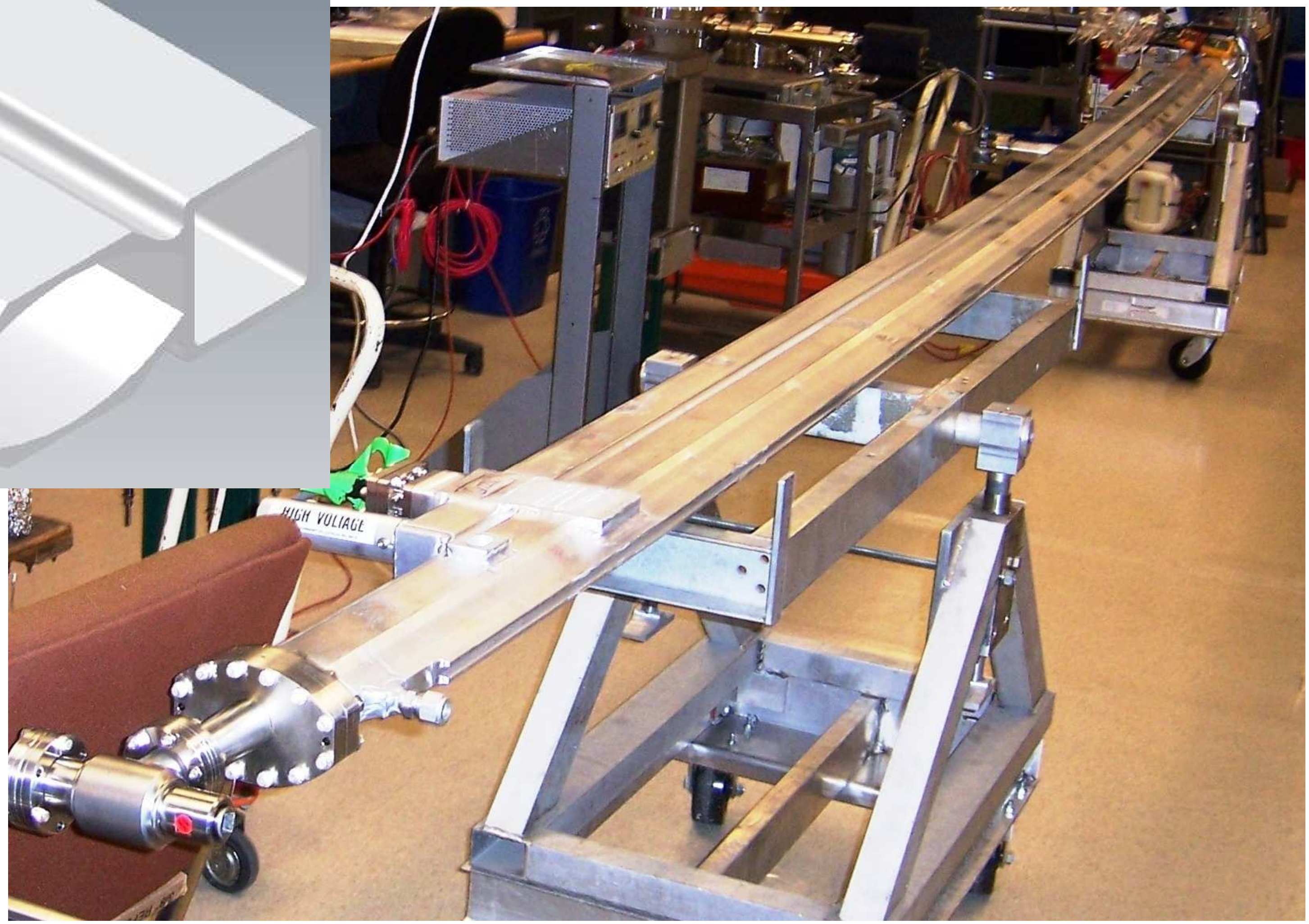
Machined Aluminum "Switch-yard" Chamber





Aluminum Electron Beam Stopper

Extruded Beam Pipes – Complex Shape



Copper and Alloys

- Copper and alloys are designated by a system starting with letter "C", followed by 5 digits, more copper contents with lower numbers.
- Typical copper alloys are C10100 (OFHC), C26800 (Yellow Brass, Zinc alloy), C61400 (Bronze, Silicon alloy), C17200 (Beryllium coppers)
- Low-to-moderate strength, good formability
- Excellent electrical and thermal characteristics
- Difficult to weld (e-beam welding is best)
- May be joined by welding, brazing, and soldering
- Good outgassing characteristics, rates can be decreased by following good machining techniques, chemical and baking (~200° C)

Oxygen-Free High Conductivity (OFHC) Copper

- *Oxygen-free high thermal conductivity (OFHC) copper generally refers to a group of wrought high conductivity copper alloys that have been electrolytically refined to reduce the level of oxygen to 0.001% or below.*
- *OFHC is often used in accelerator vacuum system, where high heat load in encountered. It is also used to construct normal conducting radio-frequency (RF) cavities.*
- *C10100 – This is the purest grade, with 99.99% Cu, <0.0005% (or 5 ppm) oxygen content.*
- *C10200 – 99.95% Cu (including Ag), <0.001% (10-ppm) oxygen content.*
- *C11000 – Also know as Electrolytic-Tough-Pitch (ETP) copper. It is* 99.9% pure and has 0.02% to 0.04% oxygen content (typical).
- *Low oxygen content is critical for vacuum assemblies involving welding*

OFHC Copper Properties

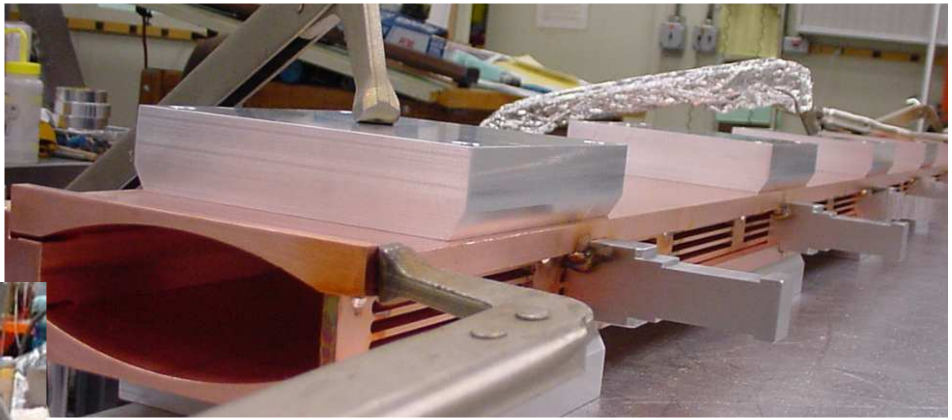
Density	Electric Resistivity	Thermal Conductivity	C.T.E.	M.P.
8.9 g/cc	1.71×10^{-6} Ω-cm	383 ~ 391 W/m-K	17.0 μm/m-K	1083°C

Temper Designation Standard	**Tensile Strength (ksi)**		**Yield Strength**
	Min.	Max.	(ksi, min.)
060 Soft	30	38	--
H00 Cold-Rolled, 1/8-hard	32	40	20
H01 Cold-rolled, ¼-hard	34	42	28
H02 Half Hard	37	46	30
H03 ¾-hard	41	50	32
H04 Full hard	43	52	35

Copper Vacuum Chamber Example

C10100 ½-Hard Cu sheet bend to U-box to form a TiSP pumping plenum

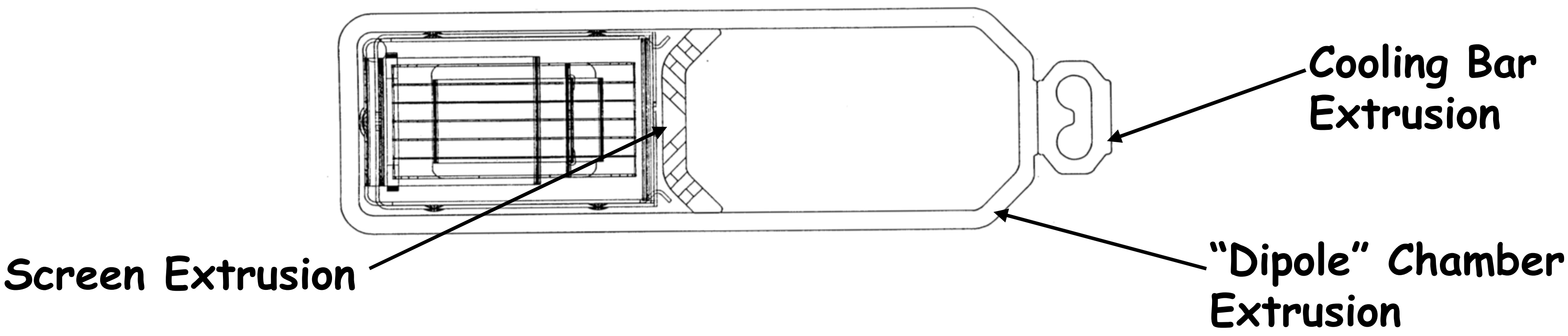
C10100 ½-Hard Cu plates machined to form a beam pipe



SST L-shaped plates added to complete vacuum envelop, with enhance mechanical strength.

(Flanges to be added)

Copper Extrusions



Machined Copper Chamber (PEP-II RF Cavities)

- 26 cavities
- $4M total fabrication cost
- Integral cooling channels with electroformed cover
- 5 axis machining
- e-beam welded
- 17 separate manufacturing steps

Glidcop®

Glidcop is pure copper with Al_2O_3 dispersed throughout.

- *High strength, moderate formability, poor weldability.*
- *Available in sheets, plate, wire, and extruded rounds.*
- *Maintains good mechanical strength after brazing.*
- *Outgassing rates are similar to pure copper.*
- *Thermal and electrical properties are good.*

Grade Designations		Copper		Al_2O_3	
UNS	SCM Metal Prod.	Wt %	Vol %	Wt %	Vol %
C15715	Glidcop AL-15	99.7	99.3	0.3	0.7
C15725	Glidcop AL-25	9.5	98.8	0.5	1.2
C15760	Glidcop AL-60	98.9	97.3	1.1	2.7

Ref. SCM Metal Products

Glidcop™ Physical Properties

Property	C15715	C15725	C15760	OFE Cu
Melting Point (°C)	1083	1083	1083	1083
Density (lb/in^3)	0.321	0.320	0.318	0.323
Electrical Resistivity (Ω)	11.19	11.91	13.29	10.20
Elect. Conduct. (% IACS*)	92	87	78	101
Therm. Conduct. (W/m-K)	365	344	322	391
Coeff. Of Therm. Exp. (°C^{-1})	16.6×10^{-6}	16.6×10^{-6}	16.6×10^{-6}	17.7×10^{-6}
Mod. Of Elasticity (psi)	19×10^6	19×10^6	19×10^6	19×10^6

* International Annealed copper Standard

Ref. SCM Metal Products

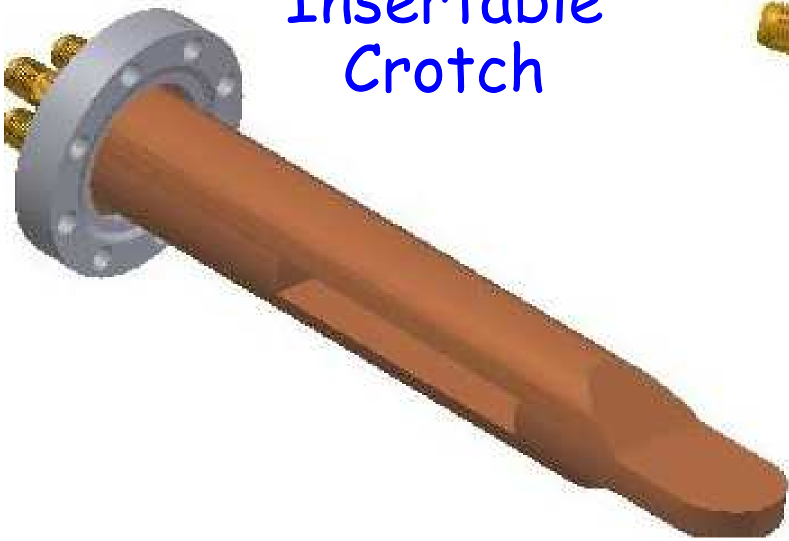
Glidcop™ Mechanical Properties [1]

Grade	Form	Tensile Strength (ksi)[2]	Yield Strength (ksi)[2]
AL-15 (C15715)	Plate	53 ~ 70	37 ~ 66
	Rod	57 ~ 72	47 ~ 66
	Rounds	53	37
AL-25 (C15725)	Plate	60 ~ 76	43 ~ 68
	Rod	64 ~ 80	52 ~ 77
	Rounds	60	43
AL-60 (C15760)	Plate	--	--
	Rod	72 ~ 90	69 ~ 87
	Rounds	68	48
C10100		30 ~ 50	20 ~ 35

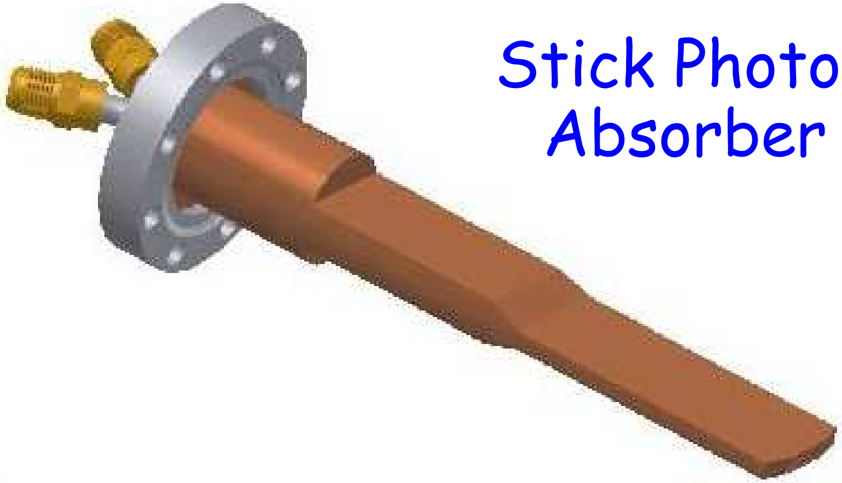
1. *Ref. http://www.hoganas.com*
2. *Large spread reflect strength at different tempers*

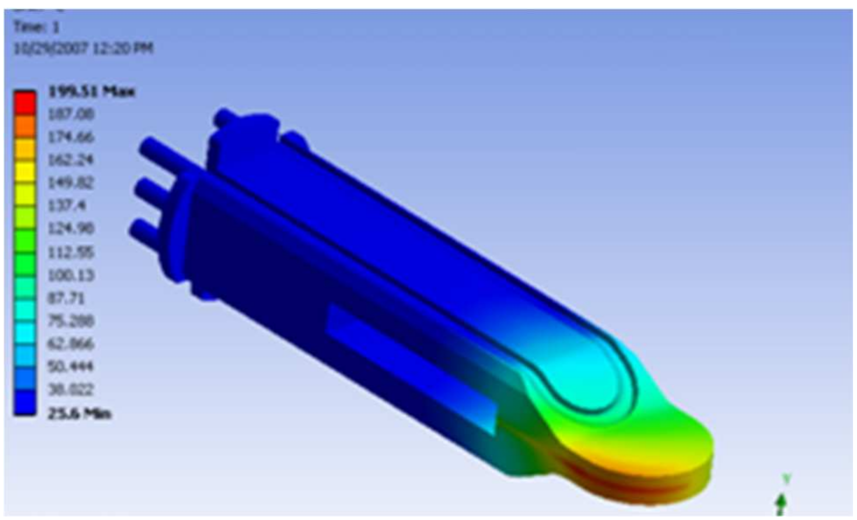
NSLS II Crotch and Absorber Made of Glidcop™

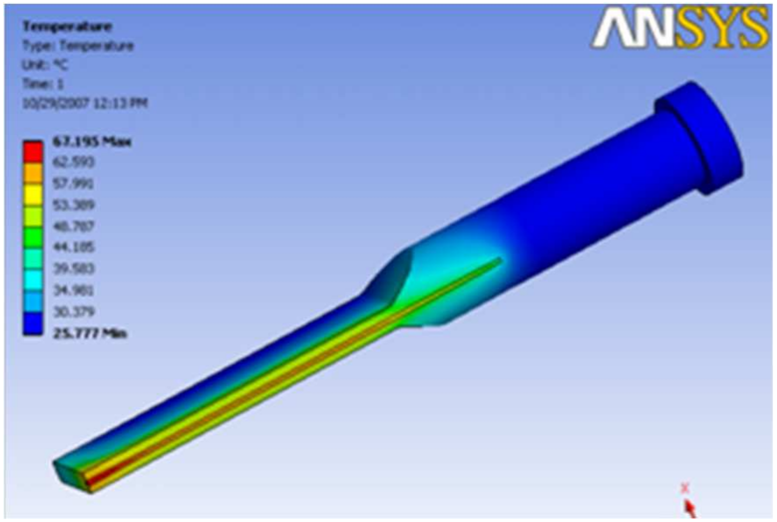
Insertable Crotch



Stick Photon Absorber







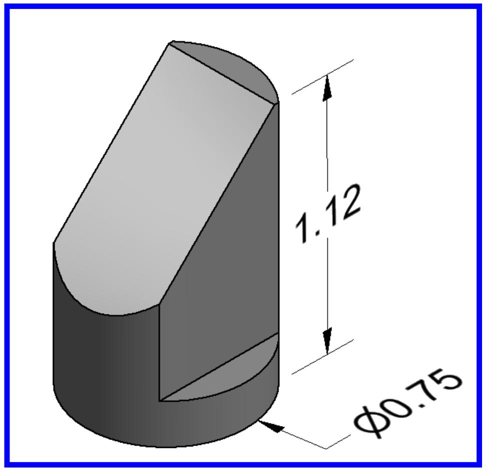
Ref: H. Hseuh, NSLS II, BNL

Other Metals – Beryllium

- Beryllium is the lightest metal with good mechanical strength and good thermal conductivity.
- Beryllium is machinable and can be jointed via vacuum braze or e-beam welding.
- Beryllium is hazard mat'l, must be handled by highly trained experts

UHV X-ray Windows

75μm Be
e^- Injection Window



SynchLight Mirror

Other Metals – Niobium & Titanium

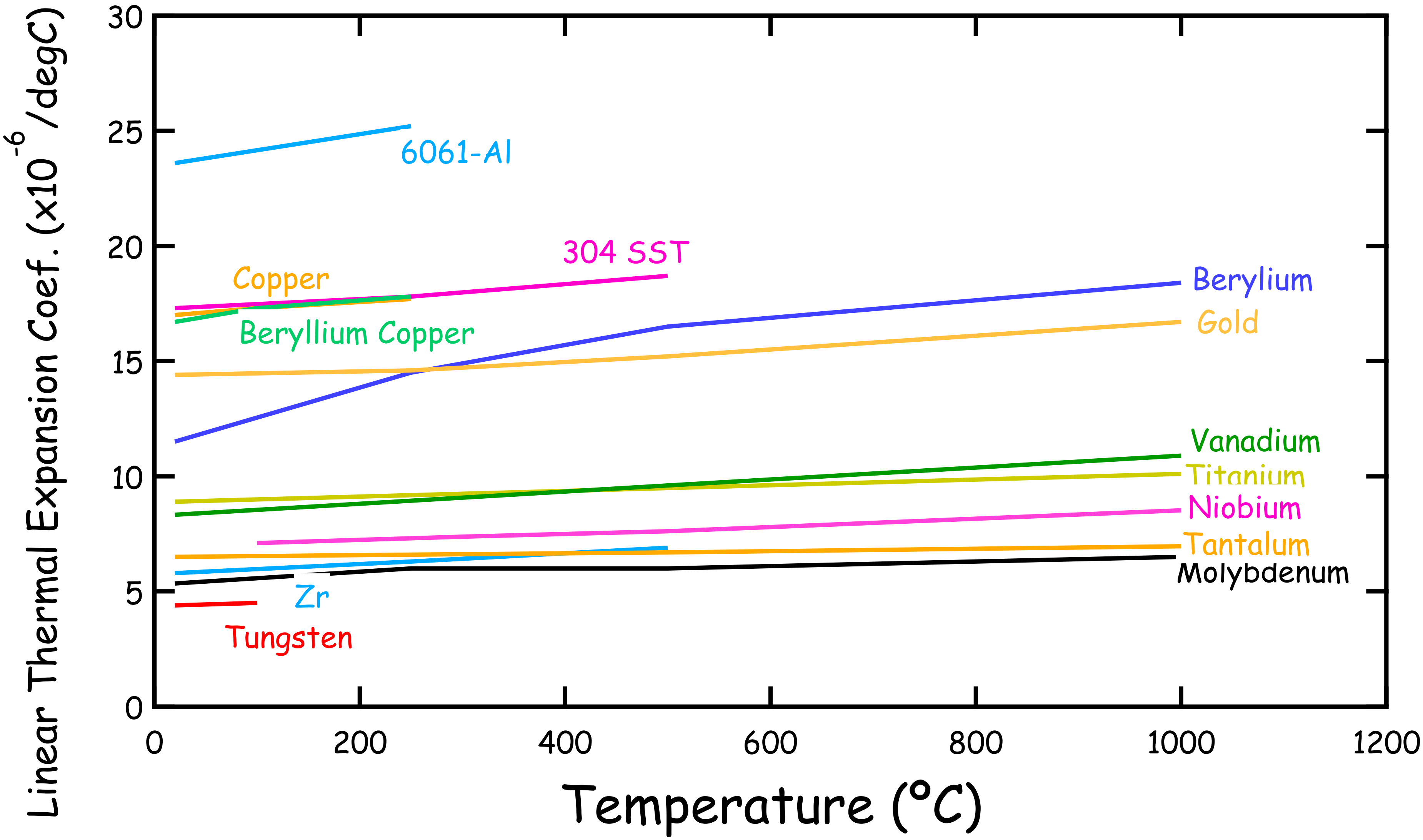
- High purity, small grain niobium is the key material for constructing superconducting RF cavities for many existing and future (such as Jlab, Cornell CESR and ERL, Tesla, ILC, etc.) facilities

- The grade od the Nb material is usually certified by so-called RRR (Residual-resistance ratio). Hydrogen in the Nb bulk is often degassed for high-Q cavities.

- To match CTE, titanium (grade 1 and grade 5) are used to joint to Nb cavities for flanges and helium vessels.

- E-beam welding is the primary technique for Nb and Ti.

C.T.E. of some metals



Non-Metals – Ceramics and Glasses

- Alumina ceramics ($Al2O_3$ > 99%) are widely used for electric breaks, instrument and electric power feedthroughs, RF windows in the accelerator vacuum systems.
- Alumina ceramic beam pipes with thin inner metallic coating are also used as a part of pulsed magnet for beam feedback, injection kickers, etc.
- Ceramics are jointed to metal flanges using vacuum furnace braze technique.
- Many type of glasses are used mainly as viewports on vacuum systems, for visual inspection of in-vacuum components, for light transmissions (laser entrance, beam profile viewers, etc.)
- Machined ceramic parts are UHV compatible. Special diamond-tipped tools are used for ceramic machining. There are also machinable ceramics, such Macor®.

Properties of Some Glasses for Vacuum

Property	Fused Silica	Pyrex 7740	7720[a]	Soda 7052[a]	0080	Lead 0120
Composition						
SiO_2	100	81	73	65	73	56
B_2O_3		13	15	18		
Na_2O		4	4	2	17	4
Al_2O_3		2	2	7	1	2
K_2O				3		9
PbO			6			29
LiO				1		
Other				3	9	
Viscosity characteristics						
Strain point °C	956	510	484	436	473	395
Annealing point °C	1084	560	523	480	514	435
Softening point °C	1580	821	755	712	696	630
Working point °C	—	1252	1146	1128	1005	985
Expansion coefficient $\times 10^{-7}$/°C	3.5	35	43	53	105	97
Shock temperature, 1/4-in. plate °C	1000	130	130	100	50	50
Specific gravity	2.20	2.23	2.35	2.27	2.47	3.05

Source. Reprinted with permission from Corning Glass Works, Corning, NY.
[a] 7720 glass is used for sealing to tungsten and 7052 glass is used for sealing to Kovar.

Properties of Some Ceramics for Vacuum

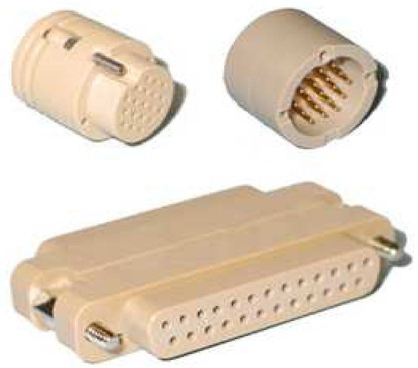
Table 16.6 Physical Properties of Some Ceramics

Ceramic	Main Body Composition	Expansion Coefficient ($\times 10^{-7}$)	Softening Temperature (°C)	Tensile Strength (10^6 kg/m^2)	Specific Gravity
Steatite	$MgOSiO_2$	70–90	1400	6	2.6
Forsterite	$2MgOSiO_2$	90–120	1400	7	2.9
Zircon porcelain	ZnO_2SiO_2	30–50	1500	8	3.7
85% alumina	Al_2O_3	50–70	1400	14	3.4
95% alumina	Al_2O_3	50–70	1650	18	3.6
98% alumina	Al_2O_3	50–70	1700	20	3.8
Pyroceram 9696[a]	Corderite ceramic	57	1250	14[b]	2.6
Macor 9658[a]	Fluro-phlogophite	94	800	10[b]	2.52

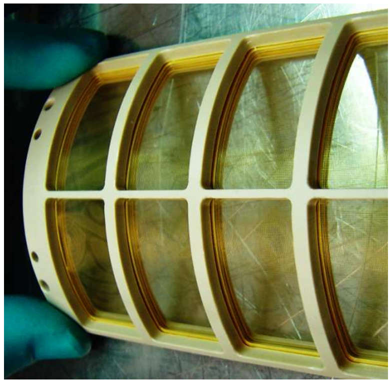
Source. Reprinted with permission from *Vacuum*, **25**, p. 469, G. F. Weston. Copyright 1975, Pergamon Press, Ltd.
[a] Reprinted with permission from Corning Glass Works, Corning, NY.
[b] Modulus of rupture.

Non-Metals – Elastomers and Polymers

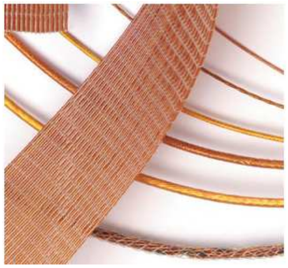
- *Elastomers, polymers and plastics have also found application in accelerator vacuum systems. Their vacuum properties and radiation resistance must be verified for the applications.*
- *Elastomers, particularly Viton® (fluorocarbon) are usually used as vacuum seals, often as gate seals for UHV gate valves.*
- *Though Teflon is UHV compatible, it is easily hardened and break down under radiation. PEEK (Polyether ether ketone) is a type of engineered plastics that is suitable for accelerator UHV applications. PEEK has good formability and machinability. The most uses are in vacuum multi-pin connectors.*
- *Kapton® (polyimide) films are suitable for accelerator UHV applications.*



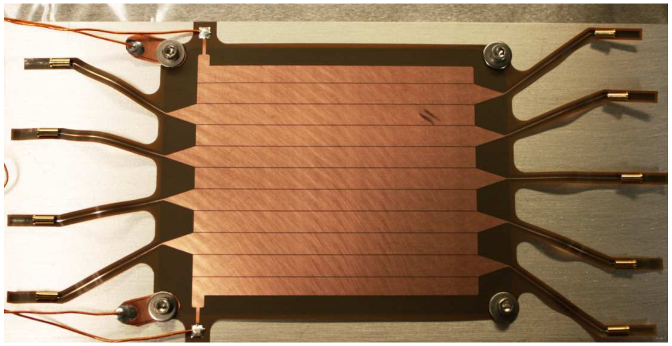
PEEK Connectors



Machined PEEK



Kapton Coated Wires



Cu-clad Kapton in-vacuum PCBs

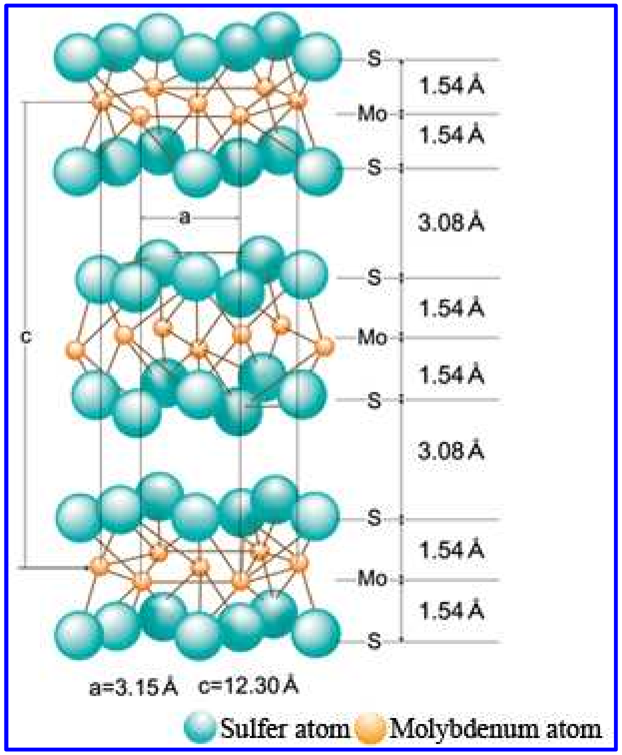
Dry Lubrications in UHV Systems

- For in-vacuum movement that involves two metallic surfaces in contact, particularly two similar metals, lubrication is between the contacting surfaces is necessary.

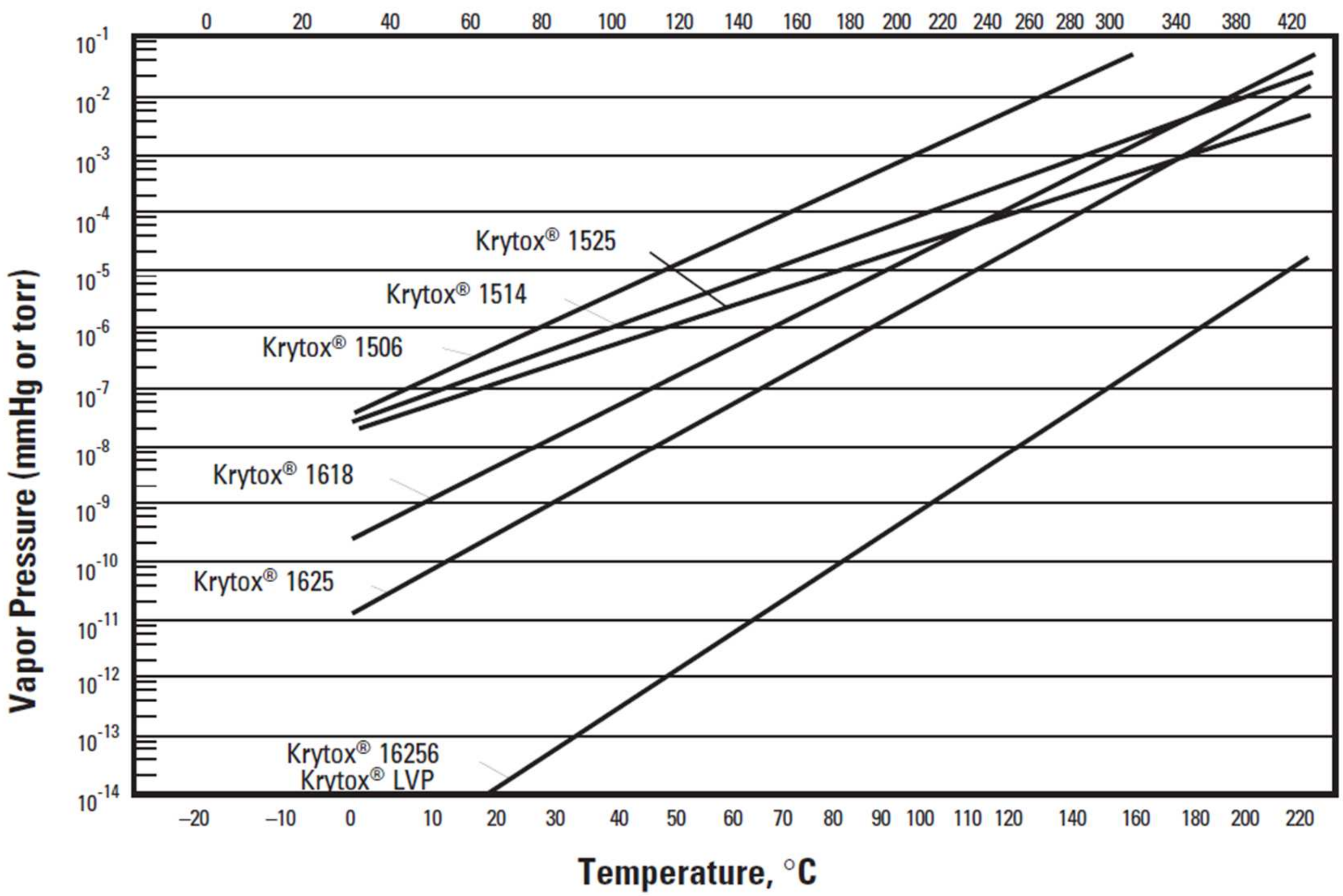
- For UHV applications, dry-lubrication is widely used. In a dry lubrication, the process of lubricating relies on a solid film.

- The desirable properties of a dry lubricant are low vapor pressure, low shear strength, and good adhesion to the base metal.

- Commonly used UHV-compatible dry lubricants are silver (electroplated), MoS_2, WS_2 (Dicronite®) (via PVD). Teflon coating is also a UHV-compatible dry lubricant, however, it is not durable in radiation environment.

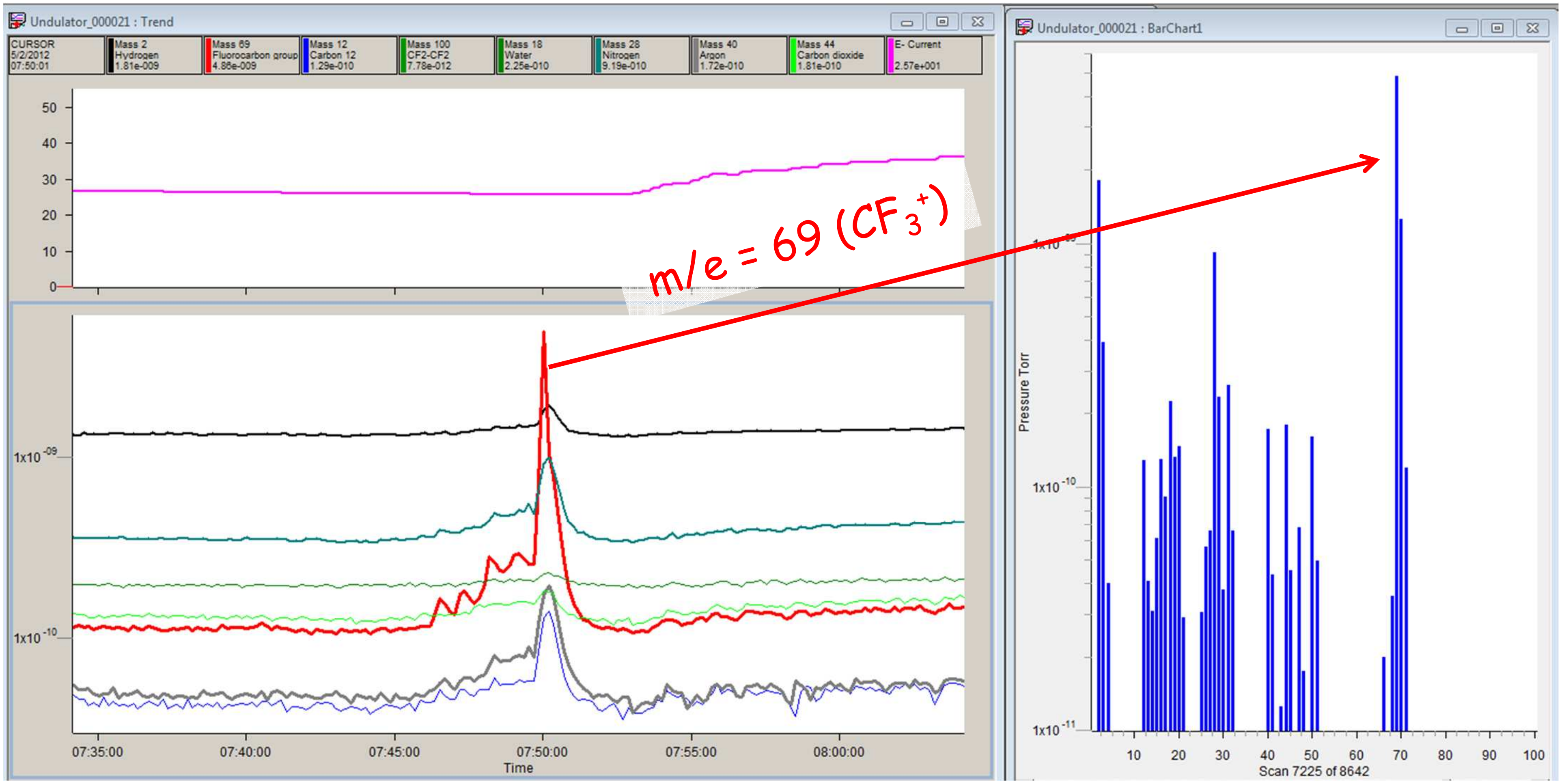


UHV-compatible grease lubricants

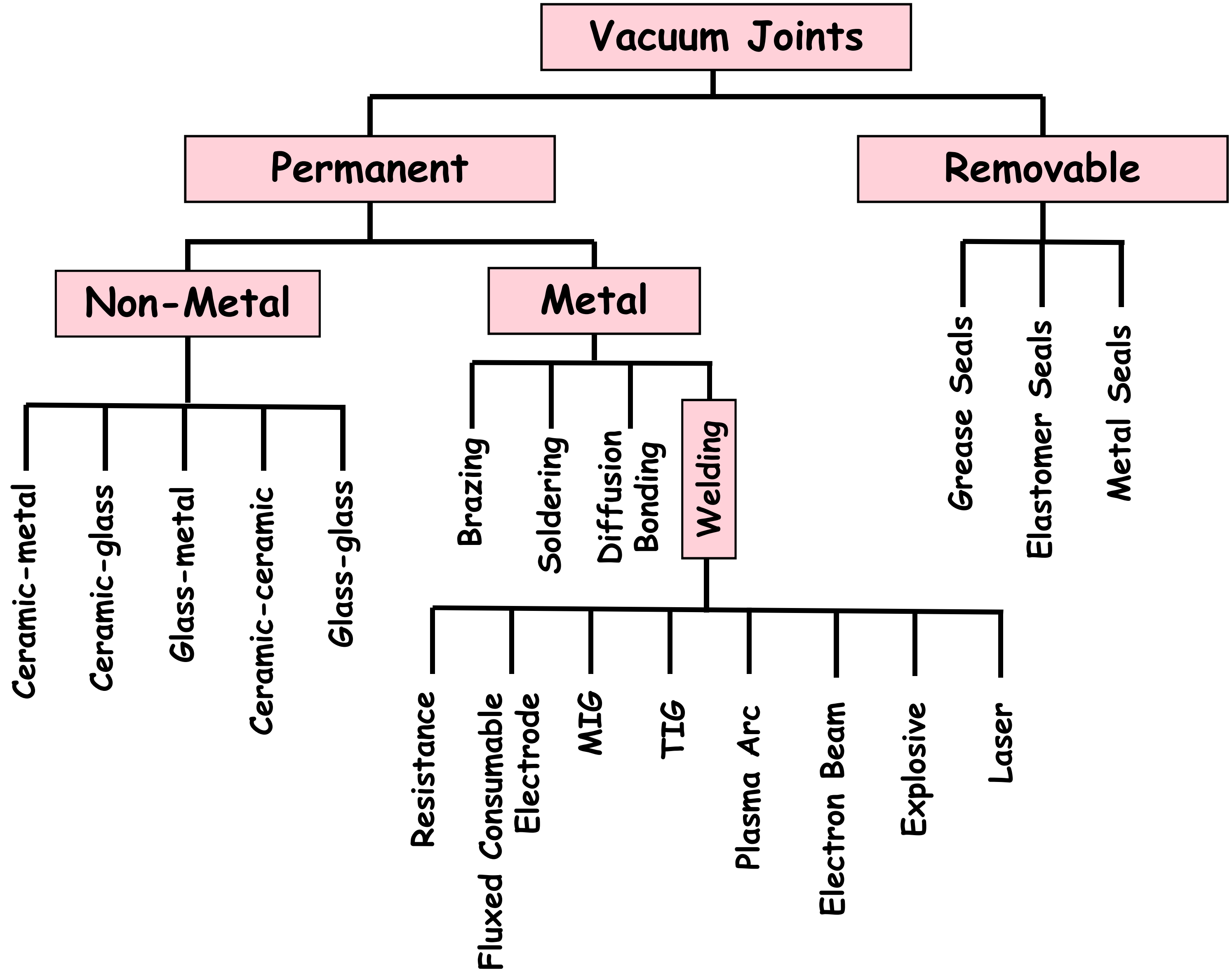


However, extreme low vapor pressure may not be good enough in applications where energized desorption may occur.

Stimulated desorption of Krytox



Methods of Making Vacuum Joints

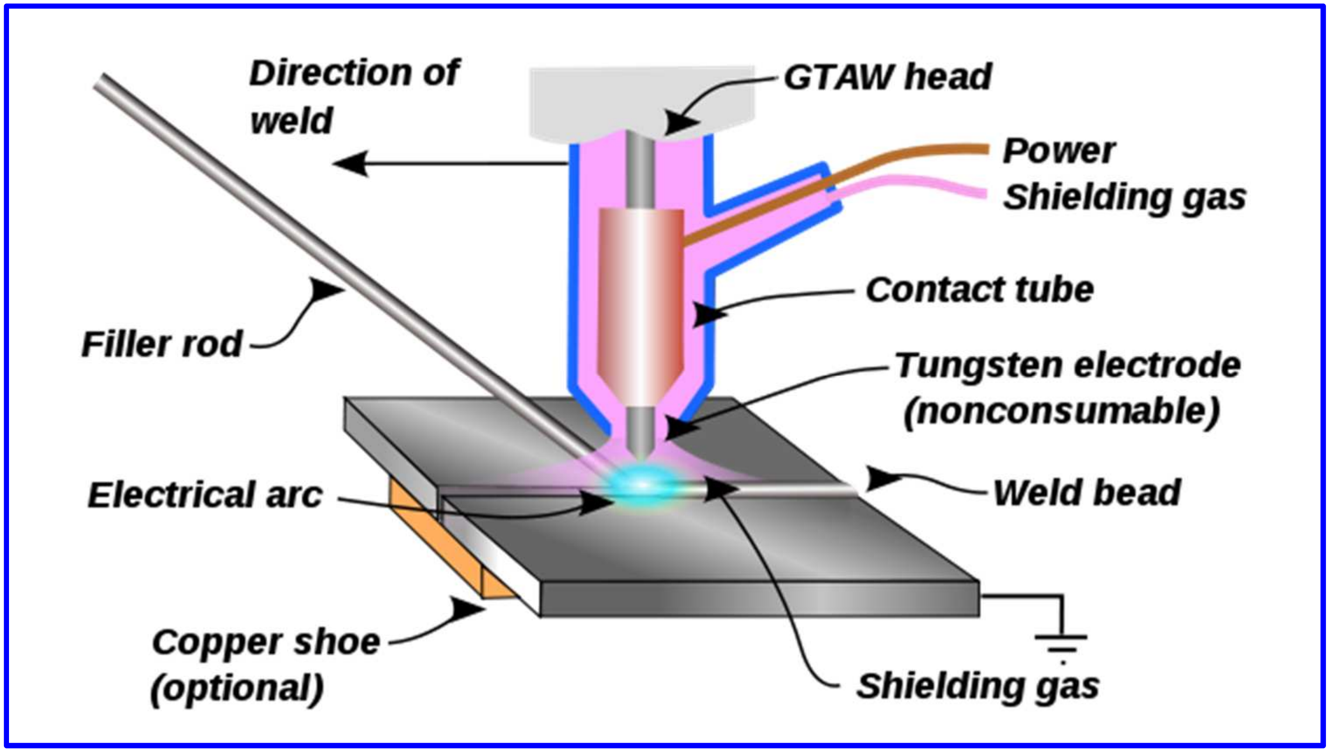


Welding

Welding is the process where two materials are joined by fusion

- Welding is the most common method for joining metals in vacuum systems.
- Inert gas welding is the most common type of welding (TIG, MIG).
- Joint design is critical from vacuum, metallurgical and distortion standpoints.
- Cleanliness is essential.
- Other welding processes to consider are electron beam and laser welding.

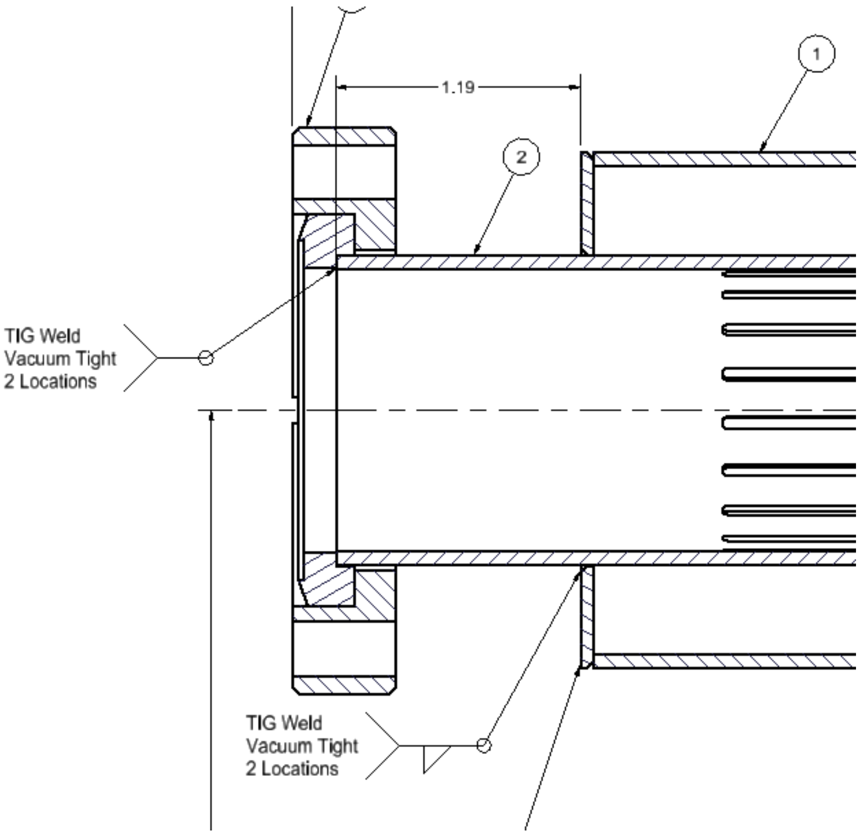
TIG – Tungsten Inert Gas Welding

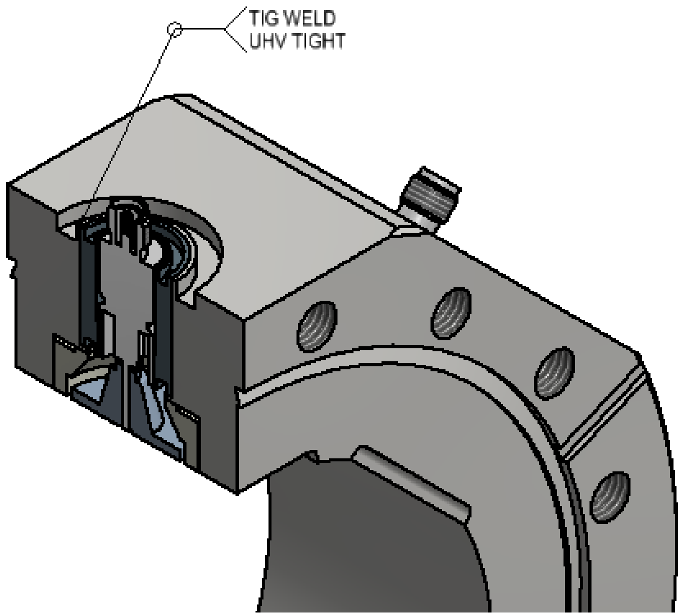


- *TIG welding is one of most difficult welding, when operating manually.*
- *Inert gas mixture (Ar and He) form a shield to protect the hot-zone from oxidization. The composition of the gas mixture vary with metal and mass.*
- *Arc power may be direct current or alternate current*
- *Filler rod is often used, but not needed for some fusion welds.*

Welding Stainless Steel

- TIG welding of stainless steels is among easiest, and heat-affected zone (HAZ) is very small.
- In most cases, filler is not needed. However, reinforce stitch welds with filler are added for strengthening the welded joint.





Welding Copper

- The high thermal conductivity of copper makes welding difficult. Heating causes the copper to re-crystalize forming large grain size and annealing. Distortion is also a big problem.
- Copper weldment can be fused via TIG with or without fillers.
- Braze copper to copper, or copper to stainless steel is also done with TIG technique, using CuSil (72%Ag-28%Cu) alloy fillers. (At Cornell, we call this BT-weld, or Braze-TIG.)
- Copper requires:
  1. Very high welding speeds
  2. Excellent material purity (OFE copper) and cleanliness.
  3. Good joint design
  4. Welding coppers must be done in an inert glove-box, or at least purging in-vacuum surfaces.
- Electron beam welding is an excellent process for welding copper.
- Vacuum furnace braze is also a good option for coppers.

Welding Aluminum

- Low melting point, relatively high thermal conductivity, and high rate of thermal expansion make welding aluminum more problematic than stainless steel.

- Aluminum requires:
  - 1. High welding speeds (higher current densities)
  - 2. Good material purity and cleanliness
  - 3. Good joint design

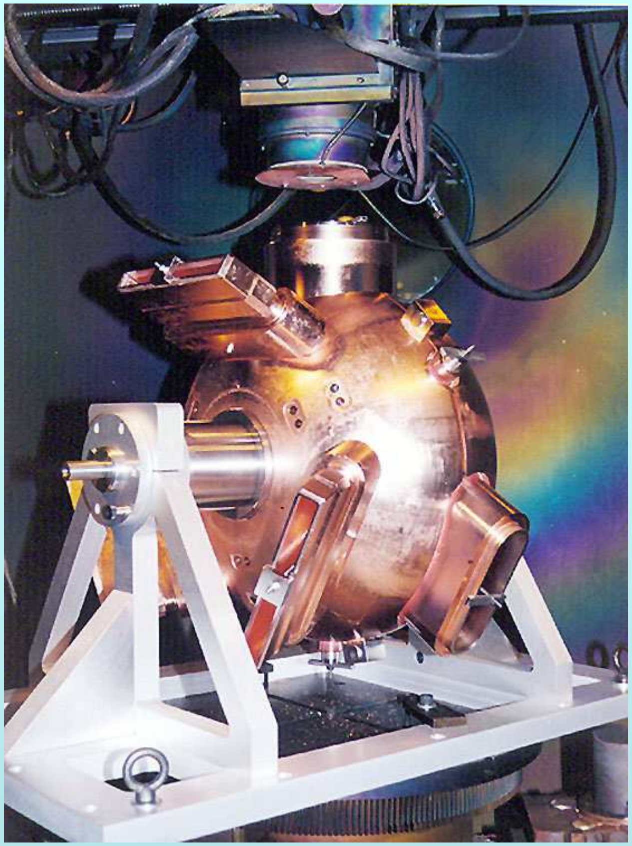
- Aluminum welds have a tendency to crack from excessive shrinkage stresses due to their high rate of thermal contraction. Filler rods (usually 4043 or similar alloys) always needed.

- To keep the aluminum weldment clean from oxidization, AC power is usually used during TIG, with characteristic popping noises.

Electron Beam Welding (EBW)

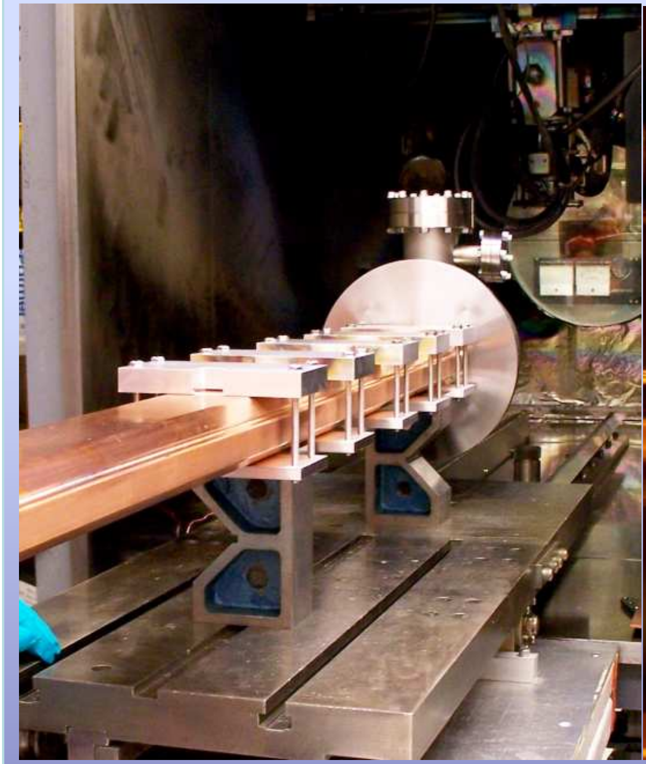
- **EBW provides extremely high energy density in its focused beam producing deep, narrow welds.**
- **This rapid welding process minimizes distortion and the heat affected zone.**
- **Very good control and reproducibility in weld penetration.**
- **A disadvantage of EBW is that the process takes place under vacuum (P = 10^{-5} Torr):**
  - **Extensive fixturing required**
  - **High initial cost**
  - **Weld preps are extremely critical, as no filler used.**
  - **Complexity**
  - **Welds are not cleanable**

Copper chambers EBW

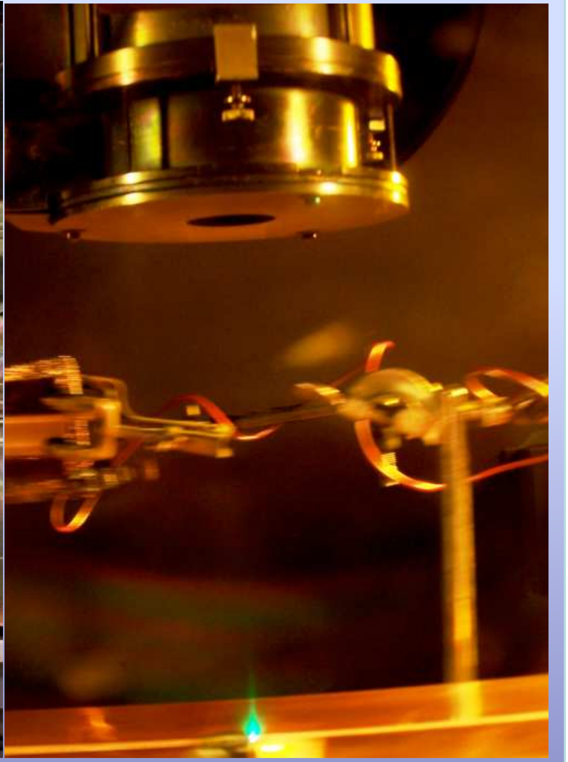


RF Cavity

Welding 1-mm thick Copper Cover on CesrTA EC Detector Chamber



Load into EBW Chamber



E-beam welding

SLAC Electron Beam Welder

Soldering

Soldering is the process where materials are joined together by the flow of a "filler metal" through capillary action.

- ***Soldering is differentiated from brazing primarily by the melting temperature of the filler metals. Solder alloys melt below 450°C.***
- ***Because of lower working temperature, usually corrosive flux is needed to ensure proper 'wetting' of the surfaces.***
- ***All soft solders are unacceptable for UHV systems because:***
  - ***They contain Pb, Sn, Bi, Zn (vapor pressures are too high)***
  - ***System bake-out temperatures typically exceed alloy melting points.***
  - ***Residuals of corrosive flux left on the joints, a long-term reliability issue.***
- ***Most silver solders are unacceptable.***

Brazing

Brazing is the process where two dissimilar materials are joined together by the flow of a "filler metal" through capillary action.

- ***There are several different brazing processes:***
  1. *Torch*
  2. *Furnace*
  3. *Induction*
  4. *Dip*
  5. *Resistance*

- ***Brazing can be used to join many dissimilar metals. The notable exceptions are aluminum and magnesium.***

- ***Cleanliness is important in brazing. Cleanliness is maintained by use of a flux or by controlling the atmosphere (vacuum or H_2).***

- ***For vacuum furnace brazing, flux is NOT used.***

Brazing (Cont.)

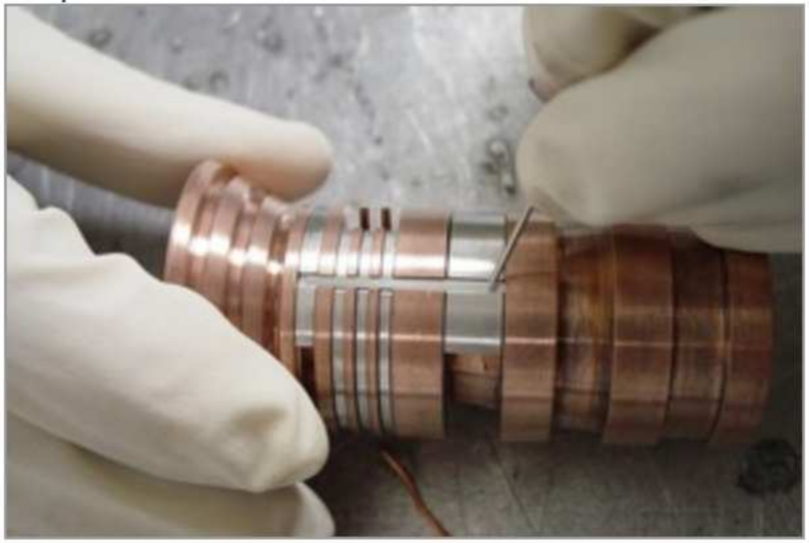
- ***Filler metals (brazing alloys) come in the form of wire, foils, or paste.***
- ***Brazing alloys are selected to have melting points below that of the base metal. The brazing alloys must be able to 'wet' the base metal(s).***
- ***Generally, brazing alloys can be categorized into eutectic or non-eutectic. For eutectic alloy, the transitions between solidus and liquids occur at a very narrow band (within a degree). Eutectic alloys are usually preferable.***
- ***Multiple braze steps are possible by choosing alloys of differing melting points and proceeding sequentially from highest to lowest temperature.***
- ***Braze joints require tight tolerances for a good fit (0.002" to 0.004") to ensure capillary flow.***

Some Braze Alloys for UHV Components

Alloy	Brazing Temperature	Composition
Georo™	361°C	88% Au, 12% Ge
CuSil™	780°C	72% Ag, 28% Cu
BAu -2	890°C	80% Au, 20% Cu
Au-Cu-Ni	925°C	81.5% Au, 16.5% Cu, 2% Ni
BAu -4	950°C	82% Au, 18% Ni
50/50 Au-Cu	970°C	50% Au, 50% Cu
35/65 Au-Cu	1010°C	35% Au, 65% Cu

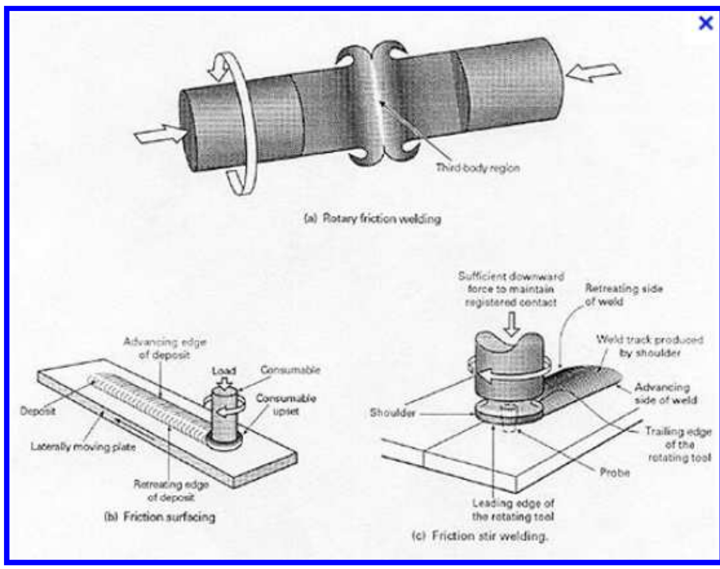
Diffusion Bonding

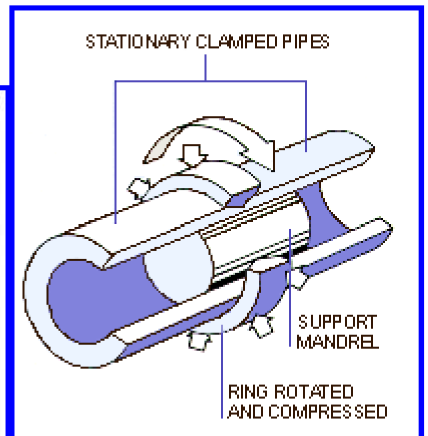
- **Diffusion bonding is a joining technique where pre-machined components are held together under modest loads at elevated temperatures.**
  - ***The loads are usually well below those producing deformation.***
  - ***Bonding temperatures typically range from 50-80% of melting temperatures of the metals.***
  - ***Processing times vary from 1 minute to over an hour.***
  - ***Most diffusion bonding operations are conducted in vacuum or in an inert gas atmosphere***
- **Diffusion bonding requires very clean components with excellent surface finishes.**
- **Diffusion bonding can also bonding dissimilar materials**



Friction Bonding/Welding

- Friction welding (FW) is a class of solid-state welding processes that generates heat through mechanical friction between a moving work piece and a stationary component, with the addition of a lateral force called "upset" to plastically displace and fuse the materials.
- FW is useful to bond dissimilar materials, such as aluminum to stainless steel, which otherwise difficult to joint.





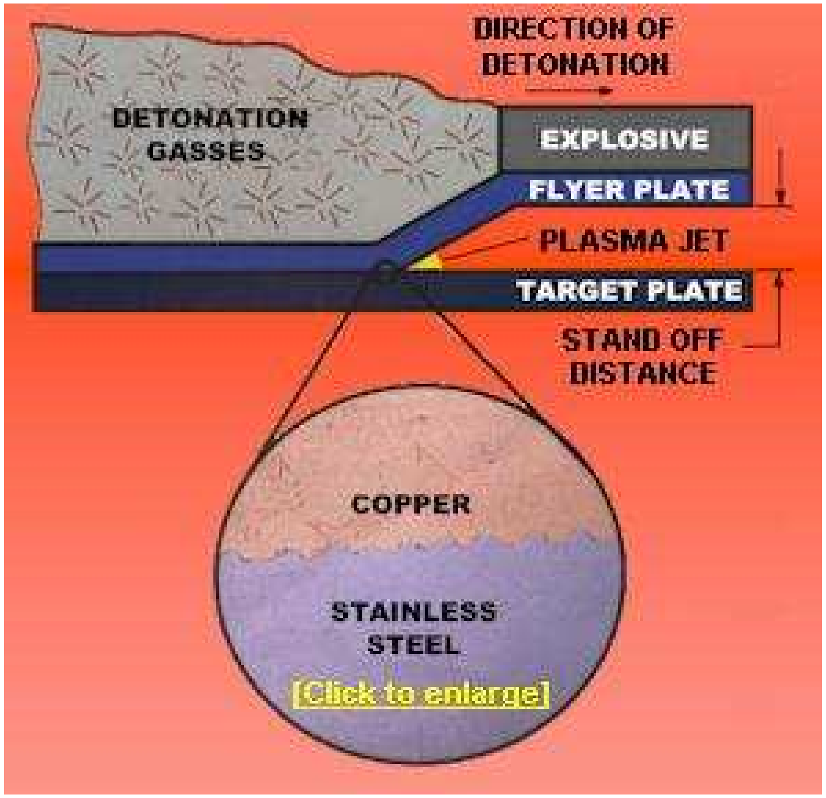
100s used on CESR SLDJTs

Explosion Bonding

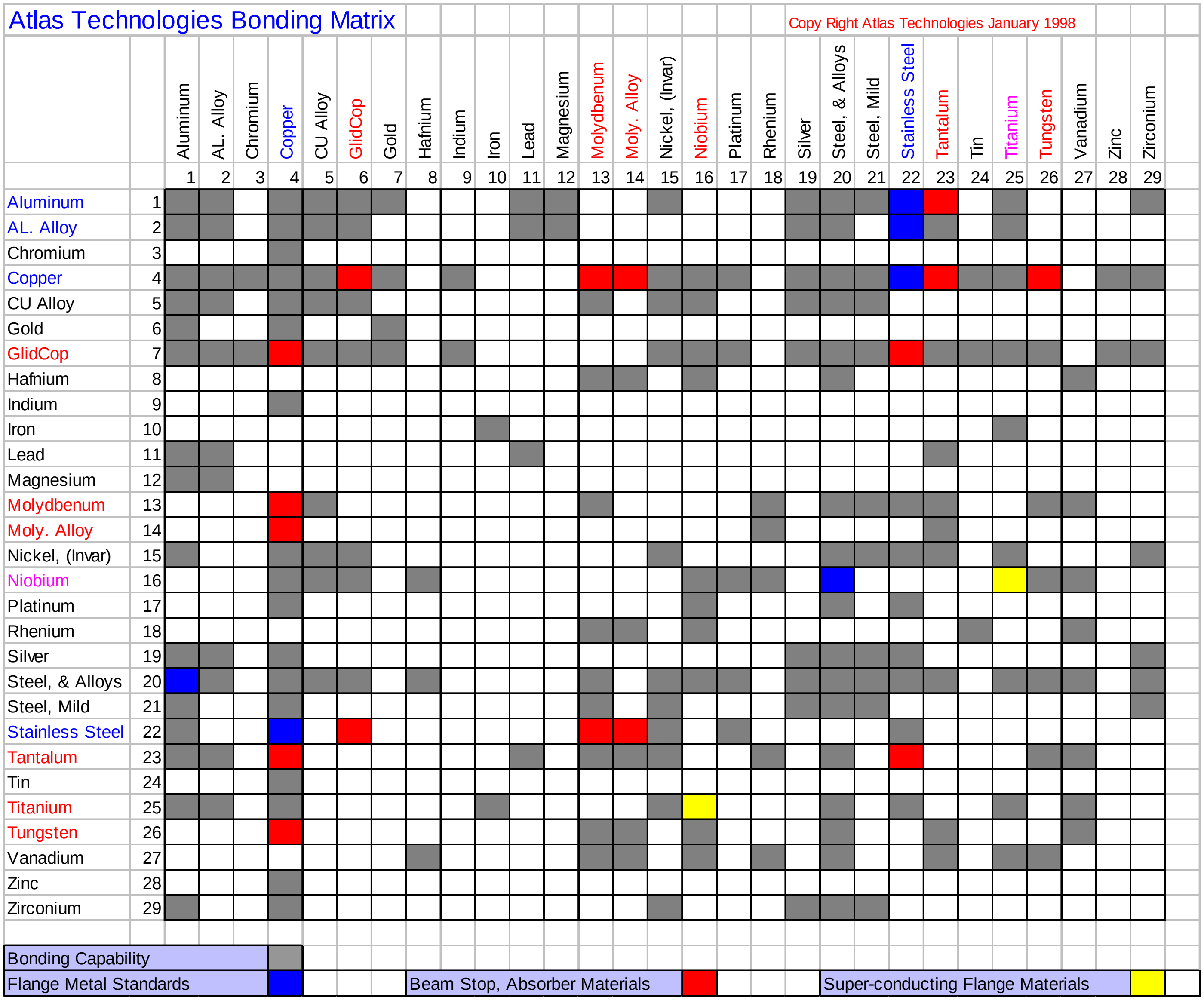
- *Two Plates Are Spaced One Above the Other with Ammonium Nitrate Explosives on top. Thin transitional metal sheet(s) is often used in order to bond dissimilar metals. A progressive charge is detonated and the plates Accelerated to Contact.*

- *Extreme heat and pressure created at Impact and Ultra Clean Surfaces to fuse the plates to form metallurgical bonding.*

Explosive Forming



A Claim – *All Metal Combinations can be bonded*



Explosion Bonding – Examples

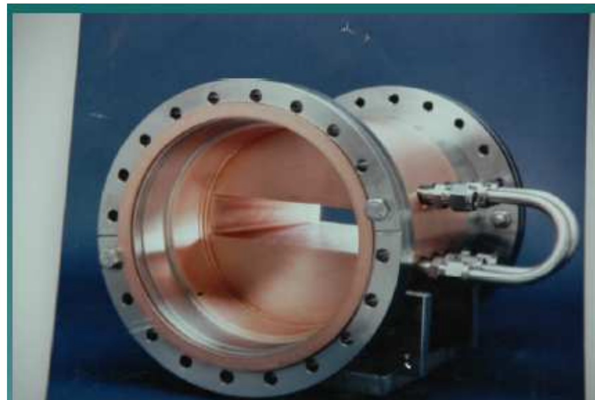
Alum / Stainless


Alum Tube / Steel Billet

Ref: PA&E Bonded Metals Division

Alum / Stainless


Copper / Stainless


Cu / SS Exit Slit for UHV Beam Line


Titanium / Alum

Clad Tubes


Cu / SS

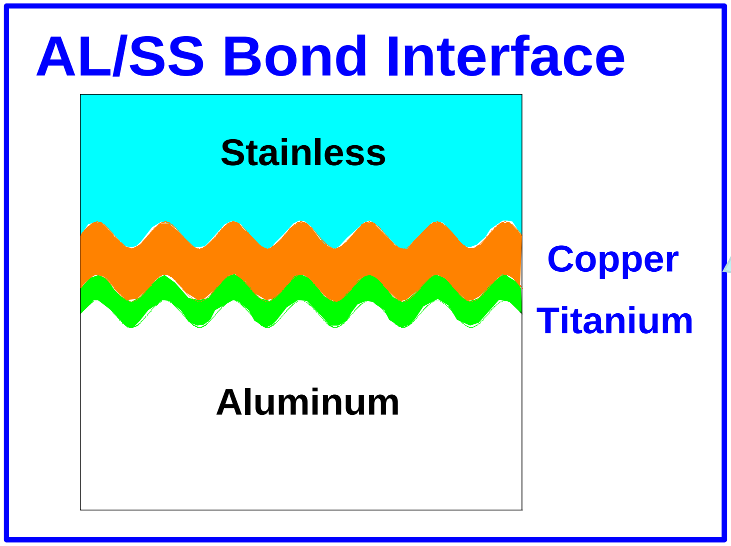

Alum / Steel


Cu / Nb

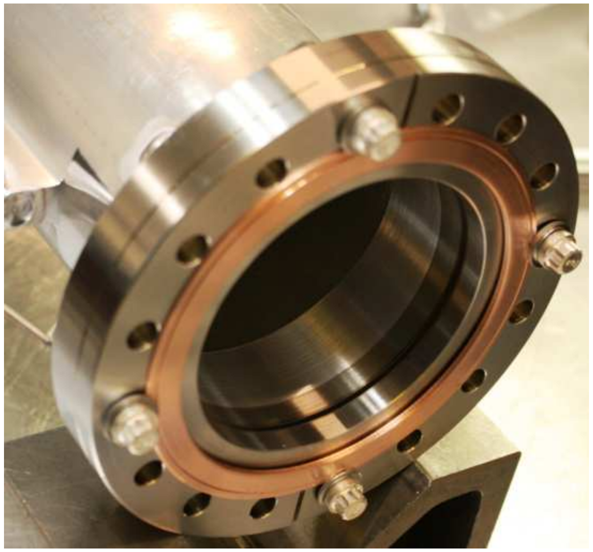
SS/AL Bond Interface
Patent# 5836623

- Diffusion Inhibiting Layers: Copper and Titanium Interlayer Enables Bonding AL/SS
- Vacuum: <1×10^{-10}cc He/Sec
- Thermal: Peak 500°C at weld up 0-250°C Operational
- Mechanical: Tensile 38,000 p

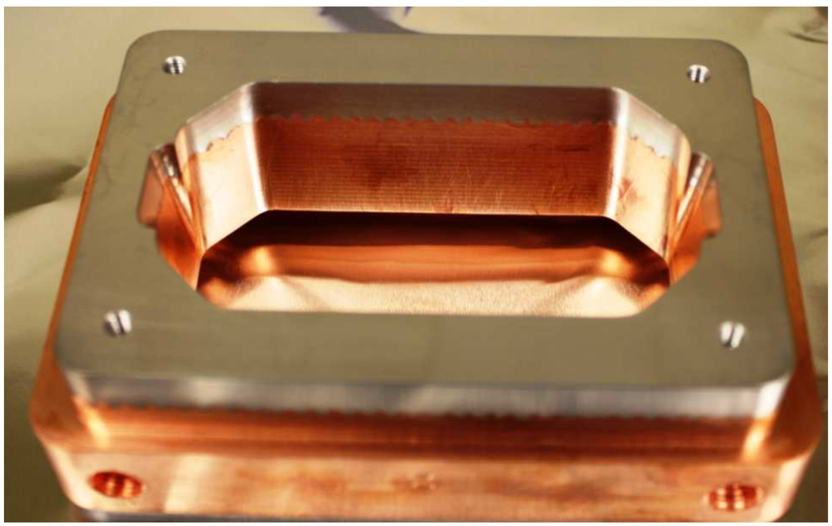
Ref: Atlas Technologies



Applications for bi-metallic joints



Alum/SST transition enable welding instrument feedthroughs to aluminum beampipe



Cu/SST transition used on Cesr-C damping wiggler beampipes

Demountable Metal Sealed Joints

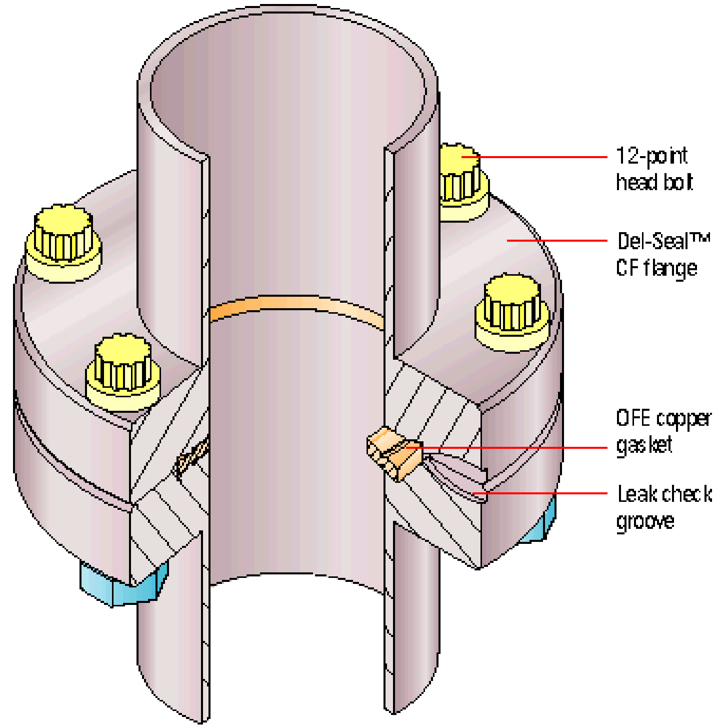
There are a variety of metal seals available for vacuum systems, including:

- ConFlat® flanges: for flanges OD <26"
- Helicoflex® seals: for customer designed flanges
- Metal wire seal flanges: for large flanges
- VATSEAL® flanges: good RF properties

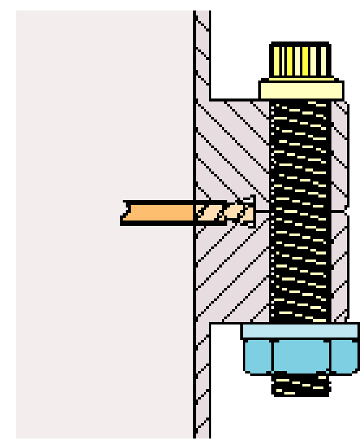
Metal seals are used for UHV systems, where permeation, as well as radiation damages, are not acceptable.

Conflat® Flanges

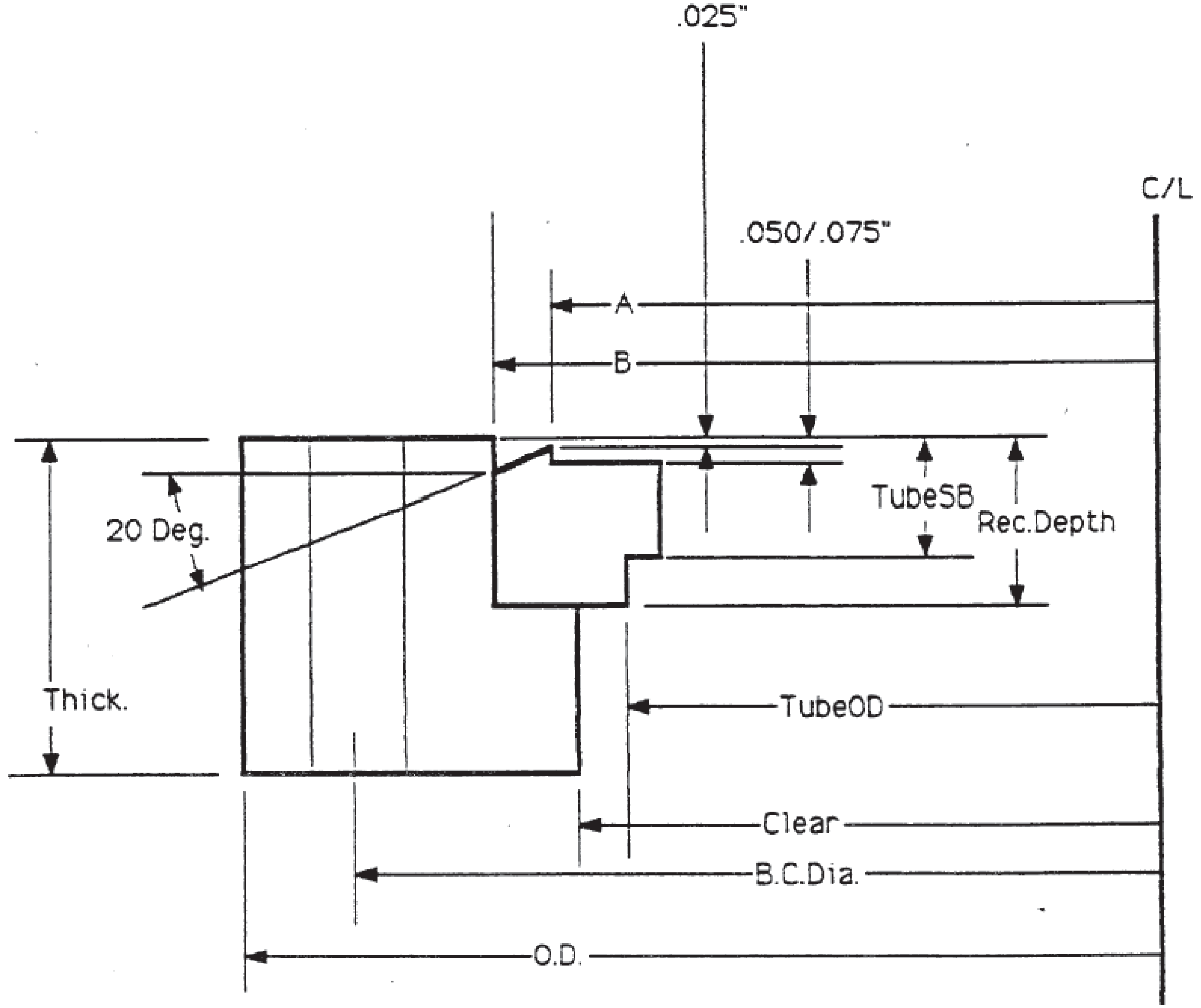
- Conflat® style metal seal flanges are the most widely used for UHV vacuum systems.
- During sealing, knife-edges of a pairing stainless steel flanges plastically deform a copper gasket to form a reliable seal.
- The close match of C.T.E. of stainless steel and copper ensure proper sealing force through temperature cycles, up to 450°C.



- Gaskets are usually made of ½-hard OFHC. Silver-plated Cu gaskets are used for system baked at temperature higher than 250°C.
- Standard sizes range from 1-1/3" to 16" OD, with fixed and rotatable styles.



Conflat® Flanges Cont.

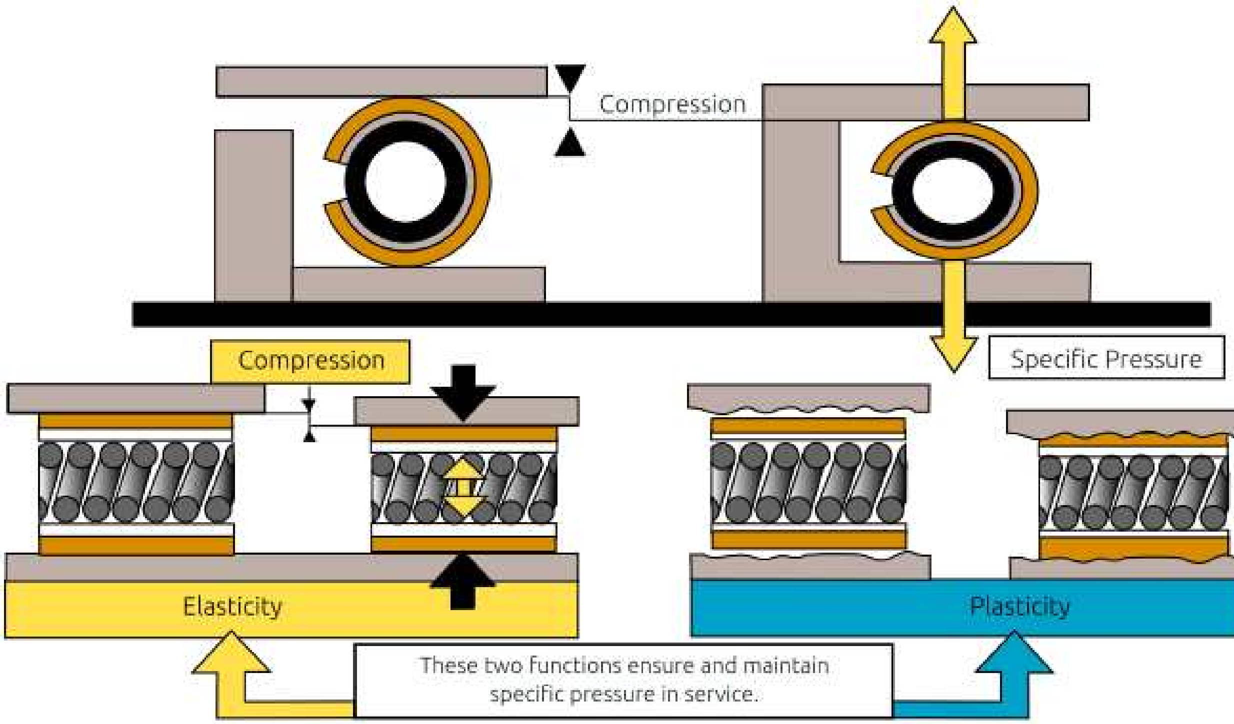


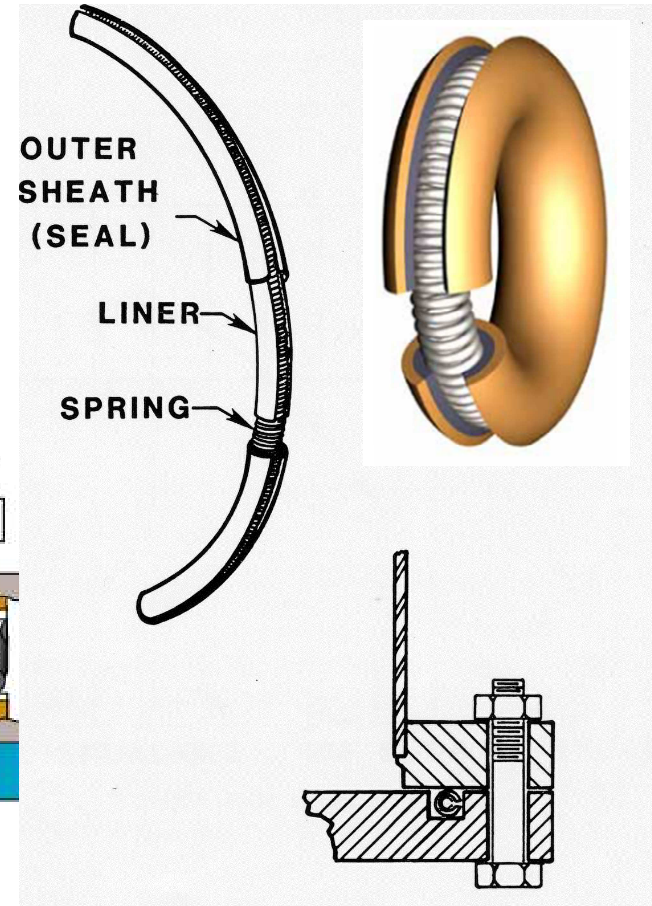
Conflat® Flanges Cont.

O.D.	Config.	Bolts	B.C.Dia.	Gas.OD	Gas.ID	Thick.	TubeSB	TubeOD		Clear	RecDepth	A-Dia.	B-Dia.
1.33"	fixed	6	1.060	0.834	0.640	0.280	0.500	0.75				0.718	0.841
133	rot	8-32								0.750	0.280		
2 1/8"	fixed	4	1.625	1.290	1.010	0.470	0.170	1.00				1.086	1.297
218	rot	1/4-28								1.075	0.236		
2 3/4"	fixed	6	2.312	1.895	1.451	0.500	0.209	1.50				1.650	1.902
275	rot	1/4-28								1.560	0.300		1.906
3 3/8"	fixed	8	2.850	2.425	2.010	0.625	0.225	2.00				2.188	✓2.432
338	rot	5/16-24								2.030	0.318	2.200	
4 1/2"	fixed	8	3.628	3.243	2.506	0.687	0.375	2.50				3.040	3.250
450	rot	5/16-24				0.750				2.625	0.500		
4 5/8"	fixed	10	4.030	3.598	3.010	0.750	0.375	3.00				~~3.395~~	3.605
458	rot	5/16-24				0.810				3.100	0.505	3.347	
6"	fixed	16	5.128	4.743	4.006	0.781	0.438	4.00				4.540	4.750
600	rot	5/16-24				0.843				4.125	0.563		
6 3/4"	fixed	18	5.969	5.567	5.010	0.840	0.460	5.00				5.364	5.574
675	rot	5/16-24								5.125	0.563		
8"	fixed	20	7.128	6.743	6.007	0.875	0.500	6.00				6.540	6.750
800	rot	5/16-24				0.937				6.125	0.624		
10"	fixed	24	9.128	8.743	8.007	0.968	0.500	8.00				8.540	8.750
1000	rot	5/16-24								8.125	0.675		
13 1/4"	fixed	30	12.060	11.587	10.810	1.120	0.500	10.75				11.350	11.595
1325	rot	3/8-24								10.875	0.775		
14"	fixed	30	12.810			1.120	0.875	12.00					
1400	rot	3/8-24								12.250	0.775		
16 1/2"	fixed	36	15.310			1.120	0.875	14.00					
1650	rot	3/8-24								14.290	0.775		

Helicoflex® Flanges

- **Metal O-ring using an internal spring to maintain the seal force, while outer layer of the gasket deforms to make seal.**
- **Vacuum rated to 1 x 10^{-13} Torr; Temperature rated to 450°C.**
- **Typical size range: 10" - 20" od**

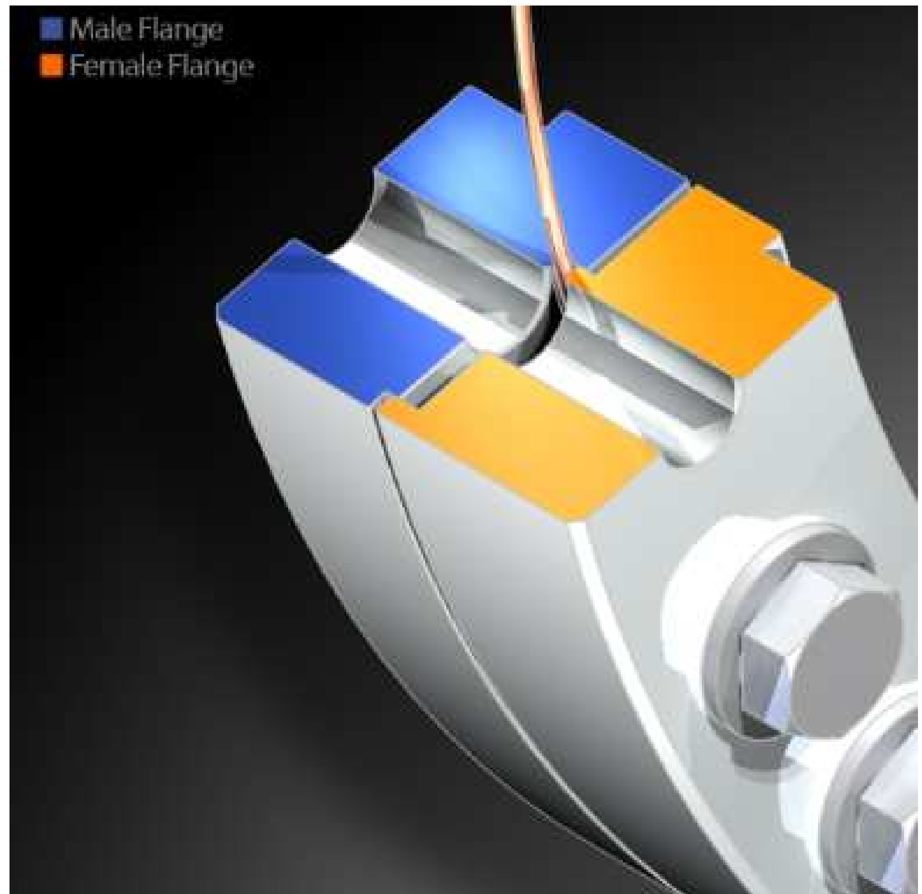




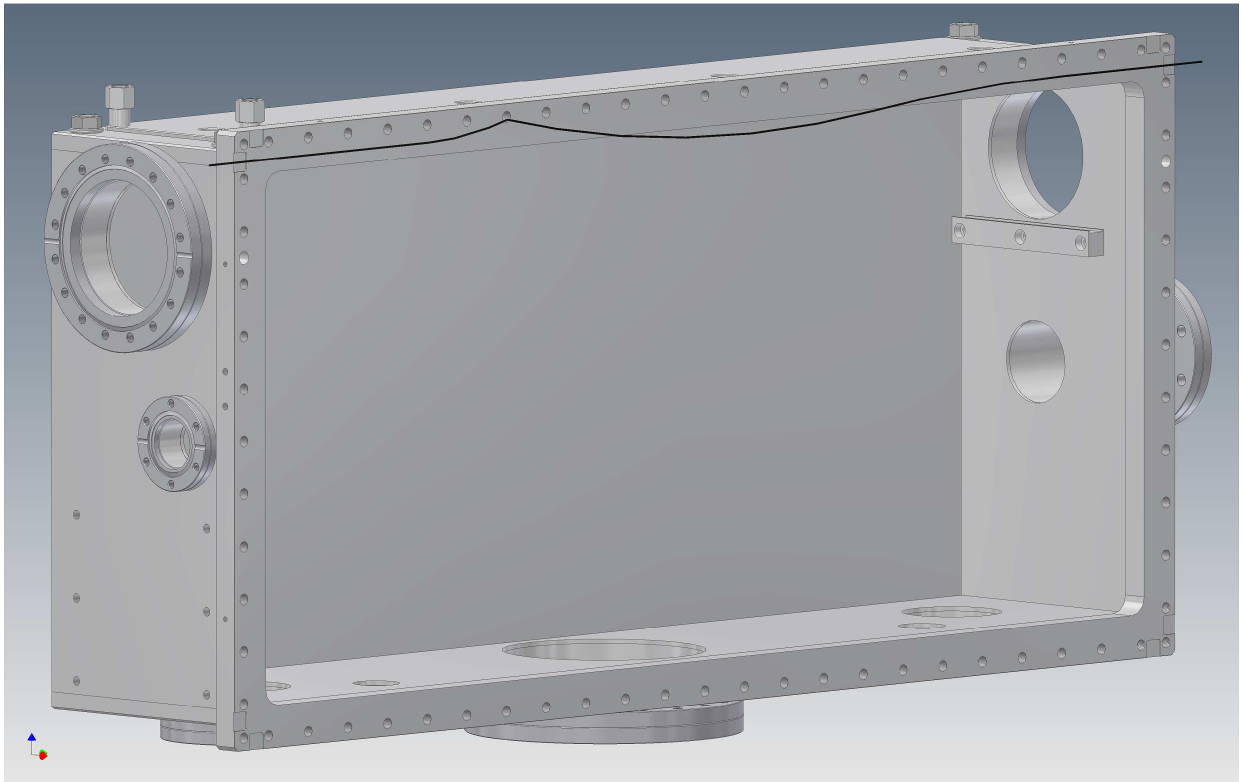
Ref: http://www.techneticsgroup.com

Commercial Wire Seal Flanges

- **Vacuum rated to 1 x 10^{-13} Torr, Temperature rated to 450°C with copper wire gasket.**
- **Typical size range: 20" – 27" od with >30" possible**
- **Warning – male and female flanges**

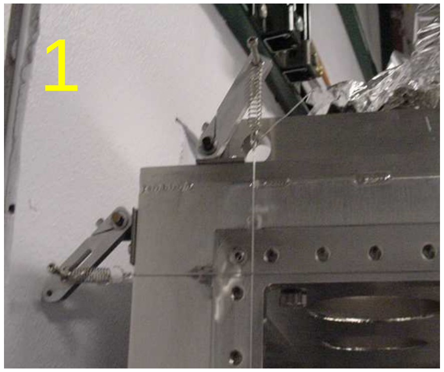


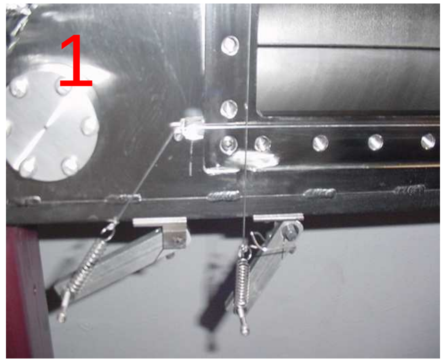
Large Wire Seal Flanges at CHESS

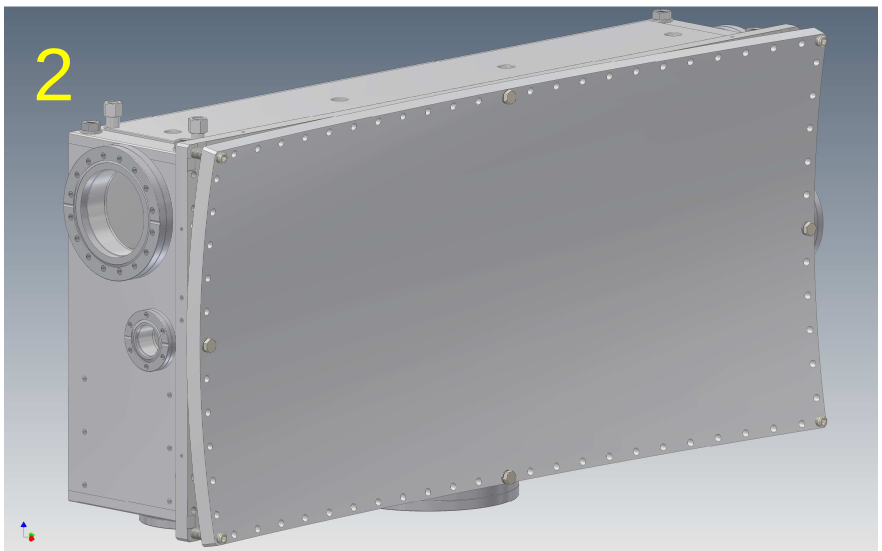


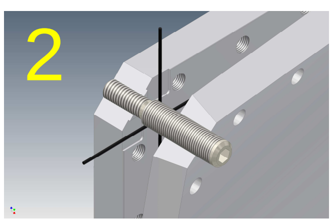
- As with many X-ray light sources, it is always a challenge to make reliable UHV-compatible seal on a very large lid (often in vertical position) for X-ray optics, as elastomer seal is not acceptable.
- A reliable, inexpensive and very scalable aluminum wire seal scheme was developed at CHESS, and also adapted by NSLS II.

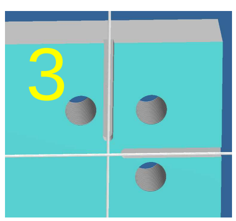
Large Wire Seal Flanges at CHESS Cont.











How the seal is made:

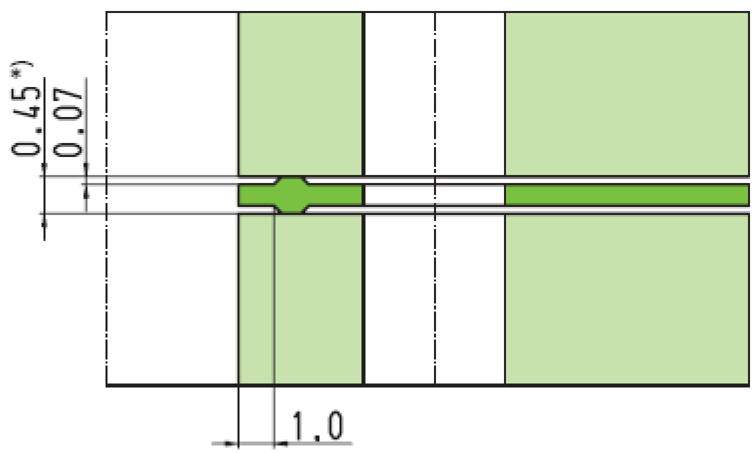
1. Four aluminum wires are stretched across sealing surfaces, and tensioned with springs.
2. The large lid is placed (with exaggerated bending) over the wires. Tightening from center towards to the corners, to ensure that the wires kept stretched .
3. Under cuts at corners may improved sealing reliability.

Features of the seals:

1. No 'upper-size' limit.
2. Reproducible and reliable seals
3. Relatively relax seal surface finish, but need to be flat.
4. Only work on flanges with straight sealing edges/

VATSEAL® Flanges

- A style of metal seal for vacuum, cryogenics and high temperature applications.
- silver-plated or gold-plated copper gaskets
- VATSEAL metal seals make a leak-tight seal and at the same time a reliable, low resistance RF contact



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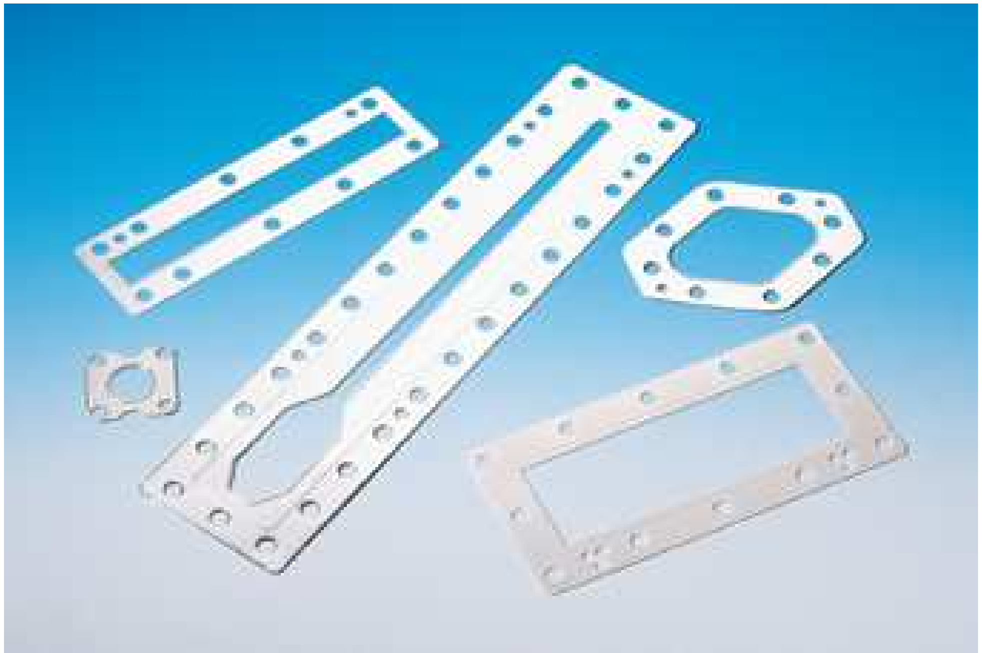
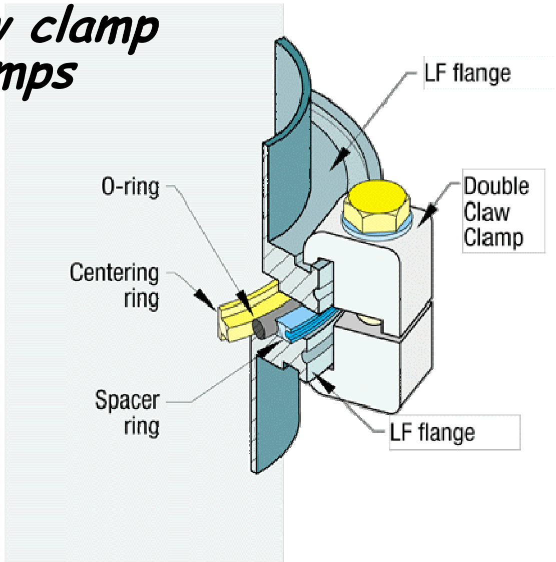


Elastomer Flanges

Elastomer (O-ring) sealed flanges found their uses in accelerators mostly in high-vacuum, or insolation vacuum for cryo-genic systems (such as superconducting magnet.

ISO Flanges

Flanges come in a variety of fastening styles:
- **Kwik-flange**
- **Rotatable & Non-rotatable**
- **Double claw clamp**
- **Banded clamps**



ASA Flanges

Typical size range: 1" to 12" dia.