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Technology of Noble Gas Detectors

The technology of noble fluid detectors has been rapidly developing in the last two decades. The subject area attracted attention of researchers and detector technologists at many universities and national laboratories. A valuable progress in the development of this technology has been achieved mostly due to the discovery of effective methods of purification of large amounts of noble gases, the introduction of low-noise electronics, and the development of new VUV sensitive photosensors such as UV photodiodes and compact photomultiplier tubes capable of working at low temperatures and at elevated pressures. In this chapter, we describe specific technical solutions and methods supporting operation of noble fluid detectors. The chapter includes recommendations on construction materials, requirements of mechanical design, references to proven electrical and optical parts, most applicable insulators, feedthroughs, safety devices, photosensors, etc. Significant emphasis will be placed upon the description of purification methods, systems monitoring purity and other important properties of the media. The chapter cannot cover all aspects of the technology but it may serve as an introduction to the technology for beginners.

8.1
Selection of Materials and Mechanical Design

The materials of choice for pure noble gas detectors are very similar to materials used in ultrahigh vacuum systems. The major requirement is to reduce the outgassing rate to a value that the desired purity of working media can be provided.

8.1.1
Metals

8.1.1.1 Construction Metals

Austenitic stainless steel is the most commonly used metal for manufacturing vessels of noble gas detectors. Russian 12X18H10T and US 304 stainless steel

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(T304 Alloy; density 8.03 g cm^{-3}; composition: 9.25%Ni, 19.00%Cr, 1.00%Si, 2.00%Mn, 0.080%C, 0.045%P, 0.030%S, the rest is Fe) are chosen most frequently for their satisfactory argon-arc welding, good mechanical properties, and acceptable outgassing rates. Usually this kind of steel is not used at temperatures above 1200 K. The radioactivity of the stainless steel is ranged between 0.02 and 0.1 Bq kg^{-1}.

Aluminum and aluminum alloys are very cheap, easy to machine, and have a low outgassing rate as long as the alloy does not have a high zinc content. They have the disadvantage of low strength at high temperatures and high distortion when welding. Alloys with a copper content also present welding problems. Aluminum that will be exposed to a vacuum should never be anodized due to serious outgassing problems. There are also some potentially violent chemical reactions that can develop when cleaning freshly machined aluminum with trichloroethane or trichloroethylene-based vapor degreasers. The high vacuum sealing between two aluminum flanges may constitute a problem, however.

Oxygen-free high conductivity (OFHC) copper is easily machined with good corrosion resistance and is widely used in detectors. It is not generally used for vessels that require baking due to possible heavy oxidation. The low radioactivity of OFHC copper is an important property for some applications.

Titanium alloys are sometimes used for fabrication of special low-mass and low-radioactive (for selected alloys) vessels. Titanium requires special techniques for arc welding to protect it from intensive oxidation at elevated temperatures.

Brass has good corrosion resistance and in the past often used as a major construction metal. In modern pure systems, brass components are usually nickel-plated to reduce outgassing due to the zinc content.

8.1.1.2 **Sealings**

Metal sealings are most often used in the constructions of noble gas detectors that require periodic openings as well as in gas fittings of associated vacuum and purification systems.

Copper rings are commonly used for systems with ConFlat-type flanges that use a copper ring compressed between two knife edges. The seals are bakeable up to 720 K, and are widely used because of relatively low cost and because the thermal expansion coefficient of copper is very close to that of stainless steel.

Aluminum wire rings are very cheap and bakeable up to 500 K.

Indium wire can be used between flat flanges. It is very soft and continues to flow after initial tightening (needs special groves for good sealing). Combined indium-coated copper gaskets can be used for sealing very different materials such as optical windows between steel flanges, for example. It can be heated up to 400 K.

Gold wire is often used for ultrahigh vacuum seals between flat surfaces and can be baked to 720 K.

Swagelok, Tylok, VCR, and other whole-metal brand seals are now widely used. The best practical results were achieved with VCR-type sealings capable of operating at elevated and cryogenic temperatures, at high-vacuum and high-pressure conditions.

Helicoflex spring energized seals consist of a jacket tube and helical spring inserted inside. The sealing principle is based upon the plastic deformation of a jacket (most often made of aluminum) and the compression resistance provided by the spring. Each coil of the helical spring acts independently and allows the seal to conform to imperfections on the sealed flange surfaces. The seal perfectly performs in the temperature range from cryogenic to 1255 K and the pressure range from ultrahigh vacuum to 340 MPa. Special designed Helicoflex seals can be used with the ConFlat flanges. The main disadvantages are that Helicoflex seals are relatively expensive and can be used only once.

8.1.2
Insulators

Generally, the use of plastics should be kept to a minimum due to their high gas permeability and high desorption rates compared with metals, glass and ceramics. In spite of this, plastics are often used in vacuum systems because of their insulating properties, elasticity, low radioactivity, and affordable price.

PTFE (Teflon DuPont) has self-lubricating properties, a relatively low outgassing rate, is a good electrical insulator, and can be used at higher temperatures than other plastics. High permeability makes PTFE unsuitable as a part of the vacuum envelope.

Nylon has self-lubricating properties but a high outgassing rate and a high adsorption rate for water is a drawback.

PVC has a high outgassing rate but does find application for rough vacuum lines and temporary connections such as to a leak detector.

Polyethylene may be usable if well outgassed. It is inherently low-background material with high electric strength. In the UK the polymer is called *polythene*. The main disadvantage is its relatively low melting temperature.

Vespel polyimide is ultrahigh vacuum compatible, easily machined, and an excellent insulator from DuPont. Vespel tends to be very expensive.

G10 Glass Epoxy is available in blocks and sheets, difficult to machine, and has a high initial outgassing rate. It is often used for printing circuits in, for example, liquid argon and liquid krypton ionization calorimeters.

Fluoroplastics include Kel-F, PVDF (Kynar), TFE, etc. Kel F has a fairly tolerable outgassing rate and while expensive it is much cheaper than Vespel for some applications.

Kapton is a DuPont polyimide film that has more than 35 years of proven performance as the flexible material of choice in applications involving very high (673 K) or very low (4 K) temperature extremes. Kapton is used in a wide variety of applications such as substrates for flexible printed circuits, transformer and capacitor insulation and perfectly performed as a construction material of electrode systems of noble liquid ionization calorimeters.

Cirlex is an all-polyimide sheet material made of Kapton films. With a thickness of 3–4 mm and plated with copper, it has demonstrated a good performance for fabrication of printed circuit boards for LXe detectors. It has a temperature range of 4 to 624 K; electrical strength for breakdown 2790 V mil^{-1} at thickness of .009″ (.23 mm).

Ceramics are widely used, with alumina ceramic (92–99.8% Al_2O_3) being the most widely used material out of a variety of fine ceramics. It features the same crystal structure as sapphire and ruby. Alumina ceramic demonstrates a low leakage current, low outgassing rate, low gas permeability, and can be used from cryogenic temperatures up to 1800 K. The ceramic is most often used for manufacturing electrical feedthroughs due to highly developed technology of the ceramic to metal brazing. There are also some machinable ceramics available such as Macor, which includes mica and because of that cannot be used for low-background applications. All ceramics are brittle and must be handled with care but mechanically perform much better than any glass.

8.1.3 Feedthroughs

Types of feedthroughs used in noble gas detectors include single-channel, multipin and high voltage electrical feedthroughs, fiber optic feedthroughs, and motion feedthroughs. The following basic principles have to be taken into consideration when selecting the feedthroughs:

- Construction material should be clean and do not impose a risk of contamination of noble gas with electronegative and molecular impurities.
- Construction should be helium-leak tight at least at a level of 10^{-9} mbar L s^{-1}.
- Radioactive or Rn-emitting (porous) materials are not permitted or should be shielded for low-background applications.

8.1.3.1 Electrical Feedthroughs

Glass-to-metal sealed electrical feedthroughs have often been used in the past. Ceramic-to-metal seals, bonding metals to ceramics, are fundamental to the electrical feedthroughs used in contemporary devices. This kind of ceramic feedthrough can operate from cryogenic to 723 K and from ultrahigh vacuum to 24 MPa pressure. Multipin instrumentation feedthroughs contain more than one conductor path or pin and are also fitted with a fastening air-side connector. These feedthroughs are used for the transmission of voltage and current signals. Among many manufacturing companies the authors prefer products of CeramTec and Kyocera.

There are a few designs of HV feedthroughs discussed in the literature. In fact, all those designs are based on the idea of HV cable connectors:

1. Ground shielding of HV cable is firmly connected to the body of the device with a nut or flange.

2. At this point, the cable has no shielding (open cable), consisting of a conductor surrounded with a thick enough insulator, and introduces HV to the point of application; it is important that the length of the open cable is selected long enough to withstand surface breakdown between the point of HV application and grounded point of the shielding connection.

ICARUS design [399] follows the design of the detachable HV cable. This is a solid HV cable with tube conductor installed inside a long high-density polyethylene (HDPE) rod, which is sealed to the detector body with Viton O-rings. The O-rings are continuously flushed with dry nitrogen to prevent oxygen diffusion along the conductor but still oxygen diffusion cannot be excluded. This design is acceptable for LAr detectors with relatively liberal requirements to the gas purity but cannot be accepted for LXe detectors.

For low-background installations, the well-proven ceramic feedthrough (for example, 90 kV Ceramaseal p/n 17057-02-CF) can be mounted outside of the passive shielding to the top of the long metal pipe connected to the detector as shown in Fig. 8.1. HV insulation inside the pipe provided with two (or more) insulating tubes, which are open at both sides. The tubes could be made of Teflon or quartz. The design of this kind of HV feedthroughs with quartz insulating tubes has been proven in a LAr ionization chamber used in the experiment searching for double beta decay of ^{100}Mo [400], in the high-pressure xenon ionization chamber used in the experiment searching for double beta decay of ^{136}Xe [401], and in the large LKr/LXe spark purifier [402].

8.1.3.2 **Optical Fiber Feedthroughs**

The use of epoxy is undesirable as outgassing can occur. As an example of clean design, we mention the Oxford Electronics optical fiber vacuum feedthroughs using *CuBall* metal-coated optical fibers which are brazed to a stainless steel tube to make a vacuum tight seal and then brazed to an SMA connector on the vacuum side. The optical fiber feedthrough allows