13. Tantalum

Tantalum is a dense, ductile and malleable metal of grey-blue colour. It has good thermal and electrical conducting properties. It is easy to machine, and its fusion temperature is one of the highest amongst metals, after that of tungsten, rhenium and osmium. It is also biocompatible which makes it useful for medical applications. Tantalum also has near-zero electric resistance at low temperature, high corrosion resistance, shape memory properties and high capacitance.[1]

Tantalum is mostly used (60%) in the production of capacitors used in electronics (smartphones, computers, wireless equipment, etc.).[2] It is also used as an alloying element for super-alloys in turbines, aircraft engines and defence applications. Its resistance to corrosion and high-temperature enable its use in demanding industrial environments, cutting tools and as a refractory material.[3]

Tantalum is a high value metal that is recovered both as a main metal and as a by-product of tin operations, the latter source accounting for up to one fifth of total tantalum supply. Because of its high value, tantalum (like tin, gold and tungsten) lends itself to small scale and artisanal mining (ASM), and has been prominently linked to the conflict in the Democratic Republic of Congo. ASM can contribute significantly - an estimated one fourth of global mining production in 2009, similar to gold and tin—to the global supply of tantalum [4,5]. Because of this large contribution, it is difficult to obtain reliable statistics for tantalum mining in Africa. Traditionally, Australia has been a major producer of tantalum; however, mining operations have been intermittent in recent years because of low prices. Brazil has recently strengthened its position as leading tantalum supplier, followed by Mozambique and Rwanda.

Tantalum can be recycled from metallic scrap, however its major use in electronics is of a dissipative nature. Tantalum process scrap coming from the manufacturing of capacitors are claimed to be fully recycled.[6] Aside from this recycling in capacitor manufacturing, tantalum recycling comes from other applications such as cemented carbide and alloys (old scrap), spent sputtering targets and edge trimming and shavings from metallurgical processes (new scrap). About 300-400 t of secondary tantalum are currently used. This may represent ~20% of total supply provided through recycling[1] (figures varies between 10% and 30% recycling, depending on the source).

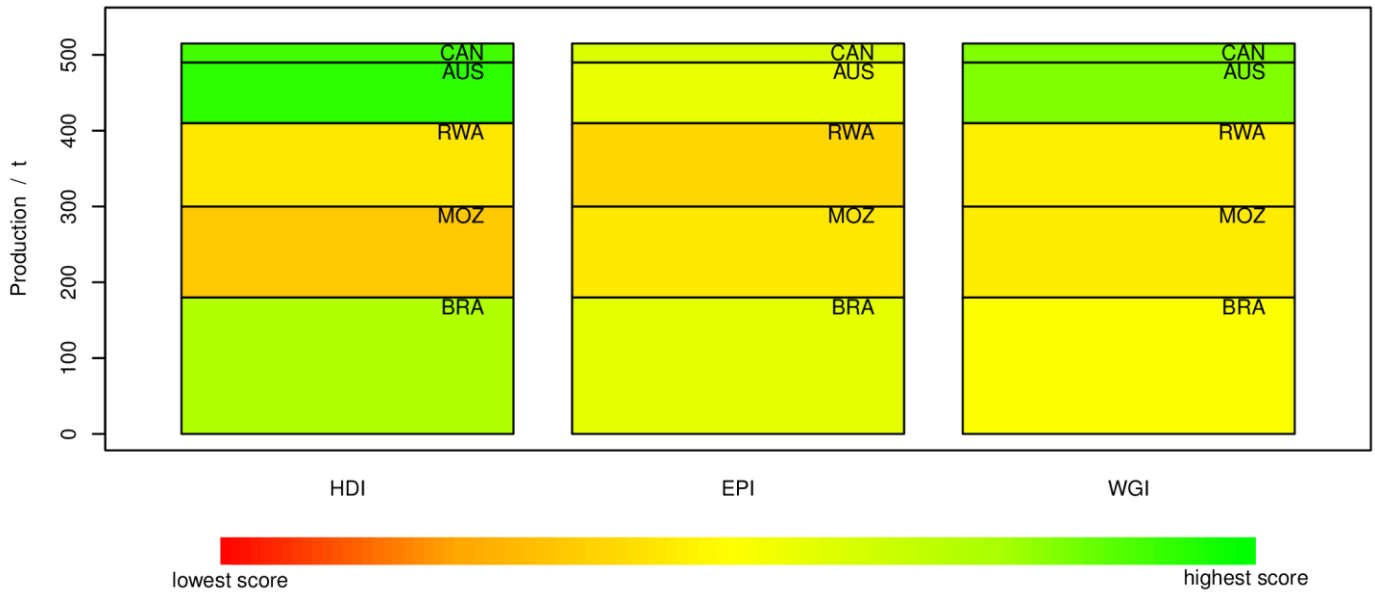

Figure 1: Distribution of tantalum production[7] and corresponding scores of the producing countries in the Human Development Index (HDI)[8], Environmental Performance Index (EPI)[9], and World Governance Indicators (WGI)[10]. Both the EPI and WGI are used to assess supply risks with the EU methodology for determining critical raw materials [11]. BRA = Brazil; MOZ = Mozambique; RWA = Ruanda; AUS = Australia; CAN = Canada.

The price of Tantalite (Ta_2O_5) increased significantly (284%) in the period from 2009 to 2011.The annual price reported in Ryan's Notes is 56.82 US$/kg in 2011.[12] In 2013 the price of Tantalite decreased continuously.[13]

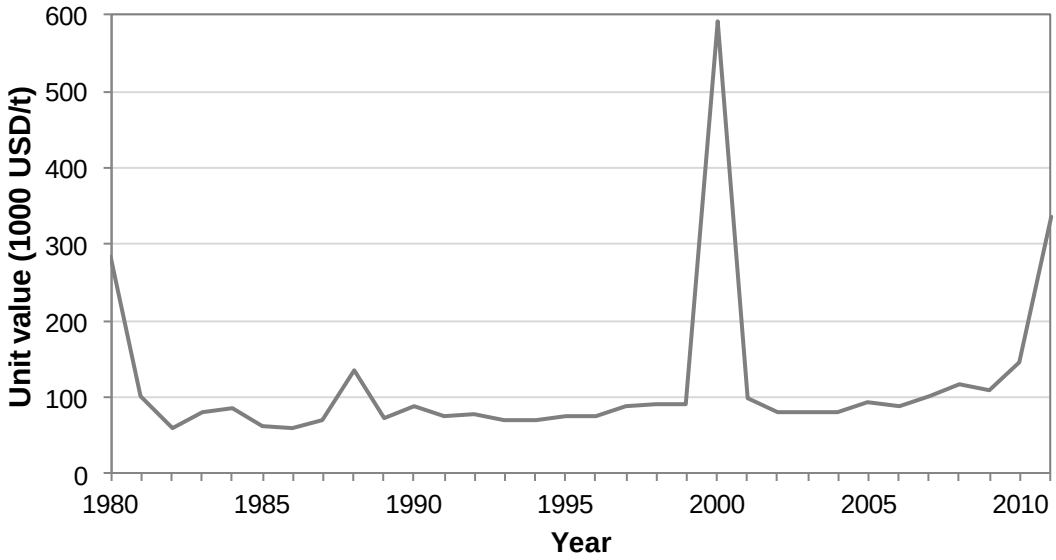

Figure 2: Tantalum price development during 1980 – 2011. The unit value is defined as the value of 1 metric ton (t) of tantalum apparent consumption (estimated).[14]

Uses and substitutability

Tantalum is mostly used in capacitors, cemented carbides and super-alloys for aerospace, automobile, defence and turbine applications.

Capacitors

The major use of tantalum powder is in ceramic capacitors, thanks to its high capacitance coefficient that enables smaller components for miniaturized and portable electronics. These components are also robust, temperature tolerant, and with low default rate. Although the material quantity per capacitor is small, electronic devices may contain numerous capacitors; a recent smartphone contains approximately 23 capacitors and smartphones are produced in very high numbers. The multiplicity of the electronic applications (automotive electronics, portable electronic boards, smartphones, etc.) and their mass production represent a massive ~50-60% of tantalum use.[1]

Different tantalum powders are used to manufacture capacitors for high-voltage applications, low-voltage and high-capacitance applications, or medium-voltage and medium capacitance applications.[15]

In terms of substitution, niobium (also considered a critical raw material) can be used to produce capacitors at lower cost, but they are usually larger and have a shorter life-span.[16] Standard aluminium capacitors are possible alternatives, but are more sensitive to harsh and hot operating conditions. Ceramic capacitors are also an option. The superior performance and robustness of tantalum capacitors remains, however, the best choice in applications where size and/or security matters (e.g. automobile anti-lock brake systems, airbag activation systems, etc.).

Cemented carbides[1]

Tantalum carbide is an extremely hard refractory ceramic which can be used for the production of high-speed cutting and boring tools, or other environments with high levels of stress and temperatures. Teeth for excavator buckets, mining drills and high-performance bearings are possible applications. These carbides are also used in refractory parts and coatings for furnaces and nuclear reactors.

In carbides applications, possible substitution of tantalum by niobium (CRM) is possible, as well as the use of tungsten (CRM) and titanium carbides (TiC) and nitride (TiN) are also possible.

Aerospace & automobile super-alloys

Tantalum super-alloys are used mostly in aerospace (75% of super-alloy demand, including jet engine and rocket engine nozzles) and defence applications (e.g. missile parts). These are typically Ni-based super-alloys with a tantalum fraction, but can also be tantalum-based super-alloys. These super-alloys are also used in other turbine-type equipment (e.g. gas turbines). Tantalum-ruthenium alloy is used in the military for its oxidation resistance and shape memory properties.

In steel super-alloy applications where strength is required at high temperature, tantalum addition can be replaced by vanadium or by molybdenum. Other possible substitutes for high-temperature applications can be hafnium, iridium (CRM), molybdenum, niobium (CRM), rhenium and tungsten (CRM).[12]

Process equipment

Tantalum alloys are usually used in applications which require corrosion resistance, good high-temperature and thermal/electric conductivity behaviour such as chemical processing equipment including heat exchangers, boilers, condensers, pressure reactors, distillation columns, crucibles, etc. Tantalum is also

used to produce dimensionally stable anodes that can be used in extreme environments such as in the production of chlorine and soda in systems with ion exchange membranes.[1]

In the domain of industrial resistance to corrosion and high-temperature environment, niobium (CRM) can be substituted for tantalum due to similar crystallographic properties. Other possible corrosion-resistant substitutes can be glass, platinum (CRM), titanium and zirconium. As for super-alloys, possible substitutes for high-temperature applications can be hafnium, iridium (CRM), molybdenum, niobium (CRM), rhenium and tungsten (CRM).[12]

Surgical applications & others

Tantalum alloys are used in invasive medical applications such as surgical tools, pacemakers (coating and capacitors) and prosthesis devices either as metal or coating (e.g. hip joints, skull plates, stents for blood vessels) owing to the biocompatibility of tantalum. It is also used in hearing aids. Some orthopaedic applications of tantalum in prosthetics can be substituted by titanium and ceramics, but some specific applications cannot be substituted, for example porous tantalum alloys used in prosthetic body parts, or pacemaker coating. Chromium/nickel steel alloys can be used for surgical equipment (e.g. stents and pinches), but with lower durability of the oxide coating layer and a lower malleability.

Tantalum is used in optics for the manufacture of specialty glass and camera/eyeglass lens, conferring a high-refractive index. It is also used in glass-coatings and X-ray film/absorbers. Niobium can also be used in some cases.

Hard disk drives use tantalum or niobium (substitute but also CRM) both in the disk themselves and in the read-write head.[17]

Lithium tantalite and niobate have unique optical, piezo and pyro-electric properties and are thus used in electronic applications like surface acoustic wave (SAW) filters for sensors in cellphones, TV sets, video recording, etc. The progressive introduction of alternative materials (e.g. $La_2Ga_5SiO_{14}$, note that La and Ga are both CRM) as substitutes for lithium tantalite for SAW is however observed.

The following applications of tantalum have also been identified, however, no additional information about possible substitution has been found in literature:

- In construction, tantalum is used in cathode protection systems for large steel structures (e.g. oil platform, bridges, water-tanks), and corrosion-resistant fasteners (e.g. nuts, bolts).
- Tantalum nitrite is used in LED applications, solar cells, transistors and integrated circuitry due to its semi-conductor characteristics.
- Tantalum film coating deposited by physical vapor deposition (PVD) is used in electronics to prevent copper migration in Si and SiO_2. Deposition is also used for media storage (USB key), inkjet printer heads and panel displays. Molecular beam epitaxy equipment, which enables even thinner layers than PVD, may also use tantalum.

Summary

The core use of tantalum in capacitors has several possible substitutes (aluminium, ceramic capacitors) that are likely to answer most common needs. Only niche capacitor applications with strong size and robustness/tolerance requirements may be more difficult to replace, but with lower demand volumes and possibly higher-value.

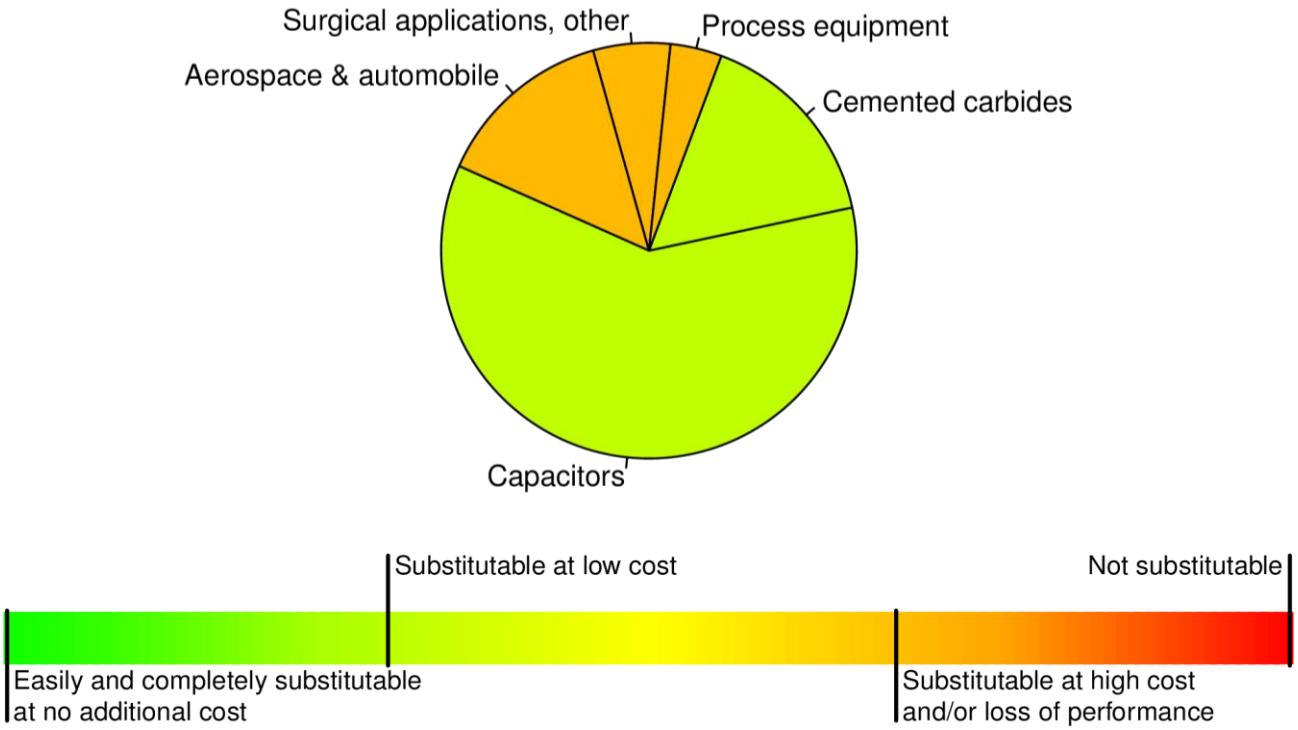

Figure 3: Distribution of end-uses and corresponding substitutability assessment for tantalum. The manner and scaling of the assessment is compatible with the work of the Ad-hoc Working Group on Defining Critical Raw Materials (2010).

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