Feedstocks for Chalcogenide Glass Optics

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ABSTRACT

Infrared optical materials are used to manufacture optical components that enable today's infrared systems. The cost of these systems is an important consideration in both the commercial and military markets. The optics are occupying a greater and greater portion of the overall bill of material as detector costs decline and the cost of traditional infrared materials increase, specifically germanium. Chalcogenide glasses have gained a renewed interest in the market due to the potential for lower cost with similar performance. Chalcogenide glasses predominantly contain one or more of the chalcogen elements along with network formers. The primary materials used include antimony, arsenic, gallium, germanium, selenium, sulfur, tellurium and tin. This paper reviews the availability, requirements of, market for, and cost of the key raw material feedstocks for chalcogenide glasses and provides valuable information for cost sensitive selection of infrared optical materials and a secure supply chain.

Keywords: Chalcogenide glass, feedstock, optical materials

1. INTRODUCTION

Infrared optical systems have been common in military systems for many decades, while historically, commercial applications have been limited. In the last decade, the decline in cost of microbolometers and the rapid growth of the personal vision system and surveillance markets has driven significant growth in the sale of commercial infrared systems. Yole Développement predicts the overall thermal camera market could reach \$9B by 2029, with significant upside potential of more than \$2.5B assuming full automotive adoption of thermal imaging for automatic emergency braking (AEB) by the same year[1]. While germanium has been the main infrared transmitting material used in many of these applications, the use of chalcogenide glass (ChG) has increased significantly. While many commercial systems have used ChG's for years, there is more interest in converting infrared systems to use ChG than there has ever been before due to changes in the global supply chain of infrared optical materials. ChG's have long been pitched as a lower cost alternative to germanium with similar performance and excellent scalability for high volume. The recently implemented export restrictions by China, the largest producer of germanium in the world, has led to a significant reduction in supply outside of China and large increases in the cost of germanium. Many ChG's contain germanium impacting both their availability and cost as well. Other feedstocks for ChG such as tellurium and gallium are being similarly impact. This paper reviews the eight most popular constituent elements or feedstocks for ChG to understand whether these materials may face similar issues.

1.1 Export Restrictions

Cost is an important consideration in selecting materials for use in both military and commercial systems. While almost all are aware of international concerns over the supply of strategic materials and the historical large swings in material pricing in infrared optical materials, specifically germanium, few people understand where the raw materials for infrared optical materials come from or their relative impact on the cost of the optical material. Feedstocks impact the cost of an optical material at its most basic level. Many of these feedstock materials are considered rare or strategic and are subject to export restrictions depending on the individual country.

Figure 1: VIG06 $As_{40}Se_{60}$ boules

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On July 3, 2023, the Chinese Ministry of Commerce (MOFCOM) announced a series of new restrictions on the export of gallium and germanium, two elements used in semiconductor and optics manufacturing. Starting in August 2023, MOFCOM Notice 2023 No. 23[2] required all exporters to obtain a license to ship germanium and gallium out of China. Exporters are required to identify the importers, application and end users. The rationale for implementation was national security and state interests.

These announcements were followed by further restrictions in August 2024 with the release of MOFCOM Notice 2024 No. 46[3]. This notice further restricts the Chinese export of gallium and germanium and adds additional restrictions for other materials, it specifically addresses:

1. The export of dual-use items to U.S. military users or for military uses is prohibited.

2. In principle, the export of the relevant dual-use items gallium, germanium, antimony, and superhard materials to the United States is not permitted; stricter end-user and end-use checks will be implemented on exports of dual-use graphite items to the United States.

This release has led to even further interest in chalcogenides, as the supply chain for germanium has been greatly reduced causing the price to increase substantially.

1.2 Chalcogenide Glasses (ChG's)

Chalcogenide glasses are a group of materials that contain one or more of the chalcogen elements, group 16 in the periodic table. These include sulfur, selenium or tellurium but exclude oxygen and polonium. To create chalcogenide glass, the chalcogen element is combined with one or more other elements or network formers to form a glass, see Figure 2. There are usually only 2-3 elements and occasionally 4+ elements found in commercial grade compositions.

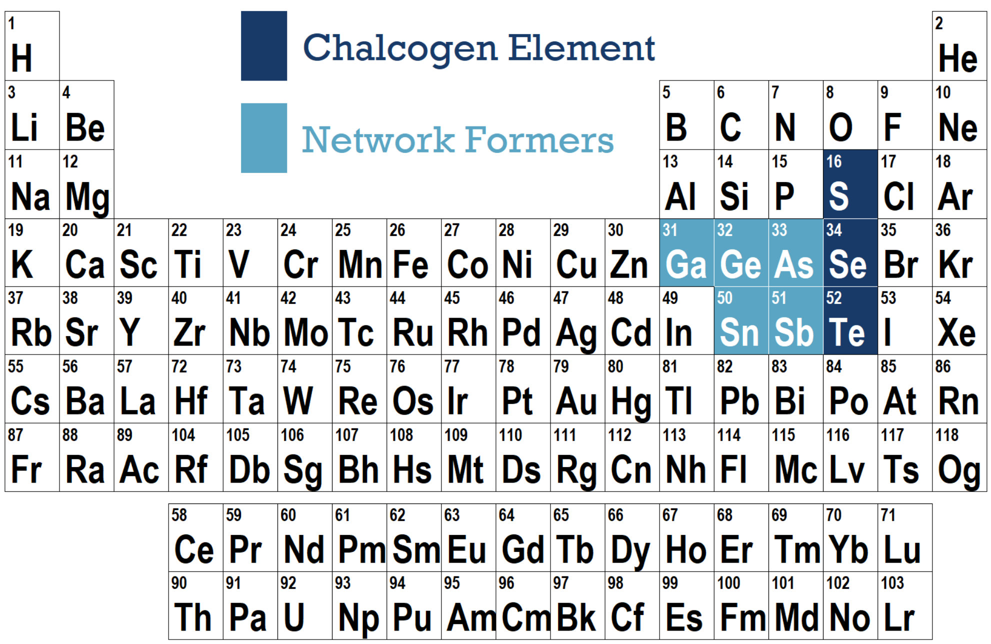

Figure 2: Common chalcogenide elements and network formers in the periodic table

Composition	Common Trade Name
$As_{40}S_{60}$	Schott IRG27, Vital VIG03
$As_{36}Se_{64}$	Amorphous Materials, AMTIR-5
$As_{40}Se_{60}$	Schott IRG26, Vital VIG06, Vitron IG6
$Ge_{10}As_{40}Se_{50}$	Schott IRG24, Vital VIG04, Vitron IG4
$Ge_{20}Sb_{15}Se_{65}$	Umicore GASIR-2, Vital VIG07
$Ge_{22}As_{20}Se_{58}$	Umicore GASIR-1, Vital VIG08
$Ge_{28}Sb_{12}Se_{60}$	Schott IRG25, Vital VIG05,Vitron IG5
$Ge_{30}Se_{32}As_{13}Te_{25}$	Schott IRG23, Vitron IG3
$Ge_{33}As_{12}Se_{55}$	Schott IRG22, Vital VIG02, Vitron IG2
$Se_{63}As_{30}Sb_{4}Sn_{3}$	Vital VIG01

Table 1: Common commercially available grades of chalcogenide glasses

Examples of the most commonly available commercial grades and their compositions are provided in Table 1. Chalcogenide glasses are now commonly used especially in high volume production applications like thermography, automotive thermal imaging, firefighting cameras and smart phone cameras; "Optical lenses have evolved from germanium to chalcogenides. They are less expensive, the raw material price is steadier than germanium and the molding process is cheaper than diamond-turning used for germanium, as long as production volumes are high like in the thermography business" [4]. The majority of ChG applications use the germanium-free composition, $As_{40}Se_{60}$. Germanium is the most expensive of the constituent elements of the chalcogenide glasses, therefore germanium containing compositions are amongst the most expensive, increasing in price as the content increases. ChG is most commonly used as an alternative to germanium. The properties of $As_{40}Se_{60}$ (Vital Materials, VIG06) are compared to the traditional infrared optical materials in Table 2[5].

Property	Vital VIG06 $As_{40}Se_{60}$	Germanium	Silicon	Zinc Selenide	Zinc Sulfide
Material Structure	Amorphous	Crystalline	Crystalline	Crystalline	Crystalline
Transmission Range	1 - 14μm	2 - 14μm	1.2 - 10μm	0.6 - 20μm	1 - 13μm
Index of Refraction	2.7781 @ 10.0μm (20°C)	4.0021 @ 10.0μm (22°C)	3.4221 @ 5.0μm (20°C)	2.4028 @ 10.6μm (20°C)	2.1921 @ 10.6μm (20°C)
Thermo-Optic Coefficient dn/dT	30.5 $\cdot 10^{-6}$/°C @ 10.0μm	416.5 $\cdot 10^{-6}$/°C @ 5.0μm	166.0 $\cdot 10^{-6}$/°C @ 2.5μm	61.0 $\cdot 10^{-6}$/°C @ 10.6μm	41.0 $\cdot 10^{-6}$/°C @ 10.6μm
Density	4.63 g/cm^3	5.33 g/cm^3	2.329 g/cm^3	5.27 g/cm^3	4.08 g/cm^3
Knoop Hardness	1.53 GPa	7.85 GPa	11.28 GPa	1.13 GPa	2.21 GPa
Thermal Linear Expansion	22.5 $\cdot 10^{-6}$/°C	5.7 $\cdot 10^{-6}$/°C	2.62 $\cdot 10^{-6}$/°C	7.57 $\cdot 10^{-6}$/°C	6.8 $\cdot 10^{-6}$/°C

Table 2: Material Property Comparison of Common Infrared Optical Materials[5]

Chalcogenides provide many advantages over the traditional infrared optical crystalline materials: germanium, silicon, zinc selenide and zinc sulfide. Amongst these advantages are low cost, high temperature coefficient of refractive index, lower density and improved transmission at elevated temperatures (ChG's are not subject to thermal runaway). The primary disadvantages are related to lower hardness. Chalcogenides also present stable pricing when compared with its primary substitute germanium which has a significant history of high price volatility[6]. One of the most important features of chalcogenide glasses for manufacturing is its amorphous nature which enables precision glass molding as a high-volume manufacturing process[7]. The most common chalcogenide glasses are listed in Table 1. There are many more chalcogenide formulations, however many of these newer chalcogenides have never been scaled to production volume, have low manufacturing readiness levels and in many situations provide trivial advantages over the common grades that have been manufactured for decades.

2. CHALCOGENIDE GLASS FEEDSTOCKS

The following eight chalcogenide glass feedstocks: antimony, arsenic, gallium, germanium, selenium, sulfur, tellurium and tin are reviewed in detail, their place in the periodic table of elements can be seen in Figure 2.

2.1 Antimony

Antimony is listed as a critical mineral by Canada[8], the EU[9] and the US[10]. It can be directly mined as stibnite (Sb_2S_3), or it can be extracted as a byproduct from gold and copper mining[11]. Around 60% of the world total production, 100,000 Metric tons (MT) comes from China, followed by Tajikistan (17%) and Russia (13%). The US imported around 4,400 MT of unwrought and powder Sb in 2024[12]. Since September 15th, 2024, China requires a permit to export antimony[13]. Then, on December 3rd, 2024, China banned the export of antimony to the US[14]. Taking the price of antimony before the announcement as a reference, it rose by 20% when the first restriction started and finished the year 82% higher. On February 26th, it was 136% higher[15]. The most common end uses of antimony are flame retardant, transportation (batteries), chemicals, ceramics and glasses[11]. It has notable niche end use, especially in the IR market for antimonide-based detectors (T2SL or InSb), as well as chalcogenide glasses. Even if the price more than doubled for antimony, at a metal price of $50/kg, it would not have a significant impact on higher value-added markets like IR.

2.2 Arsenic

Arsenic is listed as a critical mineral by the EU[9] and US[10]. Most arsenic can be recovered from copper, lead, zinc, cobalt, gold, and silver smelting by collecting dust and fumes as arsenic trioxide[16]. About 47% of arsenic trioxide is produced in Peru, while 41% comes from China for a total 58,000 MT production in 2024. The US imported around 9,100 MT of arsenic metal and compounds in 2024, there are no current export restrictions[17]. For that reason, the arsenic metal price remains around $1.6/lb.[15]. Almost all arsenic consumption is meant for wood preservatives and agricultural chemicals[16]. Ultra-high purity arsenic mostly goes to the compound semiconductor market, driven by GaAs. Chalcogenide glasses are currently a very small market for arsenic and their low price with no commercial controls makes it highly suitable for this market.

2.3 Gallium

Gallium is listed as a critical mineral by Canada[8], the EU[9] and the US[10]. It usually is extracted as a byproduct from aluminum (bauxite) and zinc refining[18]. China dominates the production of gallium which could be above 80% (up to 1,000 MT total world production)[18,19]. Recycled gallium is also a great contributor to the supply chain because most Ga-related processes in the semiconductor market generate a lot of losses[18]. The US imported roughly 19 MT of gallium in 2024[19]. In July 2023, China announced that an export permit would be required for gallium, which was in effect on August 1st, 2023[20]. In December 2024, it was officially added to the dual-use product list and banned for export to the US[14]. From July 2023, the price increased by 40% when the export control started, to increase by 120% when it was banned and reached around 140% of its July 2023 price, today[15]. The most common end usage of ultra-high purity gallium is related to compound semiconductors (66%) and around 21% is used for manufacturing NdFeB magnets[18]. Although the price increased, it is still a fifth of the germanium price, which would make it commercially more viable than germanium in a chalcogenide glass.

2.4 Germanium

Germanium is listed as a critical mineral by Canada[8], the EU[9] and the US[10]. It usually is extracted as a byproduct from zinc refining and can also be recovered from coal fly ash. China produces most of it, which could be up to 80% (world production to be between 100 – 300 MT and hard to estimate)[21]. Recycled germanium is very important outside of China because of the lack of alternate primary sources. The US imported roughly 29 MT of germanium content in 2024[22]. In July 2023, China announced that an export permit would be required for gallium, which was in effect on August 1st, 2023 [20]. In December 2024, it was officially added to the dual-use product list and banned for export to the US[14]. From July 2023, the price increased by 8% when Chinese export controls started, to increase by 119% when it was banned and reached around 131% of its July 2023 price, today[15]. Applications like fiber-optics, infrared optics and Ge-based semiconductors account for most of the end usages. Germanium has been at the core of infrared applications, but the current geopolitical trends have made it challenging on the supply chain.

2.5 Selenium

Selenium is not part of the critical mineral list of Canada, EU and US. Most selenium can be recovered from copper refining as a byproduct[23]. About half of the selenium is produced in China (world total around 4,000 MT). The US imported less than 250 MT of selenium metal and dioxide in 2024[24]. The selenium metal price remains stable around $12-13/lb without any export control[15]. Most common usage of selenium is as a metallurgical additive. Food additive and glass manufacturing are also important[24]. Chalcogenide glasses are a small market for selenium, but its low price and no export control makes it attractive for this technology.

2.6 Sulfur

Sulfur is not part of the critical mineral list of Canada, EU and US. The most common way of extracting sulfur is from petroleum and gas, or smelter gases (copper, zinc and lead)[25]. Roughly 22% of the sulfur is produced in China (world total around 85,000,000 MT), with US, Russia and Saudi Arabia accounting for 9– 10 % each. There are also many countries contributing to 5%, which makes the offer highly diverse. The US consumed roughly 9,000,000 MT of sulfur in any form in 2024, with no current export restrictions[26]. Sulfur metal price has been slightly volatile around $100/MT 27. For such high production where most of its end usage is sulfuric acid, other applications becomes somewhat niche. Sulfur is highly suitable for chalcogenide glasses as its price is stable with a diverse supply chain and high production volume.

2.7 Tellurium

Tellurium is listed as a critical mineral by Canada[8] and the US[10]. It is mostly recovered as a by-product from copper mining[28]. Most tellurium comes from China, but it can be transformed into higher purity in other countries. The US imported around 7 MT of tellurium in 2024[29], but most tellurium is being imported as CdTe for the solar industry. Since February 4th, 2025, China requires a permit to export tellurium as it is added to the dual-use products[30]. For the second half of 2024, the tellurium price was stable around $70/kg but raised by 43% to reach $100/kg today[15]. Tellurium is widely used for thermo-electrics and is half the weight of CdTe thin film photovoltaics. Other key applications are bulk CdTe/CdZnTe crystals for radiation detectors and HgCdTe infrared detectors. Since the export license is recent, the market has not stabilized yet and it will create rarity. Availability should become easier in the midterm and would be a good option for chalcogenide glasses as the price remains lower than germanium.

2.8 Tin

Tin is part of the critical mineral list of Canada[8] and US[10]. Tin can directly come from mining or smelters[31]. 23% of tin mining is produced in China, 17% in Indonesia and approximately 10% each in Burma, Brazil, Bolivia and Peru (world total ~300,000 MT). There are also many smaller contributors, making the offer very diverse. The US consumed roughly 37,000 MT of tin in 2024, with no current export restrictions[32]. Tin metal price has been slightly moving around $30/kg for the past couple years. Around half of the tin consumed is for solders, with other important end uses such as plating, chemicals and brass and bronze alloys[31]. Tin is widely produced and is stable and low cost for chalcogenide glasses.

3. CONCLUSIONS

Chalcogenide glasses have gained renewed interest in the market due to the potential for lower cost with similar performance than germanium or other infrared optical materials. This interest has grown due to the recent introduction of material-based export restrictions for germanium and other materials from China, the largest producer of germanium in the world. The primary chalcogenide glasses contain one or more of the following elements: antimony, arsenic, gallium, germanium, selenium, tellurium, sulfur, and tin. The review of each of the elemental feedstocks for chalcogenide glass revealed significant variations in pricing, availability and competing applications. Many of these feedstocks including germanium now have export restrictions from China including gallium, tellurium and antimony. These restrictions limit global supply and increase pricing. Therefore, it is important to recognize the feedstocks within the specific chalcogenide glasses and select an appropriate material that has limited supply chain risk. It is also important to be diligent and constantly review the global export policies of these materials, in order to be prepared for future restrictions. Chalcogenide glasses have an excellent future for use in infrared systems as a more economically stable solution than germanium. Many of the ChG's however, contain germanium, so it is important to understand the impact of feedstocks in order to make an informed decision when choosing an infrared optical material for an infrared system even a chalcogenide glass.

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