Quartz is one of the most common minerals in nature. According to silicate tetrahedron, it belongs to silicate varieties — the most widespread mineral group in the earth crust. Quartz — the main source of silicon, which is the second most common element in the earth’s crust. According to Academician N. P. Yushkin [1], the role of quartz is not restricted to its use as a valuable mineral, but it can be used as an indicator of the conditions of formation of minerals, as criteria for searching and evaluating of mineral deposits and in solving environmental problems. It is enough to say that nowadays about 90 % of all semiconductors and other high-tech materials are produced from quartz or its retrieved silicon. Quartz can be used as an aesthetic object as a result of its formation in various colored crystals and ornamental aggregates, but in the twenty-first century quartz is becoming a valuable material, or according to N. P. Yushkin’s expression [2], geo-materials and the key for technical processes, which are mainly responsible for the development of various industries: optical, piezo-optical, microelectronics, semiconductor, medical, defense and energy, as well as the creation and development of solar energy cluster. Thus, the historical aspect of quartz can also be regarded as a universal material of the past, present and future [3, 4].

Élite silicon, which is the basic raw materials for concentrating and converting solar energy into electricity, is extracted from rich concentrates of high-purity quartz, which has technological properties that meet all the international standard requirements [5].

Kazakhstan is considered as a major province of quartz raw materials. In the territory of the republic there are large and widespread usable quartz raw material deposits of high geological and genetic types. Plutonogenic-metamorphic quartz veins and metasomatic types (quartzites) are most frequent in Central Kazakhstan. Quartz pegmatites are in East, Central, Southern and Western Kazakhstan [6].

Rock crystal (source of piezo-raw materials), which is the raw for optical glass fusion and reception of elite silicon, is basically located in the southwestern part of the Central-Kazakhstan region — Ulytausky zone. In this zone, which extends in the meridional direction for 400 km and in width from 70 to 100 km, there are more than 16 thousand exposed crystalline quartz veins, most of them are concentrated in 12 deposits of rock crystal. Their rock crystal is transparent and translucent and occurs in pre-crystalline and milky white quartz veins.

This quartz, unfortunately, have not been studied in detail for its suitability for solar energy purposes; and it is waiting for its turn to be studied for use as raw material for solar silicon. Therefore, based on the quartz deposits of Aktas and several other occurrences of quartz in this zone, the revision of mineralogical and geochemical data was carried out to determine the usability of their raw for high-purity quartz production.

Methods and Techniques

The applied methods and techniques are laboratory. The laboratory works are the following: 1) geochemical analyses with XRF and ICP-MS techniques, and 2) beneficiation processes by froth flotation in three stages. These stages were carried out at a fixed pH condition (5.5—6) but with various time of grinding (20, 40, 60 min respectively).

The geochemical analyses with XRF technique were carried out in the Laboratory of Continental Dynamics of Northwestern University (China), while the ICP-MS analysis was carried out in the laboratory and analytical center of Xi’an Institute of Geology and Mineral Resources (China). Beneficiation processes were carried out in the laboratory of the Center of Earth Sciences, Metallurgy and Beneficiation (Kazakhstan).

Keywords: Mineral inclusions and impurities, froth flotation, hi-tech industries, silicon carbide.

AKTAS QUARTZ IN CENTRAL KAZAKHSTAN IS IMPORTANT RAW FOR THE PRODUCTION OF HI-TECH PRODUCTS

This study presents the investigation of the Aktas quartz deposit in the central part of Kazakhstan as a potential source of high-purity quartz (HPQ) for use as raw materials for special applications in high-technical industries especially solar energy industry.

Geochemical studies revealed that the Aktas quartz deposit can be classified as pure quartz one due to its high silica content 99.21—99.29 %. Also it is characterized by low contents of Al2O3, Fe2O3, CaO, MgO, Na2O, K2O and P2O5. Therefore, the quartz of this deposit without preliminary treatment matches well the requirements of the Aluminum and Ferrosilicon alloy industries.

The beneficiation processes that applied on the studied quartz samples of Aktas to remove the excess and undesirable high contents of mineral inclusions (hematite, pyrite and magnetite) and impurities (Fe2O3, TiO2, Al2O3, CaO ... etc) are related to froth flotation in three stages. These stages were carried out at a fixed pH condition (5.5—6) but with changing the time of grinding (20, 40, 60 min, respectively).

The beneficiation of Aktas quartz with froth flotation in the 1st stage (20 min time of grinding) displayed a marked increase of the SiO2 content and decrease of the Al2O3, Fe2O3 and CaO contents to a noticeable percent, while the 2nd and 3rd stages of flotation had a negative effect on the quartz and this is reflected by the decrease of SiO2 content (98.71 % in the 2nd stage and 98.83% in the 3rd stage of flotation) and increase of Fe2O3 content (0.58 % in the 2nd stage and 0.79% in the 3rd stage of flotation), therefore the 1st stage of flotation is recommended (grinding time 20 min and the pH 5.5—6), because it gives better results.

The beneficiation processes with froth flotation at a fixed condition (pH 5.5—6 and 20 min time of grinding) allowed the use of the quartz of Aktas for the production of silicon carbide.
Geochemical characteristics of Aktas quartz

Selective representative quartz samples from Aktas quartz deposits were subjected to different investigation procedures to detect their chemical components. The results will be helpful in the first classification of the quartz suitable for industrial use without any treatment or after beneficiation. On the other hand, the presence of impurities or undesirable materials will propose the methods of beneficiation in order to enhance the use of this raw.

Whole rock chemical analyses by XRF technique

The total of 3 chemically analyzed representative quartz samples are given in table (1).

Table (1) shows that the SiO2 content ranges from 99.21—99.29 % with average content 99.27 %, TiO2 content is <0.01 %, Al2O3 content ranges from 0.03 to 0.04 % with average 0.03 %, Fe2O3 content ranges from 0.15 to 0.16 % with average 0.16 % and CaO content ranges from 0.04 to 0.05 % with average 0.04 %.

From the above stated chemical results it is clear that Aktas quartz deposits can be classified as pure quartz (SiO2 99 % to 99.5 %) deposits [7] due to the high content of SiO2. Therefore these quartz materials, without treatment, match well the requirements of the following industries: Aluminum alloy industry (Si minimum 98 wt %, Fe maximum 0.02—0.05 wt % and Ca from 0.015—0.3 wt % [8]) and Ferrosilicon alloy industry (SiO2 > 98 %, Al2O3 < 0.4 %, Fe2O3, CaO and MgO < 0.2 % [9]).

Chemical analyses by ICP-MS technique

High-performance trace-element analysis by the ICP-MS technique was carried out on the quartz of Aktas to determine its trace elements concentrations. The results of the ICP-MS analyses are given in table (2).

As shown in table 2 the quartz of Aktas has low concentrations of Li (0.5 ppm), Cu (0.01 ppm) and Zr (0.29 ppm) in comparison with IOTA-STD [10], and lower concentration of Ti (0.3 ppm) in comparison with refined IOTA-STD, IOTA4, IOTA6 and IOTA8 [10]. It also has low concentrations of Al (19.0 ppm), B (0.3 ppm) and Cr (0.12 ppm), which are close to those of IOTA-STD. These low trace element concentrations determined the quartz of Aktas as high purity quartz (HPQ). On the other hand, the concentrations of Ca, Fe, K, Na, Ni and P are noticeably high in comparison with the all IOTA analogs. These high trace elements concentrations of the quartz of Aktas require intensive beneficiation processes to reach the IOTA qualifications.

Beneficiation processes of Aktas quartz

The processing technologies have to be adapted for specific requirements of quartz raw materials. Only in the rarest instances, it is possible to use raw materials right away without some prior processing. Processing technologies therefore, play a central role in the value enhancement chain and maximum utilization of quartz. These technologies are the decisive factor in the commercial success of a deposit. Process development always starts out from chemical and physical characteristics of natural quartz. In the past, special attention was paid to the development of the processes regarding sample preparation and procedures for the detection of trace impurities in quartz up to the ppb-area[11].

Table 1

<table>
<thead>
<tr>
<th>SAMPLE №</th>
<th>AKTAS 1</th>
<th>AKTAS11</th>
<th>AKTAS111</th>
<th>AV.</th>
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</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>99.29</td>
<td>99.26</td>
<td>99.27</td>
<td>99.27</td>
</tr>
<tr>
<td>TiO2</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Al2O3</td>
<td>0.03</td>
<td>0.04</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>0.16</td>
<td>0.15</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>MnO</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>MgO</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>CaO</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Na2O</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>K2O</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>L.O.I.</td>
<td>0.26</td>
<td>0.21</td>
<td>0.25</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Laboratory tests must be done to figure out optimal process combination.

Froth flotation process

The beneficiation processes that applied to the studied quartz samples of Aktas to remove the excess and undesirable high contents of mineral inclusions (hematite, pyrite and magnetite) and impurities (Fe2O3, TiO2, Al2O3, CaO, etc) are froth flotation in 3 stages at a fixed pH condition (5.5—6.0) but with various time of grinding (20, 40, 60 min respectively).

Three samples of raw quartz were subjected to the flotation process. The resulted flotation concentrates were subjected to chemical analyses by XRF. The analyses results are given in table 3.

Equipment used:

- Russian flotation device FML with rate 1200 turns/ min, pH meter gauge.

Froth flotation steps:

The froth flotation, carried out on the quartz of Aktas, is divided into two parts: main flotation and control flotation. Before the main flotation, grinding was conducted in the presence of sodium sulphide Na2S (100 g/ton). During the main flotation the following chemicals were used:

- sulfuric acid (H2SO4) for adjusting the pH condition around 5.5—6.0 (70 g/1);
- sodium silicate (Na2SiO3) for quartz depression (200 g/1);
- collectors — oleic acid and butyl xanthate (150g/t);
- foaming agent — T—66 (60 g/t).

Also during the control flotation the following chemicals were used:

- sulfuric acid (H2SO4) for adjusting the pH condition around 5.5—6.0 (20 g/1);
- collectors — oleic acid and butyl xanthate (50g/t);
- foaming agent — T—66 (30 g/t).

As shown in table 3, the beneficiation of Aktas quartz with froth flotation in the 1st stage (20 min time of grinding) displayed a marked increase in the SiO2 content (from 99.29 before flotation to 99.60 % after flotation) and decrease the Al2O3 (from 0.03 before flotation to 0.02 % after flotation), Fe2O3 (from 0.16 before flotation to 0.11 % after flotation) and CaO (from 0.05 before flotation to 0.03 % after flotation) contents to a noticeable percent, while the 2nd and 3rd...
stages of flotation had a negative effect on the quartz and it is reflected by the decrease of SiO₂ content (98.71 % in the 2nd stage and 98.83 % in the 3rd stage of flotation) and increase of Fe₂O₃ content (0.58 % in the 2nd stage and 0.79 % in the 3rd stage of flotation), therefore the 1st stage of Floatation is recommended (grinding time 20 min and the pH 5.5—6), because it gives better results.

Discussion

The geochemical analyses that carried out on the quartz of Aktas revealed that it can be classified as pure quartz due to its high silica content, which ranges from 99.21—99.29 % with an average content 99.27 %. Also it is characterized by low contents of Al₂O₃, Fe₂O₃, CaO, MgO, Na₂O, K₂O and P₂O₅.

The high-performance trace-element analysis by the ICP-MS technique revealed that the quartz of Aktas differs from IOTA-STD refined high-quality quartz by its lower concentrations of Li, Cu and Cr close to those of IOTA-STD refined quartz. Al and Ti are used as indicator elements of the quartz quality, because they are the most common trace elements. Both elements can hardly be removed during the processing of the quartz raw materials [12]. Concentrations of < 25 ppm Al and < 10 ppm Ti are considered as high purity quartz [12]. Hence the quartz of Aktas can be classified as high purity quartz due to its low contents of Al (19.0 ppm) and Ti (0.3 ppm).

On the other hand, the concentrations of Ca, FeT, K, Na, Ni and P are noticeably high in comparison with the all IOTA analogs. These high trace elements concentrations of the quartz of Aktas require intensive beneficiation processes to reach the IOTA qualifications.

The beneficiation processes that carried out on the quartz of Aktas to remove the excess and undesirable high contents of mineral inclusions (hematite, pyrite and magnetite) and impurities (Fe₂O₃, TiO₂, Al₂O₃, CaO, etc) are froth flotation in three stages. These stages were carried out at a fixed pH condition (5.5—6) but with various time of grinding (20, 40, 60 min respectively).

The first stage of froth flotation that carried out on the Aktas quartz (pH condition (5.5—6) and 20 min time of grinding) proved its efficiency and resulted to marked increase in the SiO₂ content and decrease of the Al₂O₃, Fe₂O₃ and CaO contents to a noticeable percent, while the 2nd and the 3rd stages of flotation (pH condition (5.5—6) and 40 and 60 min time of grinding, respectively) proved its inefficiency and displayed a negative effect on the quartz of Aktas and this is reflected in decrease of SiO₂ content and increase of Fe₂O₃ content.

The first stage of froth flotation has qualified the quartz of Aktas to be used for the production of silicon carbide (SiO₂ (99.50 to 99.75 %), Al₂O₃ (0.04 to 0.05 %), Fe₂O₃ (0.05 to 0.1 %) and CaO + MgO =1.1 % [9]).

Conclusion

The high degree of purity of the quartz of Aktas has nominated and qualified this raw, even without beneficiation, to be used in hi-tech industries such as Aluminium alloy and Ferrosilicon alloy industries.

The beneficiation processes with froth flotation at a fixed condition (pH (5.5—6) and 20 min time of grinding) qualified the quartz of Aktas to be used for the production of silicon carbide.

Work was carried out at Kazakh National Technical University named after K.I. Satpayev, Almaty, Kazakhstan, Address: 22 Satpayev st., Almaty, Kazakhstan, Postal code: 050013.

References