Research area: Quartz beneficiation

Supervisors:
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Objective
Norway has had, and still has a strong mining sector, which over the last years have changed from metal to industrial minerals as products. The products are generally exported. An even stronger electro-metallurgical industry makes export products mainly from imported raw materials. However, very little refining of Norwegian raw materials takes place. In this project we aim to:

• Establish a process chain producing sophisticated products from Norwegian raw materials.
• Concentrate on silicon raw materials, because we assume there will be an especially strong development in the silicone solar cell sector. Results from this project may therefore rapidly lead to practical applications in the industry.
• Develop further Norway’s unique situation to hold a key position in solar cell production. We have a raw material base and key industrial producers already working in related segments of the industry all the way from refined quartz to silicone wafers.

Background
Quartz is found in the nature in varying purity and is traded in varying quality at strongly differentiated prices. Raw material for glass is probably the largest market, which is dominated by Belgian quartz sand. Belgian quartz sand sets the price and quality standard for such products. The same material is also used for chemical feedstock and fetches prices around 150 NOK/t. Lump quartz of reasonable purity and high thermal strength for the smelter industry may be priced at 300 NOK/t while the prices of quartz for optical purposes are not disclosed. The material chain from quartz can be drawn to metallurgical grade silicon metal from 2000 NOK/t, which also is refined by Elkem to Silgrain, trichlorosilane, silicon tetrachloride at 4900 NOK/t and semiconductor quality silicon at 600 000 NOK/t.

Special products of silicon derived from quartz are often made via the expensive routes of trichlorosiane, silicon tetrachloride or sodium silicate. Volume markets are rheology control and filler in addition to the well paying semiconductor sector. The demands of purity in the last sector are in the order of 1 ppb. The chemical refinement in several steps ensures that the demands on the raw material paradoxically are not extreme, but it makes the final product expensive.

A more promising and expanding market for quartz is solar cells. Here are the demands of purity much lower than for semiconductors, in the order of 1 ppm, but not yet well defined.

Up till now the supply of raw material for solar cells has been based upon scrap from the semiconductor production. The price of this scrap is in the order of 150-200 NOK/kg. The demand for solar cells is outgrowing that of semiconductors and the price of silicone wafers has to be reduced in order to give a competitive solar cell energy price. This means that the cost of silicone also has to be cut substantially and sufficient long term supplies of this material has to be developed. In the near future lack of sufficient amounts of cheap silicone for an expanding market may threaten the position of silicone as solar cell material no 1.
A cheaper production may be achieved by using purer quartz and thereby omitting some of the expensive chemical refining steps. Norwegian Crystallite at Drag in Nordland is already producing a few thousand tonnes of refined quartz from a local deposit. (combined amount of impurities is in the range of 1 ppm). The nucleus for a industry of considerable size do therefore exist provided large reserves of quartz and reasonable methods for beneficiation are found.

**Project**

In this project we will work with Norwegian sources of quartz. A close co-operation with the ongoing NFR project “From sand to solar cells” have to be established as alternative process paths based upon purer raw materials have to be developed as an extension of existing Norwegian technology. This is the reason why professor Otto Lohne from the Department of Materials Technology and Electrochemistry is chosen as one of the supervisors for this part of the project.

One possibility, which can be based upon existing processes, is to upgrade the Elkem Silgrain production, for such a purpose. In this process carbon reduced silica is purified to a certain degree. Use of improved quality raw materials may bring the product from this process to a stage where further removal of impurities may take place in a process combined with wafer production. Our project on pure quartz production should be aimed at making the kind of sand, which would give a cost efficient chain of value development from the raw material in the ground to the finished product.

Quartz, one of the most common minerals, is found all over Norway, some as deposits of relatively pure quartz, but mostly associated with other rock forming minerals. Generally quartz has been mined from the mono mineral deposits, although some quartz has been a secondary product when making feldspar from pegmatite and granites.

Existing Norwegian processing technology for quartz sand beneficiation is mainly based upon the Lillesand operation of North Cape Minerals, where first iron bearing minerals are removed by flotation, then feldspar is concentrated by another step of flotation. Finally the remaining iron bearing minerals are removed from feldspar is by strong field magnetic separation. The process was originally based upon knowledge from the Spruce Pine area in North Carolina. The major product from such operations is feldspar, however, but at Spruce Pine the quartz is pure enough to warrant upgrading to excellent qualities.

When the process for the Drag quartz deposit, now operated by Norwegian Crystallites, was developed, our knowledge about this technology was further refined for production of pure quartz products from a high grade deposit.

Regarding other quartz mineral deposits the technology has to be developed to remove other impurities. Critical elements for the use of quartz in solar cells are first of all boron and phosphorus as they are difficult to remove by metallurgical refining. Maximum values are below 1 ppm. for each. Calcium, aluminium and metal oxides are also unwanted. To obtain a physical removal of the last traces of unwanted elements, the elements have to be present in separate minerals of sufficient size to be liberated. The characterisation and analysis of the unwanted elements and how they are distributed in the minerals will be important. Our department has access to new advanced analysis instruments, which makes such characterisation possible.
Alternatives to traditional purification to purer sand do exist. Mechanical activation, that is disturbance of the crystal lattice of the mineral by crushing may give a more reactive quartz, which may be cleaned by weak acids such as CO$_2$. Other alternatives to increase the reactivity of quartz at relatively low temperatures and pressures may also exist.

The traditional smelting/reducing technologies for silicon, which is a path for silicon production, depends today on lumpy quartz, which is heat resistant without cracking. Little is known about the mechanism, which gives competent lumps, or how to determine without full-scale tests, which deposits are suited for this purpose. This itself is an interesting point for investigation. Furthermore the most likely product from a beneficiation process will be in the form of quartz sand. Fine grained feed will blind a smelter furnace and has therefore to be agglomerated to give the required lumpy material provided the Silgrain process should be chosen. Development of competent and cheap agglomerates including binders not adding unwanted impurities will also be an important task if this path is to be followed.

The fact is that surprisingly little research has been done to assess the different quartz types of Norway or quartz generally. The way to a process for solar cell raw material therefore possesses many challenges of a basic nature. Collaboration with expertise from the geological side to the metallurgical side is required. Because the project “From sand to solar cells” already is established, formation of such contacts is already established for this project.

Because mineral processing is a wide subject, some tasks that are of importance to other parts of the value chain may also be included.

**Industrial contacts**

We have discussed this application with Norwegian Crystallites, which at present is the only producer of highly refined quartz in Norway. The company is very interested in co-operating with us in the project. Norwegian Crystallites is backed by Hustadkalk A/S, which should have the capacity to commercialise viable research results.

Other interested parties may be Elkem, which has quartz quarries and is a major user of quartz for ferrosilicone and silicone metal production and North Cape Minerals, which has the plant in Lillesand.

Elkem is well connected to the “Sand to solar cells” programme.

**Doctoral students**

Under the programme Erik Larsen is engaged as a doctoral student and Rolf Arne Kleiv as a post doctoral student for the last part of the project.