PATH-BREAKING DIRECT-TO-SILICON (DTS) APPROACH TO OBTAIN 'CRUDE' SILICON FROM HIGH PURITY QUARTZ

D.T.Barki
Noble Energy Solar Technologies Ltd
A9, Aero View Towers, Shamlal Bldgs.,
Begumpet, Hyderabad-500016., AP, India
Tel: +91 40 27762559, 66331999
dtbarki@usa.net, info@solarnest.net,
www.solarnest.net

ABSTRACT: Ever since solar photovoltaic industry came into commercial production, it has been parasitic on semiconductor industry for wafers. As a result of the photovoltaic demand for silicon raw material is now about 55% of the total demand and by 2008, which is more than the semiconductor demand level. Solar industry is in a position to have its own source of silicon now. This will continue to happen only if photovoltaic industry gets sufficient supplies of solar grade silicon.

In order to keep up the pace of photovoltaic industry, it's necessary to have dedicated silicon production. Fortunately, photovoltaic technology does not demand higher purity of silicon as that for semiconductor technology. As also that there is large amount of high purity (HP) quartz available in the earth crust, it may be imperative that a direct process to separate oxygen from quartz to get the much required 'crude' silicon (much to the comparison of crude oil, but as a green technology!). In this paper, efforts are put in to understand the possibilities to extract silicon from quartz directly with minimum modifications in conventional arc furnaces. We call this method as direct-to-silicon (DTS) approach. Though sounds simplistic, the DTS approach opens up several path-breaking options to much-needed processes for obtaining silicon crude. This paper discusses the aspects to path-breaking approach to obtainin low-cost silicon in terms of methodolgy, material availability etc. Though we are long way to go in this direction, we have begun the most desired journey through our fresh apprach to the silicon feedstock issues.

KEYWORDS:
Silicon, PV Materials, Cost reduction

1. INTRODUCTION:

Silicon is the second most abundant element in the earth crust, in the form of oxide as sand or quartz and as silicate (in the form of granite, clay and mica). Silicon is sold in a range of purity levels, or grades. For silicon to be a useful semiconductor material, it must be highly purified. For solar cells, the silicon must be 99.9999% pure (often referred as "six nines" or 6N pure). The silicon grade used in electronics industry is even more pure, typically 9N to 11N. The type of impurities also makes a difference. While carbon and oxygen are less significant, boron and phosphorous concentrations must be managed since they are important in the electrical functioning of a solar cell.

For silicon to reach semiconductor grade whether for solar cells (i.e., solar grade, SoG) or integrated circuits (electronic grade, EG) it must undergo a significant amount of processing that consumes enormous amount of energy. Silicon that is purified for the semiconductor industry is referred to as polycrystalline silicon, or polysilicon (poly-si, or simply, poly). Silicon used in solar cells has historically come from off-spec and waste silicon, produced either during the polysilicon purification process or during ingot and wafer production. But this is no longer the only source of polysilicon for the PV industry. As demand increases, solar companies are increasingly buying higher quality silicon. An industry rule of thumb is that 10% of the polysilicon sold to the semiconductor industry will eventually become available to the solar industry. However, what is important development is that the polysilicon producers are now producing silicon specifically for PV companies. In addition, new technologies are being developed to produce silicon that caters to the PV industry.

It's, therefore, evident that there is a dire need of getting our own silicon feedstock to meet the great demand by the PV industry in the coming years. The efforts in our unique and innovative silicon project are to explore for cheap silicon feedstock, which will eventually be the reason for reduced PV costs. Even at the risk of sounding simplistic, we wish to reiterate that PV must have its own 'crude' silicon if it has to meet the tremendous expectations of the world energy needs. Although there are other cost issues associated with solar cell efficiency conversions, system level efficiencies etc, we primarily deal with the basic raw material in making solar cells. Much in intention with the mundane comparison, we wish to call this basic raw material as 'crude' silicon, which with little efforts we could extract both through the earth crust as well as the crude arc furnaces. Our extensive survey and research shows that the Indian subcontinent has high purity silica quartz with zero phosphorous and negligible boron, which makes it very good for solar cell silicon.

2. THE BACKGROUND:

Solar PV is now in a commanding position after undergoing many ups and downs for the last couple of decades. This has led PV industry even bigger challenges to face if it has to forge ahead. Finding its own silicon is this biggest challenge of all. To put it in very simplistic terms, every thing seems to be is (or coming) in place except the basic raw material - silicon feedstock. It's all about the availability, quality, efficiency, and cost of silicon that will determine the future of solar industry. The issue on hand should be so commonly discussed as if we are talking of the cost of crude oil when we want to know the cost of petrol.

On a snapshot argument: why should any serious technology depend only on age-old technology routes to get its basic raw material. Or, it is better to risk to find some breakthrough solutions. The purpose of this paper is to present a path-breaking methodology to pave way for new and innovative means of finding our own crude silicon for solar PV. Though we are far from the desired results, it is hoped that our work will lead other players to work in similar lines to bring in better and widespread solutions to obtain low cost solar silicon. Why polysilicon should cost 70$/kg? Why not $20/kg? When we posed this question, in one of the Silicon PV conference, an audience said, it's a ridiculous question. Later he had to be explained that questions are never ridiculous. Our sincere effort is to find answers to the myth that silicon has to be produced with the age-old manufacturing processes.

3. WHY CRUDE SILICON ROUTE?

3.1. The trend speaks it all:

2006: Solar PV has come out of its parasitic dependency for silicon feedstock on the long-haul of left-over of semiconductor (SC) industry. The massive expansion plans of all silicon giants (Hemlock, Tokuyama, Wacker, MEMC, REC, Mitsubishi,etc) is the proof of this basic trend. Secondly, the performance of 2006 has been PV's self-proof: the silicon consumption in PV is 55% while its semiconductor counterpart with 45%.

Look at the way the major silicon producers have taken up their production goals and new processes technologies: metallurgical route. (See Table 1:). The most striking piece of information in Table 1 is the greater number of companies planning to employ direct MG to SoG technologies as a way to reduce the cost of silicon for solar applications.

Dow Corning believes its new SoG silicon offers a unique solution to the problem The product, called PV1101, derives from the purification of metallurgical grade silicon, and is used in a blend with purer silicon to manufacture silicon solar cells. Dow Corning has already supplied a couple of companies with the product to test the new material in their own production process. The undisclosed companies have blended PV 1101 into their silicon feedstock at ratios 10% and more.

Table 1: New and existing silicon producers in 2005, projected for 2010, technology employed

Company	**2010 Production capacity (MT) Projected/ Potential**	**Technology (Siemnes, FBR, VLD, MG to SoG)**
DC Chemical	3000/--	Siemens
Hoku	1500/--	Siemens
Isofoton et al.	2500/--	Siemens*
French consortium	2000/3000	Siemens*
Crystal	1200/--	Siemens
Russia/FSU	--/14500	Siemens*
M.Setek	6000/--	Siemens*
Elkem	5000/10000	MG to SoG
JSSI	850/--	Silane to SoG
ARISE	--/2000	MG to SoG*
JFE Steel	100/--	MG to SoG
SolarValue	5300/10000	MG to SoG
Global PV Specialist	--/2000	MG to SoG
Total China	7300/22100	Siemens*
Total	34,750/63,600	

Dow Corning has ambitious plans of raising its blend ratio to 80% by 2010. The Norwegian Elkem Solar, a division of Elkem As produces the precursor feedstock for polysilicon production, silicon metal. The company claims to have 50% of the silicon metal market. Elkem Solar has been developing a new process for solar grade polysilicon production. Currently in pilot scale production, expects to be producing on a commercial by 2007.

Dow Corning and Elkem's contribution to the future silicon supply is important for two reasons. First, they would constitute a large percentage of the total production capacity available by 2010. Second, the silicon will be solar grade, and thus expectedly lower in cost. In addition, there are companies such as JSSI, SolarValue, JFE Steel, ARISE, and Global PV specialists who have wisely and daringly taken up the route of MG to SoG, who support indirectly that the MG route is the sustainable business approach to the sustainable solar technology deployment. Importantly, there are no new surprises in this approach as the silicon purification process is of Siemens method which has been mastered over several decades and the entire silicon industry is comfortable with it.

It's rather imperative that the silicon giants concentrate on building their technology and capacity to meet the burgeoning silicon requirement by PV sector. This time, it should be on a long term, economical and environmentally benign way. Therefore, it is becoming necessary to have forthright silicon processing steps that lead to uninterrupted supply of silicon feedstock to the growing PV industry. In this direction, the first and foremost step is to ensure the low cost, high efficiency/yield starting 'crude' metal (Si) – silicon metal is the popular usage of commercial terminology by the PV industry to describe metallurgical grade silicon.

It's interesting to note that the earth crust hosts such near-silicon material and it's our efforts that are required now to look in this provocative direction. Without the path-breaking routes, it may be difficult to make the sustainable solar energy technology sustain as a full-blown commercial business in line with any other conventional energy options (oil, coal based).

It is evident that we need a lowest cost feedstock required to meet the expectedly large quantity of polysilicon demand year after year.

3.2 Costs matter most

Irrespective of the technological excellence and progresses, what ultimately matters is that whether the solar energy services are affordably made available to the doorstep of the common man or not. It is very easy to find out whether we have succeeded in this direction or not today. The quick indicator is that, we are not. The most predominant reason is that the PV costs are dictated by silicon feedstock stock. Then the obvious focus of the industry is to address this cost issue. While the PV industry has constant growth rate of over 40% over the last decade, it is unfortunate that the PV costs have not declined. Nevertheless, the trend has begun to show up in the direction of reducing the overall costs. The crude silicon costs matter most in bringing down the ultimate energy cost.

4. THE METHODOLGY

4.1 What is crude Silicon?

As already mentioned, we strive to achieve new and cheaper way to get low cost silicon feedstock, which we term as 'crude' silicon. It is our belief and finding that the earth offers the best (silica/quartz) silicon material in its highest purity levels that the scientific world should explore to get the silicon at lowest costs.

Table 2: Detailed analysis of elements of Noble High purity Quartz

Elements	**Noble Quartz (Sio2-99.99%)**	**Element s**	**Noble Quartz (Sio2-99.99%)**
Li	2.5	Sc	-
Be	-	Ti	2.9
B	0.23	V	-
O	Matrix	Cr	-
F	-	Mn	-
Na	1.0	Fe	-
Mg	0.32	Co	-
Al	18	Ni	-
SI	Matrix	Cu	-
P	-	Zn	-
S	0.24	Rb	-
CI	7	Zr	-
K	-	Ba	-
Ca	-	Ta	Electrode

We have also found that there is black silica that has less oxygen, which lends itself in an easy way to break the oxygen out from SiO2.It means that the arc furnace demands lower power consumption. We expect to get silica with as low as oxygen, which is very easy to process to get the silicon through reduction processes. Our small scale experiments indicate that we should be able to demonstrate the best use of crude silicon for large scale production with ultimate goal to reduce the cost of silicon feedstock to a larger extent. As it is highlighted in this paper about the metallurgical grade (MG) to solar grade (SoG) is the definite futuristic silicon process routes, the crude silicon would become more and more necessary.

4.2 Nature has it all.

Our continuous research on the quality of silica quartz material that is present in the earth crust has led us to believe that we are not far from the days when we will be able to produce crude silicon as easily as crude oil is being extracted. Just as several metal compounds are available in the earth, the metal elements are also available in their pure form. We are able to get high purity silica quartz with no traces of phosphorous and negligible boron, with less than 30% oxygen, which could make it very easy to breakaway oxygen with lesser amount of power consumption.

Figure 1: View of NEST's Quartz Mines

The above picture shows the quartz mine where we find the purest form of silica quartz. We have found that the there are two types of materials, which are of potential raw material for the production of crude silicon. One type is with snow white color with excellent matrix of SiO2 (Figure 2).

Figure 2: Snow white Quartz

Whereas the second type with traces as black material, as if it is grey silicon .This is obviously due to less oxygen content in the silica.

5. ANALYSIS OF ELEMENTS, TRIALS AND RESULTS ON MAKING CRUDE SILICON:

Based on research work that started over 3 years ago as a way to find silicon at 'throw-away' price, we have run-through some trials of extracting crude silicon. We admit that our initial trials for obtaining 'crude' silicon are using rather crude methods where efficiency to remove impurities has been low but enough to make many grades with our own high purity low- cost quartz with no traces of phosphorous and negligible traces of boron. The advantage with our approach is that we have found low-boron and nil-phosphorous HP quartz than any other known or published sources for the purpose so far. See the following comparative results.

Table 3: Our HP quartz comes with lowest possible boron and phosphorous concentration as extracted from the earth crust

Element	**Concentration (ppmwt)**	
	***Noble Quartz**	**Other best-claimed Quartz**
B	0.23	2.0
P	0	13

*****_Noble is the first word of our company name, which is used for describing the unusually high purity n-B and z-P quartz. n-B: negligible-boron; z-P: zero-phosphorous_

While the other companies with lowest B/P impurity quartz are boasting of certain minimum levels and set serious target to reduce these impurities, we have discovered HP quartz far exceeding the desired or expected purity levels straight from the earth (without additional cleaning processes).

The best attributes of our breakthrough approach are a) high purity quartz with highest matrix of SiO_2, b) Low boron and phosphorous in the as-extracted quartz, and, c) Quartz with very low oxygen (30%). These attributes are going to help us in a long way to bring down the cost of basic feedstock. We are striving to adopt cleaner and modified approaches to avoid adding impurities to the process and trying to clean them up later, when we start with the least of the impurities on hand. We know that it is not as simple as it is said. But we have the path that is now broken to be perfected over immediate future. We have designed several experiments and planned for pilot production by 2010. The priority patents are being obtained for our approach to producing silicon feedstock.

7. SUMMARY:

The fast growing solar industry needs its own dependable source of silicon feedstock. Most widely followed and adopted process is MG to SoG route, characterized by many giant silicon producers. Low cost and uninterrupted bulk supply are the longstanding solutions for the sustainable solar energy to become sustainable as a business energy option in the midst of existing energy options. Cheap and almost naturally available crude silica – 'crude' silicon – is what is the need of the hour. We have found large deposits of high purity silica with low oxygen content also. Most importantly, the low boron and low phosphorous quartz is available to get the 'crude' silicon as easily and cheap way. Our trials show that we will be able to demonstrate processing of 'crude' silicon by 2010 in a pilot scale.