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Challenging Issues of Silicon Manufacturing Technology in Bangladesh

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Abstract: The knowledge related to available high-quality sand deposits, Si manufacturing process and different challenging issues in manufacturing is essential for developing the silicon industry in Bangladesh, which is addressed in this article. For high-tech applications, the primary element silica needs to be 98% pure, at least. A case study in Bangladesh shows that Bipinganj sand, with the high quartz percentages, low moisture content, is suitable for the industrial-grade silicon production. No trace of Boron content has been found in the sand of Shameshwari river near Bipinganj locality. Some other potential sand deposits in Bangladesh which contain a high amount of silica are Balijuri of Sherpur district, Moulvibazar, Dakshin zangal of Hathhazari Upazila in Chittagong district, Chauddagram of Comilla district and Shajibazar of Habiganj district etc. Metallurgical grade silicon (MG-Si) is the precursor for the solar grade (SoG) and electronic-grade silicon. In photovoltaic and electronic applications, an electric arc furnace is used for the growth of MGS. Some parameters, such as furnace temperature and heat loss, need to be considered for good quality material production. MG-Si can be produced through both carbon reduction and magnesium reduction processes. Mg reduction is comparatively expensive. Silicon production from waste glasses can be a potential technology for MG-Si production in respective to Bangladesh.

1. INTRODUCTION

Most of the semiconductor devices are built on silicon wafer. The basis of electronic industries is semiconductor devices, and it is one of the largest industries in the world [1]. Silicon is the second most abundant element in the crust of the earth. It is found in a form of rocks, sand, clays and soil. The silicon present in those elements is combined with oxygen as silicon dioxide or as silicates. Different countries like China, Russia, USA, Germany etc. dominate the electronics market because of their technologies to extract highly purified silicone from the silicon ore [2]-[4]. Applications of Si wafer are versatile from photovoltaic (PV) technology to integrated circuit (IC) where several components (active and passive) such as resistors, diodes, transistors etc. and external connections are fabricated. Silicon generally extracted from high grades silica content sand and highly purified silicon (99.999999%) is required for electronic devices. More than 300 steps are needed to transform sand into silicon. But the whole process can be grouped into 10 main areas. The kind of furnace that is now used to produce silicon, the electric arc furnace, was first invented for steel by French inventor Paul Louis Toussaint Heroult in 1899. In 1905, the first United States electric arc furnace was constructed in Syracuse, New York. In recent years, furnace technology has improved concerning the electrodes used as a heating element. The study's objective is to highlight the challenges and difficulties in the fabrication of metallurgical and electronic grade silicon for Bangladesh. Some leading semiconductor development companies in Bangladesh are Ulkasemi, Neural Semiconductor of DBL group. This article will help the investors, stakeholders; policymakers invest in growing up silicon manufacturing industries in Bangladesh.

2. RAW MATERIALS

The reaction of silica and carbon manufactures silicon. Usually, silica is produced as the gravel of metallurgical grade. The coal is

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usually of low ash content so that the impurities can be minimized, containing carbon of about 60%, and is sized in a way so that it can match with the size of the gravel. Wood chips usually contain hardwood of 1/2 x 1/8 inch size (1 x. 3 cm size). Table 1 shows an overview of sand deposits in Bangladesh. In Balijuri, Sherpur district, there is a 59610 square meters of sand deposit of 0.64 million tons. Other places such as Hobigonj (Noyapara Shahibazar), Comilla (Noyapara Chauddagram), Shunamgonj (Lalghat Lakma), and Dinajpur (Barapukuria) are also essential sources of sand.

Table 1. Reserve silica sand in Bangladesh [5], [6].

Area	District	Placement (from surface, m)	Thickness (m)	Coverage (sq. km)	Reserves (million tons)
Balijuri	Sherpur	0.15-2.4	0.15-2.6	30 lenses 0.596	0.64
Noyapara Shahibazar	Hobigonj	0.15-1.2	0.15-1.8	Length 15 km Width 0.5-1 km 36 lens; 0.98	1.41
Noyapara Chauddagram	Comilla	0.5-3.5	0.25-1.7	Length 16 km Width 0.5-1.5 km 34 lens; 0.234	0.285
Lalghat Lakma	Shunamgonj	23.78, 72.95 Two layers	1st layer 1.22 2nd layer 1.83	164m	2.25
Madhypara	Dinajpur	110-130	5.2-16	1	17.25
Barapukuria	Dinajpur	118-180	16.48-40.86	1	90

Sands from different reverses such as Jamuna, Tista, Gorai and Brahmpaputra are also potential silica resources with some limitation for the possible use in fabrication of high tech grade silicon[7], [8]. Amounts in % of several compounds in sand collected from the reversed Jamuna, Gorai and Brahmpaputra are shown in Table 2. The highest amount of silica presents in the rever of Gorai (94.4%), then Brahmpaputra (83.34%) and followed by Jamuna (81.39%).

Table 2. Composition of sand collected from Jamuna, Gorai and Brahmpaputra revers [7].

Sl. No.	Name of	Amount (%)		
	Compound	Jamuna	Gorai	Brahmpaputra
1	SiO_2	81.39	94.4	83.34
2	Al_2O_3	8.41	2.7	7.5
3	Fe_2O_3	0.20	0.18	0.19
4	CaO	1.92	0.61	1.87
5	MgO	00	00	00
6	Na_2O	1.81	0.39	1.60
7	K_2O	3.67	1.25	3.29
8	ZrO_2	2.00	0.27	1.64
9	BaO	0.14	0.10	0.13

The sands collected from these reverses can be upgraded with a higher silica content by some physical separation techniques such as density-based separation, electric and magnetic separators, etc. The amount of enrichment of silica can be achieved from 60-70% to 94% [7]. On the other hand, sand from Shameshwari rever, Bipinganj (Sub-district Durgapur, District Netrokona) [9] possesses high potentiality for the production solar grade silicon. The silica content in Bipinganj sand is relatively high, near about 97% and low moisture content [9]. Moulvibazar, Sylhet region is another very potential area for high-quality sand [10], [11]. There is near about 91% silica content in sand collected from sand deposit placed at Mokam Bazar, Moulvibazar [10]. The sand quality and silica content can be further improved by acid washing treatment. Table 3 depicted the effect of washing on the sand composition. The silica content of Sylhet sand is improved from 86.85% and to 95%. On the other hand, the silica content of Bipinganj sand is improved from 97.05% and to 99.18% [6].

Table 3. Effect of washing on the composition of sand (XRF analysis)(reprinted from [6]).

Sand (location)	Composition (wt%)						
		SiO_2	Al_2O_3	Fe_2O_3	ZrO_2	TiO_2	Cr_2O_3
Sylhet	Before wash	86.85	5.62	3.17	-	0.26	0.69
	After wash	95.31	3.60	0.78	-	-	0.05
Bipinganj	Before wash	97.05	0.90	1.12	0.02	0.19	0.43
	After wash	99.18	0.36	0.13	-	-	-

3. METALLURGICAL GRADE SILICON

Metallurgical grade silicon (MG-Si) is a 98% pure silicon with major impurities of aluminium, iron, and calcium [12]. MG-Si has a wide range of industrial applications. It is not only used in the production of hyper pure electronic grade Si, which is used in the electronic industry but also used as a deoxidizer in the steelmaking industry, making organic silicone products and an alloying element in aluminium industries [13]. MG-Si is usually produced by the carbothermic reduction process where silica is reduced by carbon. Silica sand is also known as Silicon dioxide, mixed with carbon and heated in an arc furnace beyond 2000 °C temperatures. The carbon reacts with the oxygen at that temperature so that it can become carbon dioxide. As a result, pure silicon is stored at the bottom of the furnace.

$$SiO_2(s) + 2C(s) \rightarrow Si(s,l) + 2CO(g)$$
$$\Delta H2000^\circ C = 687\ kJ/mol \tag{1}$$

Equation 1 is the overall reduction process reaction taken by several sub reaction steps inside the furnace. In this process, metal carbides first form at low temperatures. After that, when silicon forms, it displaces the carbon from it. The refining process for further purification follows this process.

3.1 Reduction Process

3.1.1 Carbon Reduction Process

The crude materials are gauged and afterwards set into the heater through the top utilising the smoke hood, basins, or vehicles. An average clump contains 1000 lb (453 kg) every one of rock and chips and 550 lb (250 kg) of coal. The cover of the heater, which contains terminals, is put into position. Electric flow is passed through the anodes to frame a circular segment. The warmth created by this circular segment at a temperature of

4000° F or 2350 °C that softens the material and results in the response of sand with carbon to shape silicon and carbon monoxide. This procedure takes around six to eight hours. The heater is continuously accused of the groups of crude materials. This silicon is then treated with oxygen, so the impurities, for example, calcium or aluminium, are decreased and leaving what's known as metallurgical grade Silicon (MGS), which is 99% pure. However, obtaining low levels of boron as an impurity can be useful as it acts as a dopant for silicon, and also it is challenging to remove. The downside of this process is that it is intensive in terms of energy and raw material. Figure 1 shows the overall reduction reaction of SiO_2 held in the furnace, which also involves the formation of SiC and SiO as intermediates. Initially, SiO and CO are produced by the reaction of molten SiO_2 and C, which takes place in the arc between the adjacent electrodes. The products then flow through the cooler region (1600°C to 1700°C) to form SiC. The generated SiC then reacts with the molten SiO_2 to get the desired product, which is molten silicon along with byproducts SiO and CO.

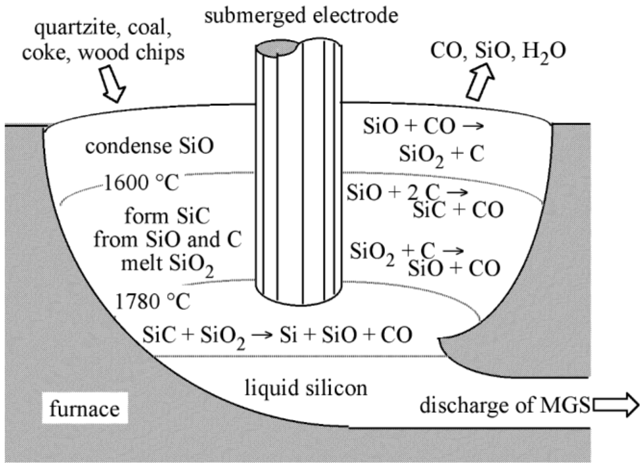

Figure 1. Electric arc furnace (submerged electrode) for the production of metallurgical grade silicon (reprinted from [14]).

3.1.2 Effect of Carbonaceous Materials on the Production Process

Energy and carbonaceous reluctant materials consumption is an important factor that influences the cost of silicon production in industries by governing the exergy and power consumption of a silicon furnace [15]. It has been found that the higher capacity (12.5MVA) submerged EAF is suitable for the use of lower carbon content coal (56 wt% C) as a reducing material. And lower capacity EAF (8MVA) is more suitable for high carbon content coal such as petroleum coke (petcoke 89.9 wt% C) [15]. It is also seen that petcoke has a more significant impact on exergetic efficiency than coal. Since petcoke has a lower reactivity due to the carbon lattice structure, it is graphitized at a temperature that is below that of the coal. Hence it is deduced that as the graphitization of carbonaceous materials rises, their resistivity deteriorates substantially, which leads to the Ohmic loss in the electrical system and thus deteriorating the furnace efficiency [15].

3.2 Silicon Manufacturing From Wasted Glasses

Manufacturing silicon from wasted glass has been an uprising demand in present silicon manufacturing industries due to its green and economical process. Silicon can be directly manufactured from glass bottles via Magnesiothermic reduction. A soda-lime-silica type of glass (glass bottles) with a high silicon dioxide content is used as the quartz source. Figure 2 shows silicon production through Magnesiothermic reduction of glass. The magnesiothermic reduction process is implemented to derive the interconnected silicon network from the glass. This method is used to reduce the silicon dioxide to nanostructured silicon because of its low operating temperature compared to carbothermal reduction (which destroys the original morphology of silicon dioxide). This allows producing a high yield of silicon. To reduce the quantity change in glass derived-silicon (gSi) during lithiation and delithiation process, a considerable quantity of sodium chloride is mixed with the quartz, which produces a cross-liked structure magnesium reduction process (exothermic) takes place. This process produces a vast amount of heat [16].

$$2Mg(g) + SiO_2(s) \rightarrow Si(s) + 2MgO(s)$$
$$\Delta H = -546.42\ \text{kJ/mol} \qquad (2)$$

$$2Mg(g) + Si(s) \rightarrow Mg_2Si(s)$$
$$\Delta H = -318.91\ \text{kJ/mol} \qquad (3)$$

This heat can fuse the silicon, which destroys its structure. The use of sodium chloride acts as a heat scavenger, which extracts a considerable portion of this heat. It has been proved that this protects the surface structure of silicon after the reduction process. Magnesium oxide and magnesium silicide also help to retain the structure of silicon.

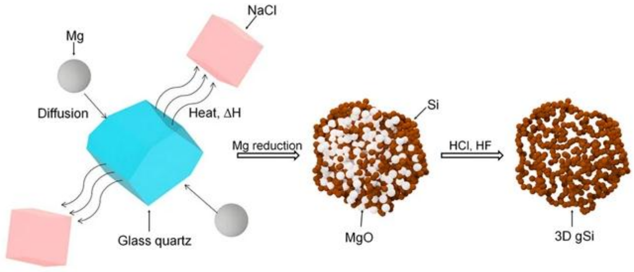

Figure 2. Diagram of silicon production through Mg reduction along with the use of NaCl as heat scavenger (reprinted from [17]).

It is then crushed into raw quartz, followed by mechanical milling to decrease the quartz size. The quartzes are then distributed in isopropanol (IPA) by ultra-sonication. The large size quartzes are settled at the bottom while the smaller ones remain floated in the IPA. The floated quartz is dried and mixed with sodium chloride, which acts as a heat scavenger and helps retain silicon dioxide. It is then mixed with magnesium for the reduction process of silicon dioxide. After cooling, the resultant product is washed with deionised water to remove sodium chloride. The yield of glass derived silicon reduced from glass powder has an approximate theoretical yield of 46.7%, which gives this procedure an industry level production method. Also, the magnesium reduction process is cheap and straightforward. Figure 3 shows all the various ways of manufacturing nanostructured silicon. One standard method is the pyrolysis of silane through chemical vapour deposition produces nanostructured silicon. Even though it has stable cycling but due to the consumption of enormous energy and costly toxic substances, it is unsuitable for large production. Another way of manufacturing silicon is the electrochemical anodization of silicon wafer in a toxic environment. But due to the highly expensive procedure, it is not suitable for mass production. Hydrolysis of tetraethyl orthosilicate (TEOS), followed by the magnesium reduction, is another technique to manufacture silicon. It is also an expensive procedure. Finally, silicon is also produced from glass bottles or any other form of the wasted glass followed by the magnesium reduction to produce nanostructured silicon. It is considered a green and economical process.

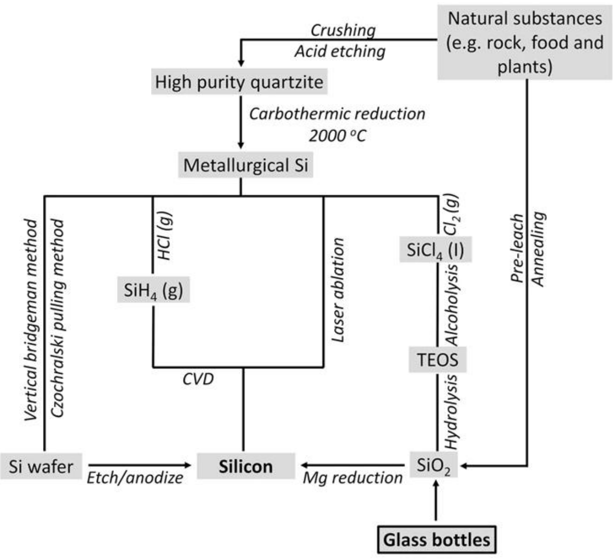

Figure 3. Flow chart silicon synthesis by Mg reduction process from waste glass bottles (reprinted from [17]).

4. ELECTRONIC GRADE SILICON

Though MGS is produced on a large scale, extreme purification is needed for electronic device fabrication to produce electronic-grade silicon. Table 4 shows the typical maximum allowable impurities concentration of solar grade silicon. The amount of oxygen and carbon should be not exceeding 1 ppm or 5×10^{16} atoms/cm^3. The formation of EGS from MGS is accomplished through chemical purification processes. The process involves converting silicon to the purified trichlorosilane gas and then reduced to obtain silicon [14]. The metallurgical grade silicon is refined when it is ground into the fine powder. Then HCl is added to it, and this mixture is heated by placing it to a fluidized bed reactor at a temperature of 300° C. As a result, a liquid silicon compound is produced known as trichlorosilane. This procedure is called chlorosilane process, otherwise called Seimens process. It includes chlorides of undesirable components, for example, iron, aluminum, boron, and phosphorus. These are expelled by fragmentary refining, and the trichlorosilane is disintegrated in hydrogen at 1000 °C [18]. An electrically warmed, ultra-unadulterated silicon pole gathers the silicon, and the outcome is electronic-grade silicon. Its immaculateness: 99.999999%. Electronic-grade silicon is otherwise called semiconductor-grade silicon (SGS). Figure 4 shows the flow of reaction during the formation of EGS in chlorosilane process starting with MGS and including recycling the byproducts ($SiCl_4$, H_2, and unreacted $SiHCl_3$), which will eventually help them to achieve higher efficiency. $SiHCl_3$ is distilled in order to produce extremely pure trichlorosilane, followed by a Chemical Vapor Deposition process to get high purity Si. EGS is the crude material for the development of monocrystalline. The reasons for the predominant use of $SiHCl_3$ in the synthesis of EGS are as follows: [14]

- $SiHCl_4$ can be effortlessly framed by the response of anhydrous hydrogen chloride with MGS at sensibly low temperatures (200 - 400 °C)
- it is fluid at room temperature, so filtration can be cultivated utilizing standard refining procedures
- it is handily dealt with and if dry can be put away in carbon steel tanks
- its fluid is effectively disintegrated and, when blended in with hydrogen, it very well may be moved in steel lines without erosion
- it can be decreased at barometrical weight within sight of hydrogen
- its affidavit can happen on warmed silicon, consequently disposing of contact with any remote surfaces that may pollute the subsequent silicon and
- It can respond at lower temperatures (1000 - 1200 °C) and at quicker rates than does $SiCl_4$

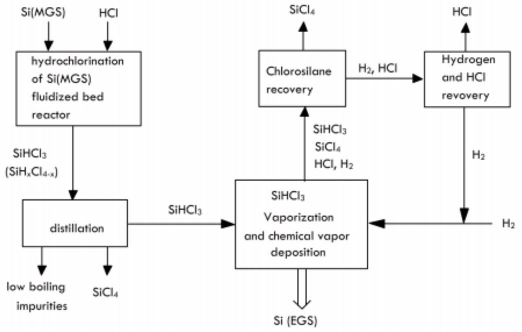

Figure 4. Schematic of the method for acquiring EGS by purifying MGS (reprinted from [14]).

Table 4. Chemical impurities in solar grade silicon [19].

Element	ppm	Atom/cm^3
Oxygen(O)	1	5×10^{16}
Carbon (C)	1	5×10^{16}
Boron (B)	0.5	2.5×10^{16}
Phosphorus (P)	0.025	1.25×10^{16}
Arsenic (As)	0.025	1.25×10^{16}
Fe, Al, Cr, Ni, Ti, Mo, V, Cu, Zn	maximum 0.1	0.5×10^{16}

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5. SINGLE CRYSTAL GROWTH

Nevertheless, electronic-grade silicon is not ideal for wafer fabrication, as it has a polycrystalline structure. This means it's made up of lots of tiny silicon crystals, and the joints between these crystals will suffer from defects known as grain boundaries. These boundaries can interrupt electronic signals, so the silicon structure has to be modified into monocrystalline silicon. The two most popular ways to grow monocrystalline from polycrystalline silicon are followed by the Czochralski method (CZ method) and Float Zone Method (FZ method).

5.1 Czochralski (CZ) Method

The Czochralski process derives from J. Czochralski, who found out the speed of metals crystallization by dragging mono- and polycrystalline against gravity out of a melt that is placed in a crucible. A quartz crucible is used in this method where the silicon is melted at a temperature beyond its melting point (1414°C). After that, a tiny crystal that acts as a seed needs to be dipped into the molten silicon. While it rotates entirely in the opposite direction of the crucible rotation, it is drawn outwards. Because of this, silicon is attracted to the seed from the crucible, developing called a boule. A boule or ingot is a rod crafted from a single silicon crystal, and its size depends on the temperature. In Figure 5, there is a quartz crucible surrounded by a heater in which silicon is melted. It shows how a seed (monocrystalline) is introduced to the molten silicon and how a single crystal is pulled out of that. Throughout the transformation, it can be seen that the direction of rotation of the crucible is exactly opposite as that of the seed.

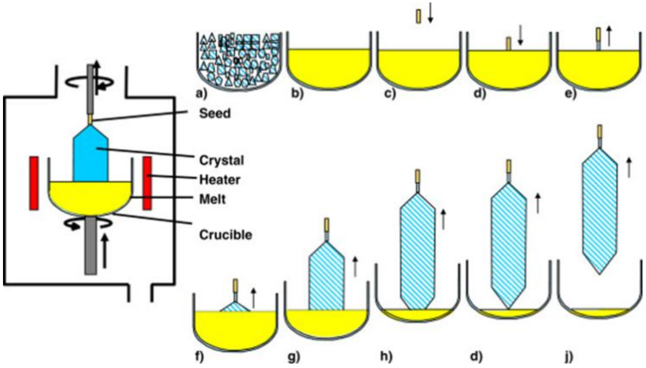

Figure 5. Schematic of crystal pulling by CZ method (reprinted from[20]).

Oxygen has some good properties in this case. Oxygen serves as an acquiring agent in the crystal (Internal Gettering) for trace metal impurities, and it can pin dislocations that significantly reinforce the crystal. Oxygen precipitates accumulating defects in the center of the wafer, and oxygen makes the Si more resistant to thermal stress during processing. That's the reason why CZ-Si is used for integrated circuit production, where there are several thermal processing steps. The debasement fixation contained in the crystal usually is not the same as the polluting influence centralization of the liquefy (fluid) at the surface, as the crystal is expelled from the dissolve. The debasement with the most elevated fixation in silicon CZ is consistently oxygen. Run of the mill measures of oxygen and carbon are [O] 5-10^{17}cm^{-3} and [C] 5-10^{15}cm^{-3}. The dissolvability of O in Si at the softening point is 10^{18} cm^{-3}, yet at room temperature diminishes by a few sets of size; consequently, the main impetus for oxygen precipitation is available. The high grouping of oxygen can likewise prompt the arrangement of undesirable electrically dynamic imperfections. These are oxygen-related thermal double donors (TDD) and shallow thermal donors (STD), essentially changing the material's resistivity.

5.2 Float Zone (FZ) Method

The floating zone (FZ) process is based on the principle of zone melting. Silicon single crystal production takes place in an inert gaseous environment or under vacuum. The process starts with a high-purity polycrystalline rod and a monocrystalline seed crystal placed in a vertical position and rotated face to face, as shown in Figure 6. The rod is partly burned with a radio frequency. The seed is brought up from below to come into contact with the drop of the melt produced at the poly rod's tip. As the liquid region is passed along the polysilicon, the molten silicon solidifies into one single crystal and, at the same time, purifies the substance. Therefore FZ silicon can easily achieve much higher purity and higher resistivity [21].

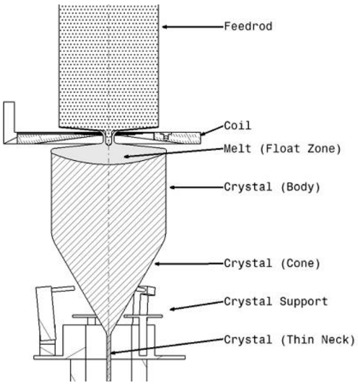

Figure 6. Schematic of FZ process for single crystal manufacturing(reprinted from [22]).

Since the melt never comes into contact with anything other than vacuum (or inert gases), there is no absorption of impurities picked up by the melt by dissolving the crucible material as in the process of CZ crystal growth. This is particularly true for oxygen, which is not avoidable in the growth of CZ crystals. Hence, FZ crystals are always used when concentrations of deficient oxygen are necessary. However, on the off chance that we think about mechanical quality, it has been perceived for a long time that FZ silicon, which contains fewer oxygen pollutions than CZ silicon, is precisely more fragile and progressively powerless against thermal stress during gadget manufacture. High-temperature handling of silicon wafers regularly delivers enough thermal stress to produce slip separations and warpage during electronic gadget fabricating. These impacts realize yield misfortune because of cracked intersections, dielectric absconds, and diminished lifetime just as decreased photolithographic yields because of wafer levelness corruption. So It is clear that separations are created at the

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soften contact during the seeding activity because of thermal shock [23].

6. FURNACE DESIGN

An electric arc furnace (EAF) is one that heats charged materials in an electric arc. Furnaces used in the industry vary in size from small with a capacity of about 1 ton-400 ton units used for secondary steelmaking. The industrial temperatures of the electric arc furnace can hit 1,800 °C (3,272 °F), while the laboratory versions can reach 3,000 °C (5,432 °F). Arc furnaces vary from induction furnaces, in where the charging material is explicitly subjected to an electric arc, and the current flows through charged material throughout the furnace ports. For example, in an electric arc furnace used for MGS production, as shown in Figure 7, when power is fed to the furnace, there is current flow between the graphite electrodes and the grounded neutral connection. The arc formed between the electrodes generates a huge amount of direct and radiant heat due to the high voltage, which eventually melts the raw material placed in the furnace. The EAF consists of the following components: (i) Furnace structure: refractory-lined steel vessel. (ii) Electrodes and electrode clamping/closing/opening system, (iii) Fume extraction system, (iv) Furnace tilting system, and (vi) Electrical system: Transformer, cables, and accessories and control system [24].

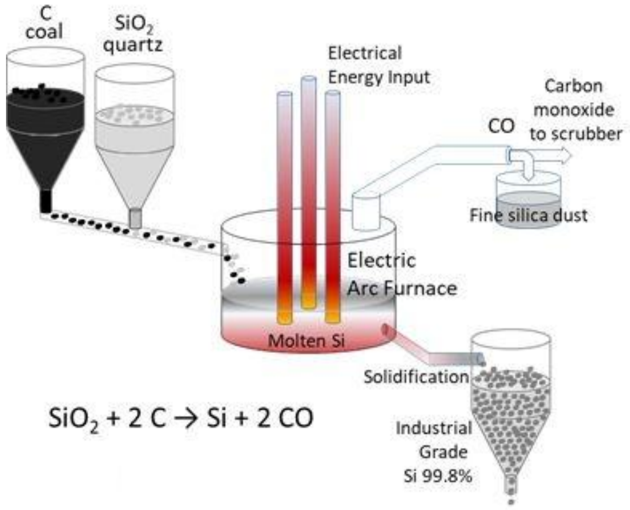

Figure 7. Basic design of Electric Arc Furnace for pure Si production (reprinted from [25]).

6.1 Crucible Design

The crucible is indeed the component in which the Si production is to be made. It has to meet specific criteria: good electrical conductivity, a melting level of more than 2100°C, good corrosion resistance and, in specific, no chemical process infection allowed. Graphite, whose melting point is 3499.9 ° C, and that is a great electrical driver; furthermore, it is among the natural carbon allotropies. This would also not alter the chemical reactions that are performed within the furnace. The relationship among both the crucible's diameter and height can be as follows as equation (4).

$$D=5\times H \qquad (4)$$

Where, D = Bath diameter and H = Total depth of the bath. Approximately 1/5 of the total bath depth is the height of the spherical section. The conical part depth is 4/5 of the total depth of the bath.

6.2 Electrode Design

The role of the electrodes in the use of the EAF is of utmost importance. Electrodes permit electrical power to be transmitted from the generator to the load stored in the furnace. The diameter of the electrodes d (cm) can be calculated using the following formula [26]:

$$d = (0.406\times I^2\times \delta/K)^{1/3} \qquad (5)$$

Where d is the diameter of the electrodes (cm), I = current (A), δ= electrodes resistivity (500 °C), $\delta = 10\ \Omega\ \mathrm{mm}^2/\mathrm{m}$ for the graphite electrodes, K= Coefficient for the graphite electrodes, $K=2.1\times 104\ \mathrm{W/m}^2$. The usage of electrodes while being used is primarily due to two pathologies: (a) Graphite sublimation up to the electrode level (level wear), (b) Lateral oxidation enhanced by high electrode temperatures. Both processes have a virtually equivalent incidence.

6.3 Electrode Holders Design

The clamp-on in which the electrodes are held, on one side, to support the electrodes and, on the other, to carry the current. It was thus selected to assign the red copper component because of excellent electrical conductivity. Three electrodes were installed to guarantee uniformity of the temperature. The electrode holders are fastened to supports constructed of polyamide and stainless steel, which ensures electrical insulation.

6.4 Heat Insulation of the Engine

The task is at a temperature that can reach 2100 °C within the engine and surpass the 2000 °C. Stainless steel has been used as a product for the engine. The solubility of stainless steel is around 1400 °C, thus by restricting to shield the engine from this high temperature by decelerating the diffusion of heat which allows saving energy. The insulation material should have a low coefficient of thermal conductivity. Hence, refractory brick was selected in this criterion. Thus, a low brick width would have been adequate to get good thermal insulation. The refractory brick guarantees our engine's strong thermal insulation, although it is prone to sterilize the materials from the chemical reactions stored within the crucible. Thus a coal seam is inserted with a robust thermal insulator and therefore does not sterilize the chemical processes products. To prevent impurities due to the use of coal, a degasification with nitrogen is done to remove any contaminants on the surface, such as hydrogen.

7. CHALLENGING ISSUES

Currently, CMOS technique is employed for IC fabrication, which uses a pair of transistors, one of which uses electrons, and the other holes created because of the electron. But electron-hole mobility in silicone is minimal, so this is an obstacle to higher performance – so much so that manufacturers have had to boost it for many years by mixing germanium with silicon. The second problem with silicon is that output severely degrades at high temperatures. Modern ICs with billions of transistors produce tremendous heat, and because of this, so much effort is needed to cool them. Eventually, silicone transmits very little light. Silicon, oxides, germanium, and III-V materials are crystalline structures that rely on their properties for the integrity of the crystal. It can't be just thrown them in silicon together and get the best of both. The big ongoing technical challenge is dealing with this problem, the crystal lattice mismatch. Crystal defects present in the material which are mentioned in Figure 8 can cause interruption to the electronic signals. The defect thus affects the electrical, mechanical and optical behaviour of the silicon. There are mainly three types of crystal defects. They are point defect, dislocation and growth defect.

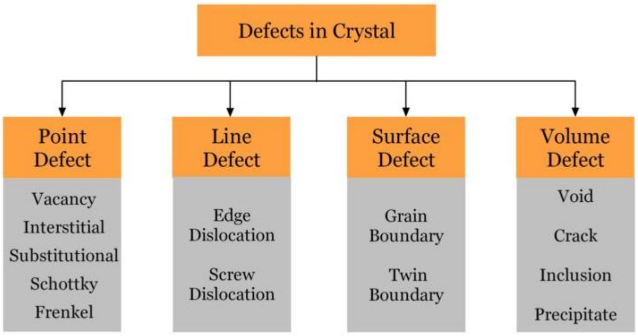

Figure 8. Classification of Crystalline Defects in solids (reprinted from[27])

7.1 Point Defect

Point defects occur where an atom is absent in the lattice structure or is in an unusual position. Point defects include self-interstitial atoms, interstitial impurities, substitution atoms and vacancies. The accumulation of intrinsic point defects in monocrystalline silicon (vacancies and Si interstitials) has a significant impact on the operation of electronic devices. This agglomeration of vacancies contributes to the creation of tiny holes (so-called voids, roughly 100 nm in size), the aggregation of Si interstitials exerts tremendous stress on the Si matrix, which produces a network of dislocation loops around the initial defect beyond a critical scale [28]. Such dislocation loops are typical of the size of microns. These are up to this point more impeding to the activity of frameworks than opportunity bunches. The element size of electronic gadgets has now fallen underneath the size of 100 nm, implying that void totals are not, at this point, worthy to numerous gadget producers too.

7.2 Dislocation

Dislocation is the misplacement of unit cells in a single crystal. It occurs from lattice strain. Dislocation is of two types. They are edge dislocation and screw dislocation. Dislocations demonstrate various unusual electronic properties resulting in a significant increase in the drain current of field-effect transistors of metal-oxide-semiconductor (MOSFETs) when specified numbers of these defects are put in the tube. Measures for Si dislocations contribute to a super metallic conductivity [29]. Dislocations are commonly unwanted in silicon wafers since they fill in as sinks for metallic contaminations, disrupting diffusion profiles. Be that as it may, the capacity of dislocations to sink contaminations might be built into a wafer creation advantage. i.e., it might be utilized in the expulsion of polluting influences from the wafer, a system known as 'Gettering.'

7.3 Growth Defect

The growth defect is of two types. They are slip and twinning. The movement of mobile dislocations allows atoms to slide over each other at low-stress levels and is known as glide or slip. Crystal twinning happens when two different crystals have symmetrical sharing of some of the same crystal lattice points. The slip band includes an inhomogeneous dislocation density, which is likely to interact with small clusters of defects during motion [30].

8. DEFECT REDUCTION

Naturally, it is not possible to obtain 100% pure silicon crystalline. The point defect in the crystalline is quite familiar because of the atomic vibrations at room temperature, and it cannot be removed at all. But the other defects can be controlled by applying some methodologies. One of those methods is annealing. Annealing of silicon wafers is a high-temperature furnace procedure that can alleviate silicon tension, trigger or transfer dopants, increase the density of deposited or grown films, and restore implant damage, as shown in Figure 9 during wafer production. The annealing furnace operates by heating annealing furnace above its recrystallization temperature and then cooling down at this temperature for an acceptable amount of time once the sample has been preserved. The atoms within a sample disperse in the crystal lattice, and the number of dislocations decreases during the annealing process, increasing the ductility and hardness properties of the sample. As the solution cools down, recrystallization happens. When the sample is being heated, the diffusion rate increases by providing the energy needed to break the bonds.

Atomic motion has the effect of redistributing and eradicating disislocations. An annealing furnace has three stages; regeneration, recrystallization, and grain production. The recovery stage occurs at the lower process temperatures. It is here that the material being annealed is softened by eliminating linear defects called dislocations and the internal stresses caused by them. The recrystallization stage is where fresh strain-free grains nucleate and grow to replace the ones harvested during recovery. Growth of grain happens once recrystallization is complete and annealing is allowed to continue. The material's microstructure starts to coarsen during grain growth, and the material may lose its energy so that it would need more heat treatment.

The acceptable limits for defects in semiconductor wafers should be meager since a device built on a faulty substrate has a high certainty of performance failure even if it's a matter of minute defect level, especially when the number of layers of

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metallization increases. A typical wafer yield is around 60%, in spite of the fact that the figures rely upon the procedure utilized, at whatever point a maker moves to another, progressively lightweight plan, yields in the long run drop before assembling early-stage struggles are identified and understood.

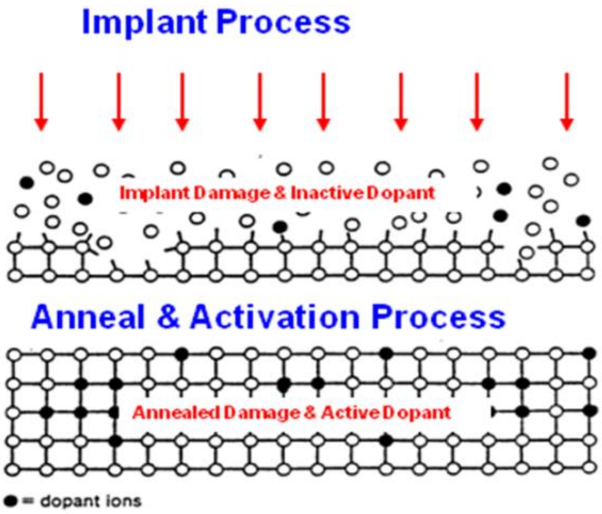

Figure 9. Crystal Structure before and after annealing (reprinted from [31]).

9. CONCLUSION

Silicon wafers play an essential role, from everyday electronic devices to the equipment used in the medical field and even in space. Without this, it would still be trapped in an age in which information is contained only in libraries, correspondence is complicated, and medical procedures were more complex. Bangladesh can be a potential place for growing up silicon industries. There are some high-quality sand deposits with a silica content of a maximum of 98% in Bangladesh. Sand content silica is converted into metallurgical grade silicon (MG-Si) through a carbon reduction process in an electric arc furnace. MG-Si is then further purified in electronic-grade silicon (EG-Si), which is highly purified. Monocrystalline EG-Si is formed through the Czochralski (CZ) or Flote zone (FZ) method with high precision so that minimum defects are existent. Both impurities and defects contain in EG-Si highly affect the device performances. The reduction of these impurities and defects is very challenging to manufacture process of electronic-grade silicon.

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