



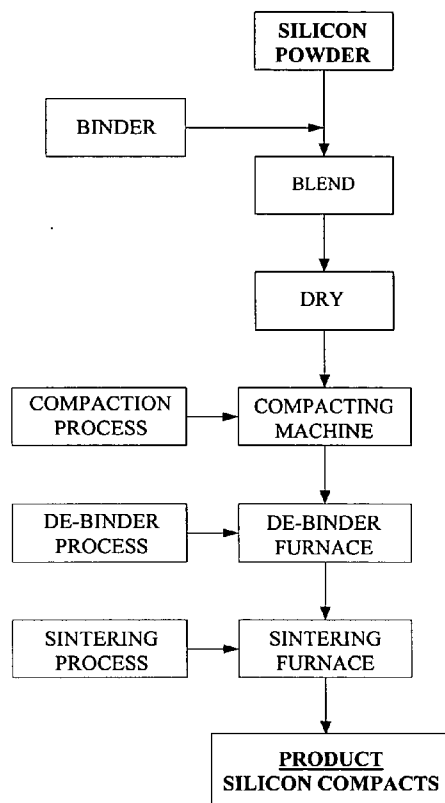
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(19) **United States**(12) **Patent Application Publication**
Hariharan et al.(10) **Pub. No.: US 2007/0014682 A1**(43) **Pub. Date: Jan. 18, 2007**(54) **CONVERSION OF HIGH PURITY SILICON
POWDER TO DENSIFIED COMPACTS****Publication Classification**(76) Inventors: **Alleppey V. Hariharan**, Austin, TX
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(52) **U.S. Cl.** **419/36**Correspondence Address:
Alleppey V. Hariharan
3225 Summer Canyon Dr
Austin, TX 78732 (US)(57) **ABSTRACT**

This invention describes methods of compacting and densifying high purity silicon powder to defined geometric forms and shapes. High purity silicon powder is first mixed with binder from a select group of binders and pressed into desired shapes in a mechanical equipment. The binder is removed either in a separate step or combined with a subsequent sintering operation. The binders and process conditions are chosen to make negligible change to the purity of the silicon in the end product. When high purity silicon powder is utilized in the process, the end use for the densified silicon compacts is primarily as feedstock for silicon-based photovoltaic manufacturing industries.

(21) Appl. No.: **11/479,735**(22) Filed: **Jun. 30, 2006****Related U.S. Application Data**

(60) Provisional application No. 60/696,235, filed on Jul. 1, 2005.



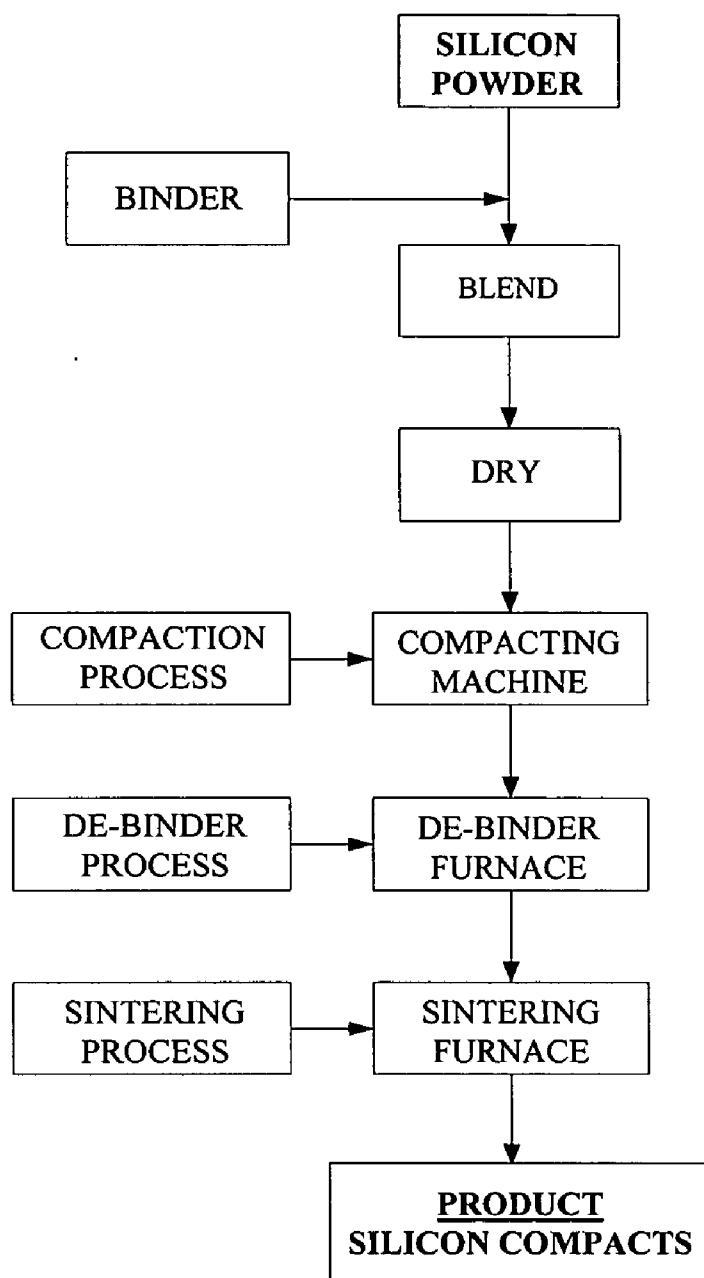


FIGURE 1. Silicon Compacting Process Flow Sheet
General Scheme

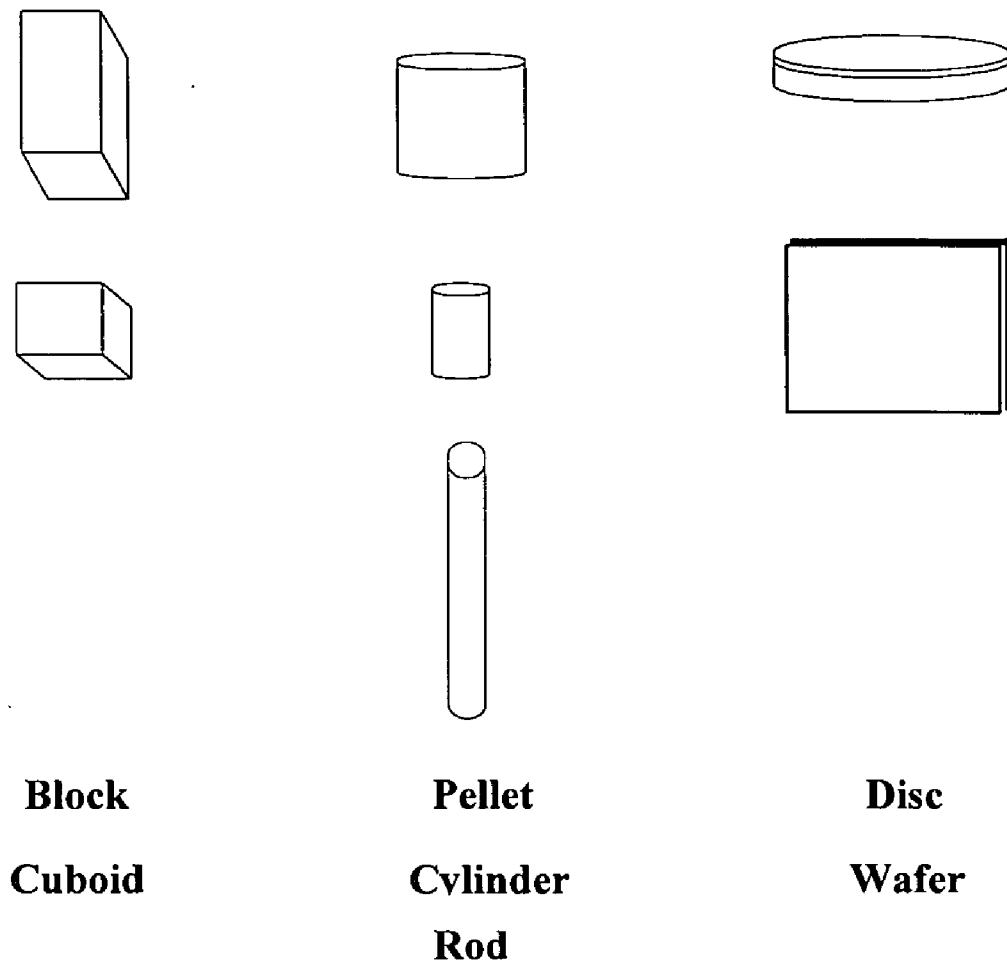


FIGURE 2. Typical Silicon Product Shapes.
Some Examples

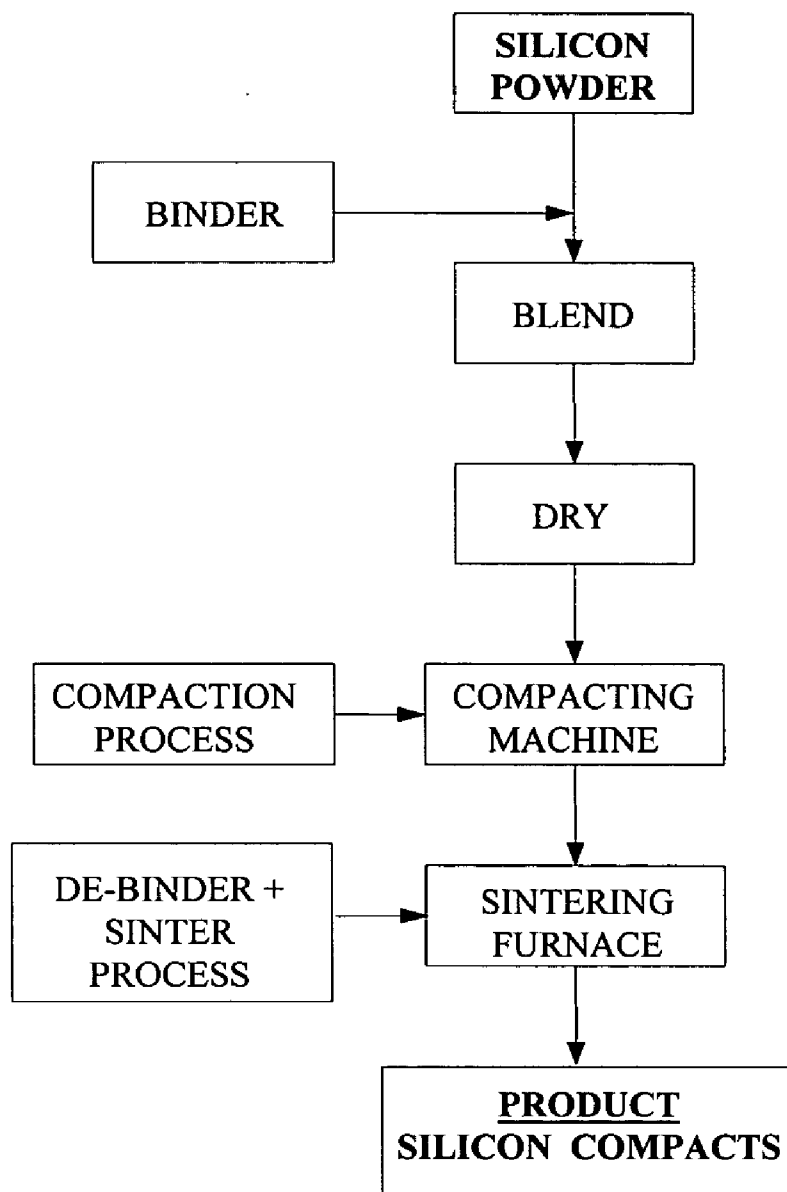


FIGURE 3. Silicon Compacting Process Flow Sheet
Combined De-Binder and Sinter Operation

CONVERSION OF HIGH PURITY SILICON POWDER TO DENSIFIED COMPACTS

RELATED DOCUMENTS

[0001] This Utility Patent Application claims priority of a Provisional Patent Application No. US60/696,235 dated Jul. 1, 2005, and titled "Powder metallurgical conversion of high purity silicon to densified compacts".

FIELD OF INVENTION

[0002] The present invention is directed towards conversion of fine silicon powder into densified silicon compacts for use in silicon melting and alloy industries. This conversion process is achieved by the use of selective binders to aid in compacting the powder towards subsequent sintering and densification. When adapted to high purity silicon powder, the end use for the densified silicon compacts is primarily as feedstock for silicon-based photovoltaic manufacturing industries.

BACKGROUND OF THE INVENTION

[0003] Compacting of powders is well known in metallurgical and ceramic process industries and is a highly developed method of manufacturing various parts and shapes. In these processes powder metals, ceramics or a mixture of ceramics and metals are compacted into various shapes by operations of cold isostatic pressing, hot isostatic pressing, extrusion, injection molding and such other arts. In all such processes some binder or additive of an inorganic or organic nature is added to effect particle binding and compaction. In some instances sintering aids are purposely added in the compaction process to aid in subsequent sintering of the compacted body. Under controlled process conditions the binders and/or additives are essentially removed leaving only very trace amounts of such residues. The final sintering operation is usually performed at high temperatures in controlled-atmosphere or air-atmosphere furnace to provide for essentially complete removal of the binders and additives, bond the particles metallurgically and impart strength to the compacted body.

[0004] Silicon powder is industrially produced by various processes. Nominal purity silicon powder is formed as reaction residues from preparation of organochlorosilanes or chlorosilanes from the reaction of elemental silicon with chlorinated hydrocarbons or hydrogen chloride. The powder is used as alloy feed in ferrous and non-ferrous industries, for manufacture of silicon nitride, and so forth. For such applications the powder is agglomerated with a binding agent to form granules of 250-500 microns. The binders are typically organic materials such as starch, and lignin. Other agglomeration methods include microwave heating of the powder to 1200-1500 C. Where it is necessary to stabilize silicon dust and powder and make them into a more stable form for transportation and disposal (deactivation of silicon) the silicon dust is milled in an aqueous solution of pH>5 to form colloidal silica. This helps to agglomerate the dust.

[0005] Ultra fine silicon is a by-product of the Fluid Bed process to manufacture high purity electronic grade polysilicon. In this process silicon is deposited by thermal decomposition of silane (SiH_4) or chlorosilane (SiCl_xH_y , where $y=4-x$) gas on granules of silicon seed particles. The granules grow in size from an initial seed size of ~0.2 mm

to ~3 mm in diameter. The granules are utilized in silicon melting and crystal growth applications. The Fluid Bed process, however, also results in a large quantity of ultra fine silicon dust. This is tapped out of the reactor outlet and remains as a process waste. This powder is of high purity, but cannot be recycled or used in silicon melting and crystal growth applications.

[0006] High-pressure hot pressing of silicon powder with sintering aids and subsequent high temperature sintering of pressed silicon bodies are known in the literature. High-pressure hot pressing of silicon powders is described in the art, such as in "*The Effects of Processing Conditions on the Density and Microstructure of Hot-Pressed Si Powder*", by C. J. Santana and K. S. Jones, J. Materials Sci. 31 (18), 4985-4990 (1996); and "*High Pressure Hot-Pressing of Si Powders*", by K. Takatori, M. Shimada and M. Koizumi, J. Jap. Soc. Powder Metal. 28 (1) 15-19 (1981). In one such application silicon powder was hot pressed into polycrystalline wafers 1.5" diameter using various process conditions, typically hot pressing at 1300 C./2000 psi in hydrogen gas ambience. The wafers were contaminated with iron, aluminum, carbon and oxygen. There are also several studies of sintering silicon compacts at high temperatures, ranging from 1250 C. to close to the melting point of Si (1412 C.), in an inert atmosphere. Silicon sintering with addition of sintering aids such as Boron, or retardants such as Tin, is described in the art, for example "*The effect of small amounts of B and Sn on Sintering of Si*" by C. Greskovich, J. Mater. Sci 16 (3), 613-619 (1981). Making silicon articles by sintering and densification is also described by Greskovich and J. H. Rosolowski in two U.S. Pat. Nos. 4,040,848 and 4,040,849. Granulation and augmentation of the silicon powder particle size by electron beam melting is described in a Japanese Patent 11199382JP. Such uses are mainly for making silicon nitride and other silicon compounds.

[0007] There is no published prior art that purports to utilize a process for effective use of otherwise unusable silicon dust and powder, i.e., there is no robust, industrially practical and cost-effective methodology to convert silicon powders to forms that keep the purity of the product close to the initial powder quality, can be produced in a manufacturing environment, and, more importantly, be transported without form failure to subsequent product users. There is also no known industrially useful and practical methodology to convert high purity silicon dust and powder to high purity densified silicon compacts that can be used as significant polysilicon feedstock for photovoltaic industries.

SUMMARY OF THE INVENTION

[0008] It is an object of the invention to provide a viable and practical process and technology to convert silicon powder into a form, typically compacted densified shapes, that can be manufactured, transported and utilized to produce silicon feed stock for other applications. It is a further object to provide a process and technology that will maintain the purity of the silicon to nearly the same level as the starting silicon powder.

[0009] It is another object of the invention to provide a system and facility for conducting a powder-to-compact conversion on a commercially useful production rate, such as high speed compacting and densification, and processing upwards of 25 kg or more of silicon powder per hour.

[0010] The most important aspect of this invention is the development of a process that provides silicon feed stock material to user industries while maintaining the product purity very close to that of the starting material. In particular, when used with the high purity silicon powder from the electronic industry it adds significant value to the material and provides a feedstock to the photovoltaic industry. In the present invention the silicon compacts can be produced in regular geometric shapes. Typically, the silicon used for crystal growth comes in irregular chunks or granules. The advantages of regular shaped silicon of this invention provide for better packing possible, whether for transportation purposes or in the crucible used for melting silicon prior to growing crystalline silicon ingots.

[0011] The process of this invention uses selective binders to the silicon powder to aid in powder flow, provide material binding and lubricity in mechanical operations in the process of converting the powders to formed shapes. An effective binder will hold dry powders or aggregate together with exceptional green strength during compacting, burning out cleanly and uniformly and provide sufficient strength during subsequent sintering to densify the parts.

[0012] While the binders are selected for their functionality, the focus is the purity of the formed compacted silicon body after subsequent process steps and near complete elimination of all byproducts and subproducts from the binder. The compacting step itself is performed at ambient temperature to prevent in-process reaction of such binders and die/punch material with the silicon, as occurs in hot pressing operations.

[0013] It is the combination of the ability to convert silicon powder into compacted form by a selective binder technique and subsequent process steps to provide densification and compact strength to the silicon compact while removing the extraneous binder material and components and sintering the compact that enables subsequent value-added use of the silicon powder, especially high purity silicon powder, for example to critical uses such as feedstock materials for photovoltaic applications. The purity level of the silicon material feedstock for photovoltaic applications should be 99.99% or better.

[0014] A similar application of selective binder is in the manufacture of nuclear fuel oxide pellets by the MOX process. In this process, small quantities of zinc stearate are utilized as an additive to provide for initial agglomeration and pellet strength while also serving as a lubricant in the pressing operation. It is removed in the subsequent high temperature sintering step.

[0015] As explained above, compacting of powders is well known in metallurgical and ceramic process industries. All such processes utilize some binder or additive to effect compaction. In some instances sintering aids are purposely added in the compacting process. Notably, the binders/additives/aids leave a residue of organic or inorganic nature during subsequent operations that render those methods useless in this instance. In addition, compacted bodies are sintered at high temperatures to provide compact strength and densification. Although a simple binder-less process is optimum, if practical, to convert high purity silicon powder to compacted shapes, such a method by itself will hardly be robust in industrial handling and transport simply due to lack of compacted body strength with such silicon.

[0016] The process of this invention utilizes either silicon-based or carbon-based types of binders, each with its specific advantages for application to silicon powder compaction.

Silicon-Based Binders are the Following Types

[0017] (a). High purity Fumed silica

[0018] (b). High purity colloidal silica, which is a suspension of tiny silica particles in an organic medium.

[0019] (c). Polyalkoxysilanes with typically 10-60% effective SiO_2 are operationally viewed as liquid sources of silicon dioxide, and possess material binding properties. Polydiethoxysiloxane with 40% SiO_2 content (ethyl silicate 40) is the most widely used polyalkoxysilane with use as a binder in such processes as investment casting.

Carbon-Based Binders are the Following Types

[0020] (d). Polyalkylene carbonate (dissolved in selective solvents) possesses a number of unique characteristics which make it ideal for use as binders with refractory materials: high purity, good binding, imparts higher green strength to compacted body, and clean burning at low de-binder temperatures. Among these, polypropylene carbonate of the type with trade name of QPAC-40 and polyethylene carbonate of the type with trade name of QPAC-25 are the most widely used binders in ceramic and powder metallurgical processing.

[0021] (e). Stearic acid or zinc stearate has binding and lubricating properties with powder compaction processes.

[0022] The binders (a), (b) and (c) belong to the specific group that contains silica (SiO_2) either as added or as the product of binder removal. Both forms of silica, fumed and colloidal, and ethyl silicate have unique properties particularly attractive to silicon powder processing. Apart from their binder properties, their cation silicon is the same as the material processed, its anion oxygen helps to form Si-O-Si type of bonds in the process and also reacts with the silicon at high temperature to form volatile SiO , and thus be removed. Because the cation content of these binders is the same as the element silicon that is intended to be processed, these are the most ideal and preferred binding additive.

[0023] The additive materials (d) and (e) are used because such binders are easy to remove, leave no or very little residues in the completed process and provide a basis to conserve the purity of the processed silicon compact.

[0024] Variations of these described binders are recognized in terms of the chemical family and form of such additives, and appropriate changes in the complete process of making the silicon compacts. Such variations should be apparent to those skilled in the art of powder metallurgical and ceramic materials processing.

[0025] In an embodiment of the method of producing densified and robust silicon compacts the ultra fine silicon powder is transferred into a clean feed hopper attached to a blending system where it is blended with the appropriate binder. After an optional drying step, depending upon the binder used, the blended and dried mix is conveyed to a batch compacting machine, such as pellet press or tablet press. By design such machines are to be of high quality to handle high purity materials. Controlled quantities of the powder are fed into the die by use of an appropriate powder feeder. Special high purity powder feeder may be required.

The powder is pressed by the punch with a press force of several tons. The pressed compact in the form of pellet or tablet is ejected into a clean collection bin and/or transferred into a conveyor system to transport to the next stage. The latter itself may be a sintering furnace if the binder is either fumed silica or zinc stearate, or to a de-binder furnace if the binder is one of the following: colloidal silica, ethyl silicate, polypropylene carbonate or stearic acid. The product from the de-binder furnace is transported to the sintering furnace. The sintered compacts are transferred to a lined storage or shipping container.

[0026] The powder compacting machinery can be semi-automatic or automated for control of operation. The compacting process machinery is located inside a controlled enclosure to maintain process and environment quality. The process facility also provides controlled ingress and filtered egress for environmental safety.

[0027] The de-binding and sintering furnaces are of the conventional type suitable for the temperature and thermal requirements and with provisions for operation in inert gases, such as argon or helium, or in reducing gas such as hydrogen or in vacuum. The process load carriers are to be high purity silica boats and trays or such refractory containers lined with silicon sheets.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 is a general flow sheet for compaction of silicon powder.

[0029] FIG. 2 gives some example shapes of the compacted silicon product.

[0030] FIG. 3 is a process flow sheet for silicon powder compaction with combined de-binder and sinter operation.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0031] A process flow sheet of converting silicon powder to compacted and densified silicon shapes is described in FIG. 1.

[0032] The invention is amenable to many embodiments. In a preferred embodiment, we utilize fine silicon powder of median particle size about 5 micrometers, bulk density 0.5 g/cc (grams per cubic centimeter) and convert them into cylindrical compact shapes or pellets or tablets of nominal sizes, for example 10 mm diameter by 20 mm length. The compacting or pellet/tablet pressing may be done on a clean multi-station press machine with compression force capacity of up to 25 tons.

[0033] The actual shape and size of the compact are not critical. In the process, preferably, a precise quantity by weight of the blended silicon powder and binder is fed into the compacting die as a unit charge, and compressed by a matching punch to the required force to achieve the pre-designed dimensions. Alternatively, the process may be operated on the basis of compressing a precise charge by volume of powder. The compaction of the precise charge may be performed, to a pre-determined final pressure, whether by calculation or trial and testing to achieve the desired result.

[0034] The compressed compact is ejected from the machine through the take-off system. The silicon compact provide a bulk material form of silicon for further operations

of de-binding and sintering that provide for binder removal and at the same time add densification and strength to the compacted form.

[0035] The term "compact" is herein inclusive of any form factor and a descriptive term that implies a compacted small volume of the raw powder material. Its shape may include cylindrical or square/rectangular block, rods, disks, flats, slabs, wafers, etc. and sizes that are practical for process machinery and handling (FIG. 2).

[0036] The invention covers the utilization of the compacted and densified dry silicon as feed material by different industries. Silicon compacts of high purity are intended as feedstock to photovoltaic materials industry to make high purity silicon crystals by various means. Silicon compacts of nominal purity are intended for auxiliary ferrosilicon, aluminosilicon and other alloy manufacturing operations.

[0037] The basic steps of a preferred method for making high purity silicon compacts is as follows: providing a source of high purity silicon powder, feeding the powder into a blender, and mixing with appropriate binder, providing an in-situ drying if desired, discharging the powder into a hopper, feeding a controlled amount by weight or volume of the powder into a die, compacting the powder with pressure, exclusive of any local additive or lubricating agents, and then discharging the dry compact from the die. The machinery may be configured to operate multiple lines of multiple dies, to meet high volume requirements. Additionally, the parts of the machinery that come into contact with the high purity silicon powder and compact may be provided with protective coating to eliminate contamination from the machinery.

[0038] Additional steps of processing the compacted shapes are: providing an inert flowing gas environment and temperature of 250-500 C. to de-binder the formed compact and providing an inert, reducing or vacuum environment and temperatures of 1000-1350 C. to effect densification and strength to the compact and further remove any binder-related residues.

[0039] The further steps of especially making high purity silicon ingots from the sintered silicon compacts is conventional and known to those familiar with the art of crystal growth. The crystal growth processes include methods such as Czochralski (CZ), Edge defined Film Growth (EFG), Heat Exchanger Method (HEM), or other.

EXAMPLES

Example 1

[0040] High purity Silicon powder is mixed with high purity fumed silica as a binder. Typically, the fumed silica is in the range 0.01-5 weight percent of the silicon powder, preferably in the range 0.05-0.2 weight percent. When added to the silicon powders, fumed silica aids powder flow, by forming a layer on the silicon surface and acts like a lubricant, aiding flow and compression. Due to the hydrophilic nature of the fumed silica it absorbs water off the surface of the particles and prevents caking. The mix is well blended, then formed into compacts or pellets/tablets of required shape. The compacted shape is then sintered in an inert gas or reducing gas such as hydrogen in inert gas or vacuum environment at 1000-1350 C. to produce the compacted densified final product.

[0041] During the sintering operation the fumed silica binder reacts with the silicon matrix to form SiO gas, which vaporizes from the compact. The residual oxygen in the sintered silicon compact is expected to be only the saturation solubility of oxygen in solid silicon (=20 ppm).

Example 2

[0042] High purity Silicon powder is mixed with high purity colloidal silica as a binder. The high purity colloidal silica is nominally 40-50% by weight SiO₂ in isopropyl alcohol or toluene. Typically, the colloidal silica is in the range 0.01-5 weight percent of the silicon powder, preferably in the range 0.05-0.2 weight percent. When added to the silicon powders, colloidal silica aids powder agglomeration and particle bonding. The mix is well blended, then dried to remove essentially all carrier solvent, then formed into compacts or pellets/tablets of required shape. The compacted shape is then sintered in an inert gas or reducing gas such as hydrogen in inert gas or vacuum environment at 1000-1350 C. to produce the compacted densified final product.

[0043] During the run up to the sintering temperature any remaining carrier solvent is removed from the compact (FIG. 3). During sintering the silica content of the binder reacts with the silicon matrix to form SiO gas, which vaporizes from the compact. The residual oxygen in the sintered silicon compact is expected to be only the saturation solubility of oxygen in solid silicon (=20 ppm).

Example 3

[0044] High purity Silicon powder is mixed with high purity ethyl silicate 40 (polydiethoxysiloxane with 40% SiO₂) as a binder. Typically, the ethyl silicate 40 is in the range 0.01-5 weight percent of the silicon powder, preferably in the range 0.05-0.5 weight percent. The mix is well blended, then formed into compacts or pellets/tablets of required shape. The use of ethyl silicate 40 binder requires a de-binder step prior to sintering. Ethyl silicate 40 decomposes completely at >300 C. to silica and ethyl alcohol. The latter boils off the compacted body without any significant reaction with silicon.

[0045] After binder removal the compacted shape is then sintered in an inert gas or reducing gas such as hydrogen in inert gas or vacuum environment at 1000-1350 C. to produce the compacted densified final product. During the sintering step all volatile decomposition products of ethyl silicate 40 will be released completely from the compact. The silica will react with silicon to form silicon monoxide, SiO, which volatilizes off from the compact. The sintered silicon compact may have only very low levels of carbon and oxygen from the binder incorporated in it (of the order of 20 ppm each).

Example 4

[0046] High purity Silicon powder is mixed with high purity polypropylene carbonate (QPAC-40) as a binder. Typically, the polypropylene carbonate is in the range 0.01-5 weight percent of the silicon powder, preferably in the range 0.05-1 weight percent. The polypropylene carbonate itself is used as a solution dissolved in solvents of the type acetone, methyl ethyl ketone, etc. The concentration of polypropy-

lene carbonate in the solution is in the range 1-25% based on weight, and preferably 10-20%.

[0047] The mix is well blended, dried and then formed into compacts or pellets/tablets of required shape. The use of polypropylene carbonate binders usually results in higher green strength in compacted bodies. Use of such a binder requires a de-binder step prior to sintering. Polypropylene carbonate binders decompose completely in air below 250 C., at temperatures at least 100 C. less than conventional binders. Complete burnout in nitrogen and argon and reducing atmospheres that contain hydrogen is possible at temperatures as low as 300 C., and under vacuum, Polypropylene carbonate burns out as carbon dioxide and water vapor. At the low temperatures of binder removal these products do not react at all significantly with silicon.

[0048] After binder removal the compacted shape is then sintered in an inert gas or reducing gas such as hydrogen in inert gas or vacuum environment at 1000-1350 C. to produce the compacted densified final product. During the sintering step all decomposition products of polypropylene carbonate will be released completely from the compact. The sintered silicon compact may have only very low levels of carbon and oxygen from the binder incorporated in it (of the order of 20 ppm each).

Example 5

[0049] High purity Silicon powder is mixed with high purity stearic acid or zinc stearate as a binder. Typically, the stearic acid or zinc stearate is in the range 0.01-5 weight percent of the silicon powder, preferably in the range 0.05-0.2 weight percent. When added to the silicon powders, stearic acid or zinc stearate acts as a binder and like a lubricant in the subsequent compacting process.

[0050] The mix is well blended, then formed into compacts or pellets/tablets of required shape. The compacted shape is then sintered in an inert gas or reducing gas such as hydrogen in inert gas or vacuum environment at 1000-1350 C. to produce the compacted densified final product.

[0051] Use of stearic acid as a binder requires a de-binder step prior to sintering. Use of zinc stearate as a binder may avoid a separate de-binding step. During the sintering operation zinc stearate decomposes to zinc oxide and organic byproducts. The latter decomposes to volatile products at temperatures <500 C. The zinc oxide vaporizes at the sintering temperatures. Any residual zinc oxide will be reduced to zinc by silicon at the high temperature of sintering. Residual zinc will also be removed in subsequent melting processes, if used. The solubility of zinc in silicon is estimated to be ~6 ppm by weight at 1300 C. Zinc has also a decontamination factor of 100,000 ($C_{\text{melt}}/C_{\text{solid}}$) in the melting and crystallization process.

[0052] Other and various embodiments will be evident to those skilled in the art, from the specification, abstract, and claims that follow.

We claim:

1. A process to form compacted densified geometric shapes from silicon powder and the resultant products thereof, which is robust for industrial manufacturing application. The densified silicon compacts may have such shapes as cylinders, cuboids, discs, wafers, etc.

2. The compacted densified form of silicon according to claim 1 that derives from high purity silicon powder, and which can be used as feedstock in photovoltaics materials industry.

3. The compacted densified form of silicon according to claim 1 that derives from nominal purity silicon powder and which can be used as feedstock in ferrous and non-ferrous alloy industry.

4. The compacted densified form of silicon according to claim 2 where the purity of the silicon powder is to be >99% and preferably >99.99%, with particle size in the range of 0.01-200 microns (preferably 0.1-40 microns) and mean size of 1-20 microns (preferably 5 microns).

5. A method for making a compacted densified silicon material comprising the steps:

Providing an agglomerate-free source of high purity silicon powder,

Blending the said silicon powder with additives including selected high purity binder.

Pre-drying the said blend,

Feeding a controlled amount of said dried blend of silicon powder and binder from said blend into a shape forming die,

Compacting with pressure said controlled amount of said blend in said die thereby forming a compact of defined shape of the blend of high purity silicon and binder

Discharging said compact from said die, and

Repeating the previous five steps thereby producing a quantity of said compacts.

All these operations to be performed at ambient temperature on a shape forming machine that uses mechanical pressure to compact the feed material,

Removing the binder in a de-binder operation by heating the pressed compact in a furnace environment of flowing inert gas or reducing gas such as hydrogen in inert gas or vacuum and at temperatures of 100-500 C., and

Sintering the de-bindered compact in a furnace environment of inert gas or reducing gas such as hydrogen in inert gas or vacuum and temperatures of 1000-1350 C. to provide for complete removal of binder materials, and to provide for silicon particle bonding, densification and compact strength.

6. A method for making a compact of silicon material according to claim 5, wherein the silicon powder is blended with a binder from select groups of binders.

7. The select groups of binders according to claim 6 are derived from select silicon-based and carbon-based high purity chemicals that have specific advantages for application to silicon powder compaction.

8. The select binders according to claim 7 consists of high purity fumed silica, high purity colloidal silica, polyalkox-

ysilanes (typically ethyl silicate with 10-60% effective silica content), polyalkylene carbonate (typically polypropylene carbonate), stearic acid and zinc stearate.

9. The select binders according to claim 7 which cannot be used directly is suspended or dissolved in inorganic carrier such as water or organic carrier solvents of the type acetone, isopropyl alcohol, methyl ethyl ketone, etc.

10. The fumed silica binder content of the blend with silicon powder according to claim 6 is in the range 0.01-5 weight percent of silicon powder, and preferably in the range 0.05-0.2 weight percent.

11. The colloidal silica binder content of the blend with silicon powder according to claim 6 is in the range 0.01-5 weight percent of silicon powder, and preferably in the range 0.05-0.2 weight percent.

12. The ethyl silicate binder content of the blend with silicon powder according to claim 6 is in the range 0.01-5 weight percent of silicon powder, and preferably in the range 0.05-0.5 weight percent.

13. The polypropylene carbonate binder content of the blend with silicon powder according to claim 6 is in the range 0.01-5 weight percent of silicon powder, and preferably in the range 0.05-1.0 weight percent.

14. The stearic acid or zinc stearate binder content of the blend with silicon powder according to claim 6 is in the range 0.01-5 weight percent of silicon powder, and preferably in the range 0.05-0.2 weight percent.

15. A method for making a compact of silicon material according to claim 5 wherein the binder chosen from the group according to claim 7 is thoroughly blended with the silicon powder to provide a uniform blend.

16. A method for making a compact of silicon material according to claim 5 wherein the blend of silicon powder and binder with carrier solvent according to claim 9 is dried at temperatures up to 150 C., and preferably at 100 C.

17. A method for making a compact of silicon material according to claim 5, said dried blend is compacted at ambient temperature by progressively compressing a controlled weight or volume of said powder to a pressure calculated to achieve a desired compact density.

18. A method for making a compact of silicon material according to claim 5, said dry compact is de-bindered in a furnace environment of inert gas or reducing gas such as hydrogen in inert gas or vacuum at temperatures of 100-500 C. to remove the binder and its decomposition products.

19. A method for making a compact of silicon material according to claim 5, said dry compact, after de-binding, is sintered in a furnace environment of inert gas or reducing gas such as hydrogen in inert gas or vacuum at temperatures of 1000-1350 C. to remove all traces of the binder and its decomposition products and provide silicon particle adhesion, bonding, densification and compact strength.

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