The Importance of Silicon production in LCA calculations for electronic equipment

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ABSTRACT

Life Cycle Assessment of some telecommunications products (telephone set , network termination for ISDN, switching boards for stations) have been developed to identify the best solutions to improve design choices and production processes from an environmental point of view.

As an example of the new trend toward the green market, a prototype of a telephone set following eco-compatible criteria, like using recycled material for case production, was developed.

In all processes that have been investigated, silicon production constitutes one of the most important ring of the chain. Due to the strategic importance of the electronics market, the secrecy of data makes the LCA study of its production really difficult and time consuming.

Overcoming these problems, the data were collected and this paper describes the silicon production for electronics applications (electronic grade silicon – e/g-Si) from raw materials extraction to wafer availability for integrated circuits (IC) production. The incidence of wafer production on CMOS production for telephone applications from an energy point of view is also given.

INTRODUCTION

Recent LCA projects have seen an upsurge of interest in the electronics field, from single components to complete apparatus. LCA of electronics equipment is strategic among producers to help to understand the environmental burden of their products, to address eco-design activities and to control the end of life scenarios [1] [2]. The project, here briefly described, started two years ago when Telecom Italia, the Italian operator, promoted a LCA study of “SIRIO 2000 basic” telephone set, the new apparatus distributed to all its private clients. The goal was to obtain the base of the information for the project of an “Eco-SIRIO 2000” apparatus with the minimum environmental load [3].

For the study of the Printed Circuit Board (PCB) production, one of the most relevant part was the analysis of monocrystalline silicon production (e/g-Si, electronical grade silicon). The lack of data and the confidentiality of the few information that usually are available, made this analysis difficult and time consuming.

This paper reports the results of the LCA calculations that have been done during the analysis of the production of silicon wafers for integrated circuits (IC) (like CMOS for telecommunication applications, network termination for ISDN or switching boards) and they are also useful for a lot of components usually used in the electronics field.

THE APPROACH

The first step of this work consists in a deep process analysis to evaluate the energy and raw materials requirements and emissions to the environment to produce 1 unit of silicon wafer; the preliminary approach is therefore based on the study of the reactions and their enthalpies (Figure 1).

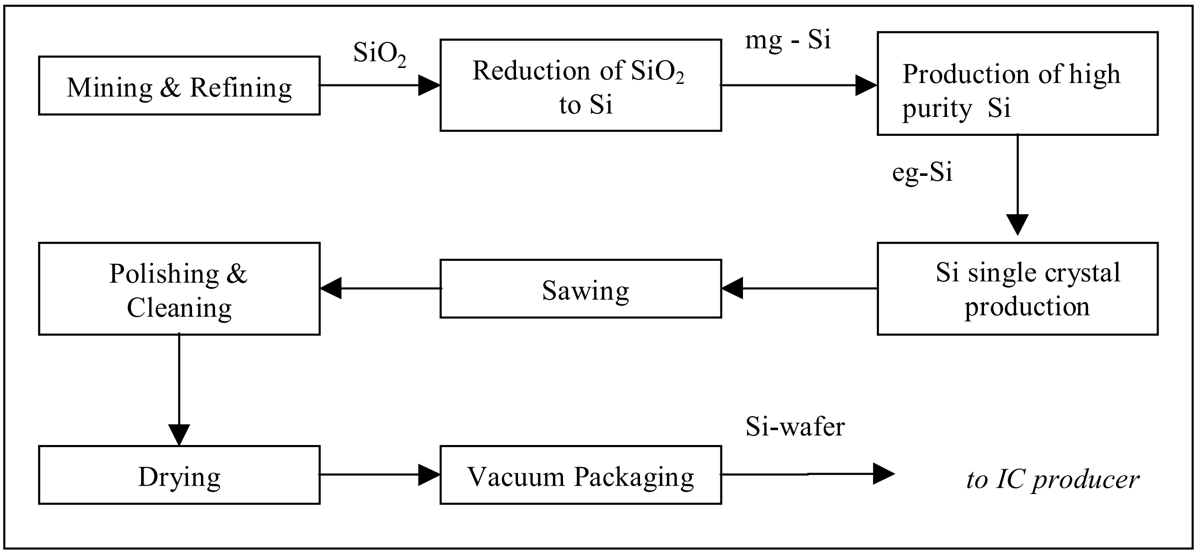

Figure 1. A simplified flow chart of Si-wafer production.

Normally, the raw material for the production of Silicon is silica sand. The mining operations are an established technology and an eco-balance of silica sand production was expressly done on the base of the information provided by the biggest Italian producer [4]. The main reaction for the reduction of silica to silicon is:

$$SiC^{s} + SiO_2^{s} \rightarrow Si^{s} + SiO^{g} + CO^{g}$$

in which carbon is provided from carborundum; alternatively, cokes, low ash coal and wood scraps may be used.

The silicon obtained by this process is the metallurgical grade silicon (m/g-Si) with 95-98% of purity. From a material consumption analysis point of view, to produce 1 kg of m/g-Si, about 3 kg of silica are needed and about 2,5 kg of carbon base materials. The silicon is then purified using trichlorosilane ($SiHCl_3$) and hydrogen from which the electronic grade silicon (e/g-Si) is obtained (>99,99% of purity). For this process, about 1 kg of hydrogen is needed. The melt of e/g-Si is then used to cast a single silicon crystal through the Czochralski method. The wafer is finally cut from the ingot, cleaned and prepared for the transport to IC producers.

INTEGRATION WITH SITE DATA AND RESULTS

The described preliminary approach was then integrated with on-site data that have been obtained with great difficulties: two cases are here considered based on the information provided by a couple of manufacturers. Since the silicon ingots vary in dimensions, depending on the size of the used crucible, Table 1 reports the wafer dimensions of the two examined cases. For confidentiality problems, both producers are anonymous.

Both cases are introduced into the Boustead Model for Life Cycle Assessment calculation in which the energy system, transports and production of ancillaries are based on the Italian situation updated at 1997.

Table 1. Wafer characteristics in the two examined cases.

Case	Wafer dimension	Weight [g]
1	Thickness: 0,065 cm; Φ = 15,24 cm; Volume = 11,87 cm^3	27,65
2	Thickness: 0,060 cm; Φ = 20,00 cm; Volume = 18,85 cm^3	43,92

Taking into account the differences in wafer dimensions, three functional units are used to report the LCA results: the wafer unit, the volume of the wafer and the mass (using a density of 2,33 g/cm^3) of the wafer (Table 2). The first information coming from the calculation model is the gross energy requirement (GER), which is the cumulative energy demand when all processes are tracked back to the raw materials extraction from the earth. From table 2, considering the mass as more useful functional unit, the production of one gram of silicon wafer for electronics applications requires approximately about 17 MJ (or about 40 MJ for 1 cm^3).

Table 2. Gross Energy requirement for the production of wafers in the 2 cases.

Case	Functional Unit		
	(MJ/wafer)	**MJ/cm^3**	**MJ/g**
1	482	41	17,4
2	753	40	17,1

The air emissions associated with each wafer produced correspond to a 100 year Global Warming Potential (GWP_{100}) of about 1 kg $CO_{2\ equivalents}$ per gram in both cases (Table 3).

Table 3. GWP_{100} in kg $CO_{2\text{-eq.}}$

Case	Functional Unit		
	kg CO2-eq./*Wafer*	**kg CO2-eq./*cm^3***	**kg CO2-eq./*g***
1	25	2,1	0,9
2	47	2,4	1,1

Then, the silicon wafer is used for the production of CMOS for telephone applications. If the case n.1 is now considered as starting material, from a wafer of 15,24 cm (6 inches) of diameter, 600 CMOS can be produced. The gross energy requirement for one CMOS production is about 3,8 MJ which takes into account appropriate process losses. The incidence of silicon wafer production on the production of one CMOS from an energy point of view is of the order of 22%.

DISCUSSION AND FINAL CONSIDERATIONS

From this experience, it is possible to indicate some relevant points of the analysis. First of all, LCA is very influenced by data collection, and the Silicon production confirmed this kind of difficulties. It is still hard to obtain information due to the strategic relevance of this market. For instance, in casting and sawing operations of silicon, losses are not so easy to be calculated with particular regard to contouring and portioning. The quantity of material that is cut off and unrecoverable strongly determine the quantity of indirect energy that has to be allocated to this process.

In both examined cases, the total yield is of about 31%, which is accounted for the production of silicon wafer from e/g-Si to the final product. This means that for every kg of e/g-Si input, the process leads to 0,31 kg of wafers.

One of the main difference in direct energy requirement was found again in the sawing operation, probably due to a different way of accounting for some services to the main production line; however, the final results are of the same order of magnitude.

Losses in integrated circuits production constitutes another significant point: normally IC producers don’t like to declare this parameter and often an average value is used. In this case a 20% of losses was considered as the most reliable figure.

Finally, the good agreement of the results obtained from the two different sources of data has to be underlined.

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