The value of solid solubility of carbon in silicon is approximately 10 ppm(a), corresponding to the homogeneous distribution of substituted carbon atoms on silicon lattice sites. This type of carbon impurity is detected by infrared spectroscopy. Higher concentrations of carbon result in SiC precipitates of different size and morphology. This type of carbon is detected and analysed by combustion methods or secondary ion mass spectroscopy (SIMS).

5.7.2.4 Challenges and achievements

The improved carbothermic reduction of silica, followed by leaching and directional solidification, has the capability to produce silicon with sub-ppm concentration of all metallic impurities. Controlling the non-metallic elements, particularly B, P, C and O, at the level required for solar cell applications remains the major challenge for the metallurgical route. Unfortunately, there is no universal method for reducing simultaneously these critical elements. As a consequence, several refining steps are necessary, with the risk of reducing the silicon yield. Another risk is the recontamination by impurities from the reactants and the lining during handling and treatment of liquid silicon. Extensive studies were done on this route in the early eighties, but efforts since then have been considerably reduced. The Japanese program headed by NEDO is to our knowledge the most accomplished project representing this route (Table 5.10; [71]). On the basis of this project's results, Kawasaki has built a 60-MT pilot plant, but the economical feasibility of the route remains uncertain. In the NEDO process, metallurgical grade silicon is purified through

1. melting of silicon by electron beam and evaporation under vacuum
2. first directional solidification
3. remelting of silicon and gas treatment ($O_2 + H_2O$) assisted by a plasma torch
4. second directional solidification.

Table 5.10 Solar grade as obtained through upgrading metallurgical grade silicon by the NEDO method according to [71]

B [ppm(w)]	P [ppm(w)]	Al [ppm(w)]	Fe [ppm(w)]	Ti [ppm(w)]	O [ppm(w)]	C [ppm(w)]	Resistivity [ohm cm]	Lifetime [μs]
0.04–0.10	0.03–0.14	<0.01	<0.05	<0.01	<6	<5	0.8–1.2	>7.7

5.7.3 Simplification of the Polysilicon Process

The Union Carbide and Ethyl Corporation polysilicon processes (Sections 5.4.2 and 5.4.3) resulted from attempts to make the Siemens process more economical. Project goals were to meet a price target of 10 US$/kg set in 1975 by the US Department of Energy (DoE). The Siemens process was fully developed around 1960, but polysilicon for electronic devices and other purposes had been produced since the forties. The Siemens process was the first design of a rational industrial process, which gained international recognition through rapid and broad licensing. At least a dozen processes had been developed prior to the Siemens process and coexisted with the Siemens process until the beginning of the seventies. Purity and high production rates based on semiconductor industry