Eco-Solar Factory: 40%plus eco-efficiency gains in the photovoltaic value chain with minimised resource and energy consumption by closed loop systems

Multicrystalline silicon ingot crystallisation from reusable crucibles

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Introduction

Silica based crucibles

Drawbacks:

- being a thermal insulator
- oxygen contamination and
- cost related due to single use

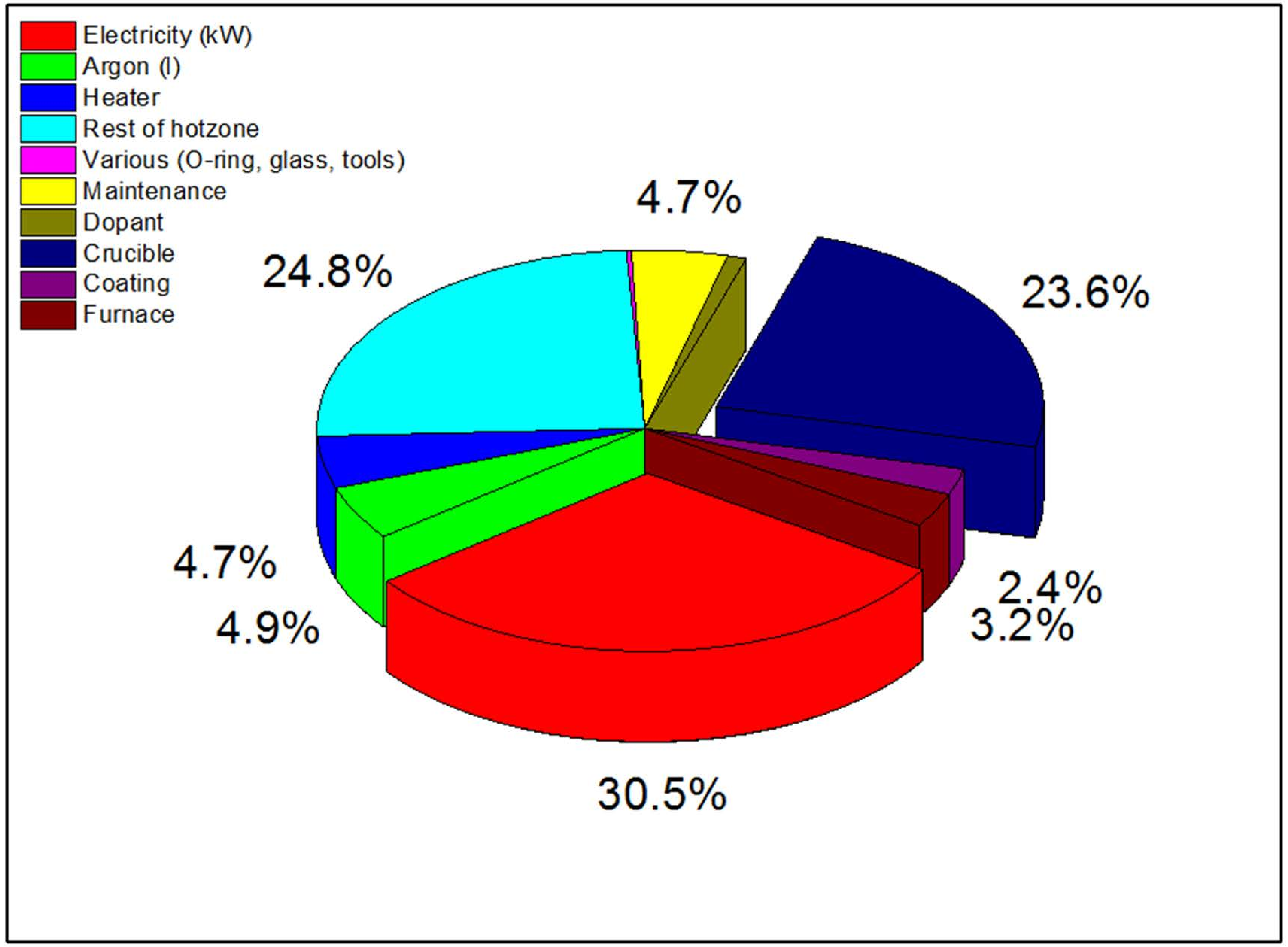
Silicon nitride crucibles

Immediate advantages:

- their increased resilience, which enables them to be reused multiple times
- lower oxygen content
- increased thermal and mechanical resistance

Introduction

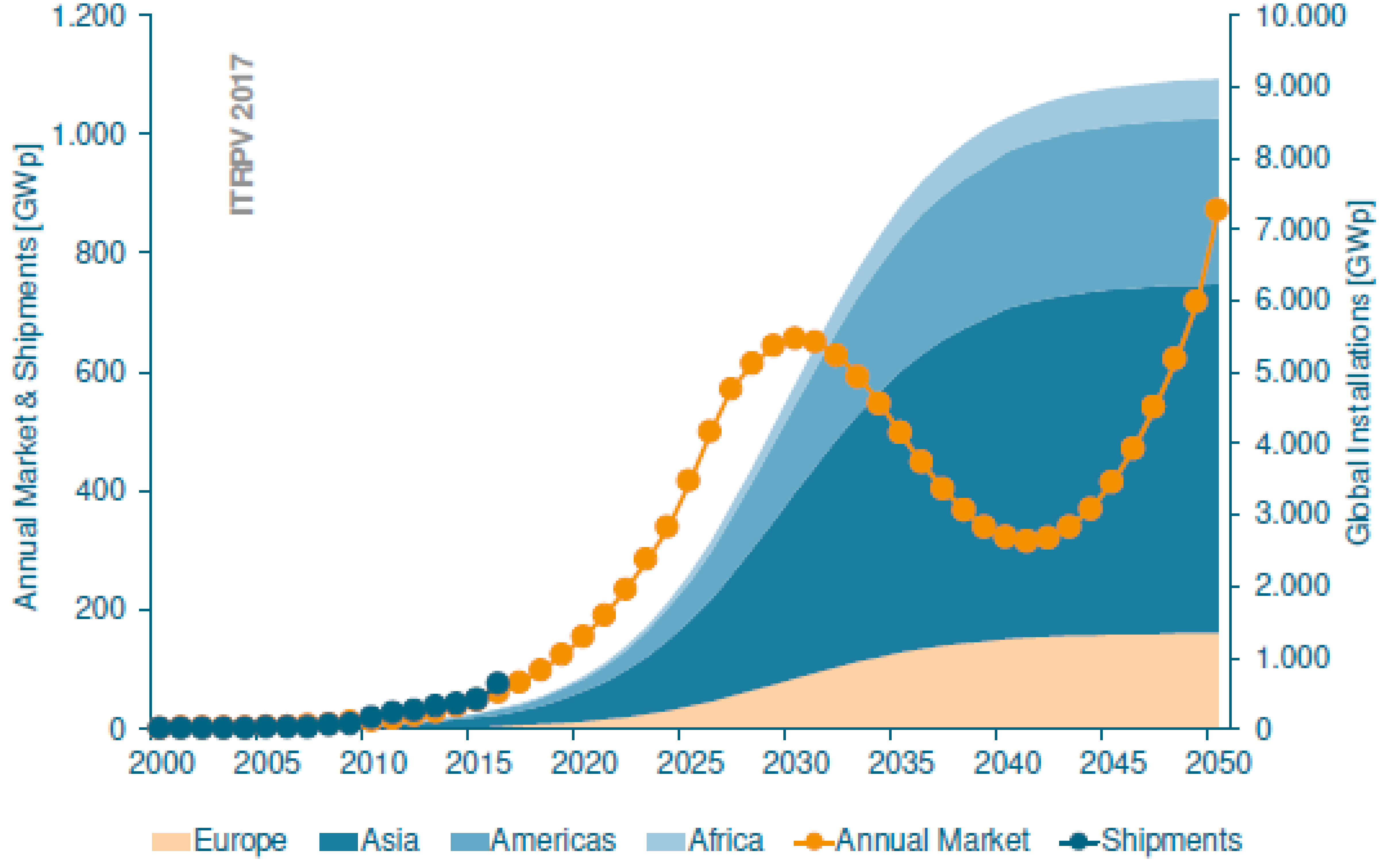
Estimation of cost distribution for conventional mc-Si growth (G6)



- 24% of the costs are related to the crucible
- 30% electricity
- 25% hotzone

Introduction

Cumulative installed PV module power and annual market



- 3.5 Mt of crucible ceramics would be landfilled
- Waste reduction of a factor of 10 in case of 10 times reuse

**Assumptions: high-ren scenario (1800 GW in 2030), market 100% c-Si, business as usual*

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Reaction bonded silicon nitride crucibles

Silicon nitride crucibles are produced by a novel state-of-the-art slip casting technique and subsequent nitridation process (patented) which include the following steps:

- Pure ***silicon powder***, ***water and other chemicals*** are ***mixed together to make a slurry***, which is then is poured into a plaster mould for slip.
- After water is absorbed by the plaster, the «***greenware***» crucible is produced and then removed from the plaster.
- ***Nitridation*** of the «greenware» crucible occurs ***at high temperatures*** (above 1000°C) and produces the final silicon nitride crucible.

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Experimental

DS induction furnace

Crystallisation

- 15 kg initial silicon charge
- p-type HPmc-Si
- Seeding with FBR granules

Crucibles

- High pure EG quartz crucibles (reference)
- Silicon nitride crucibles from Steuler Solar
- Crucibles were coated with α-Si_3N_4 and burned to prevent sticking

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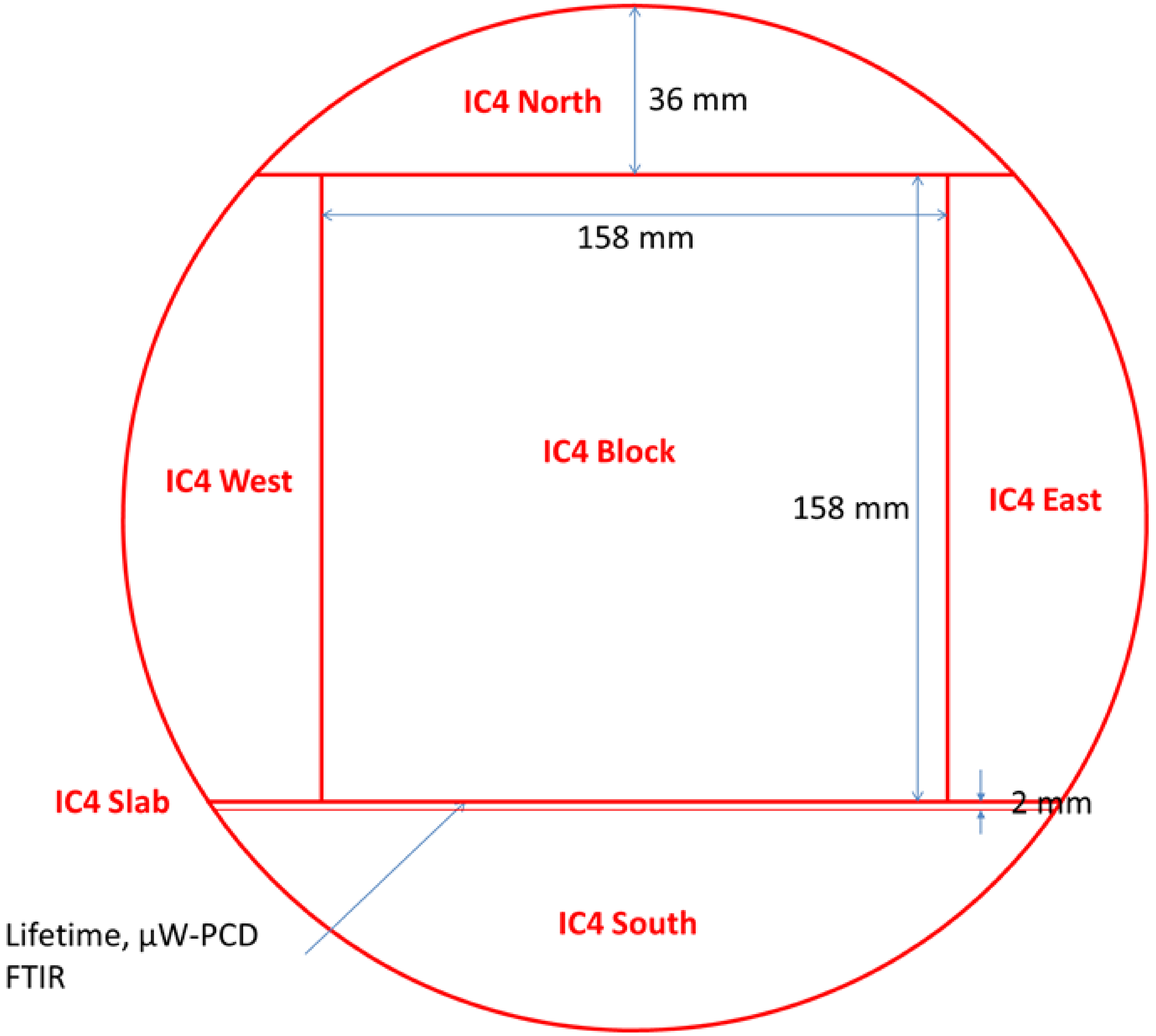
Experimental



Impurities

- FT-IR: Oi, Cs, NN and NNO complexes
- Neutron activation analysis: metallic impurities

Solid/liquid interface shape

- Lateral Photovoltage Scanning (LPS)

Charge carrier lifetime

- microwave Photoconductance Decay (µPCD)
- Microwave detected photoconductivity (MDP)
- Quasi-Steady-State Photoconductance (QSSPC)

Solar cell processing

- conventional solar cells with full-area aluminum (Al) back surface field (BSF)

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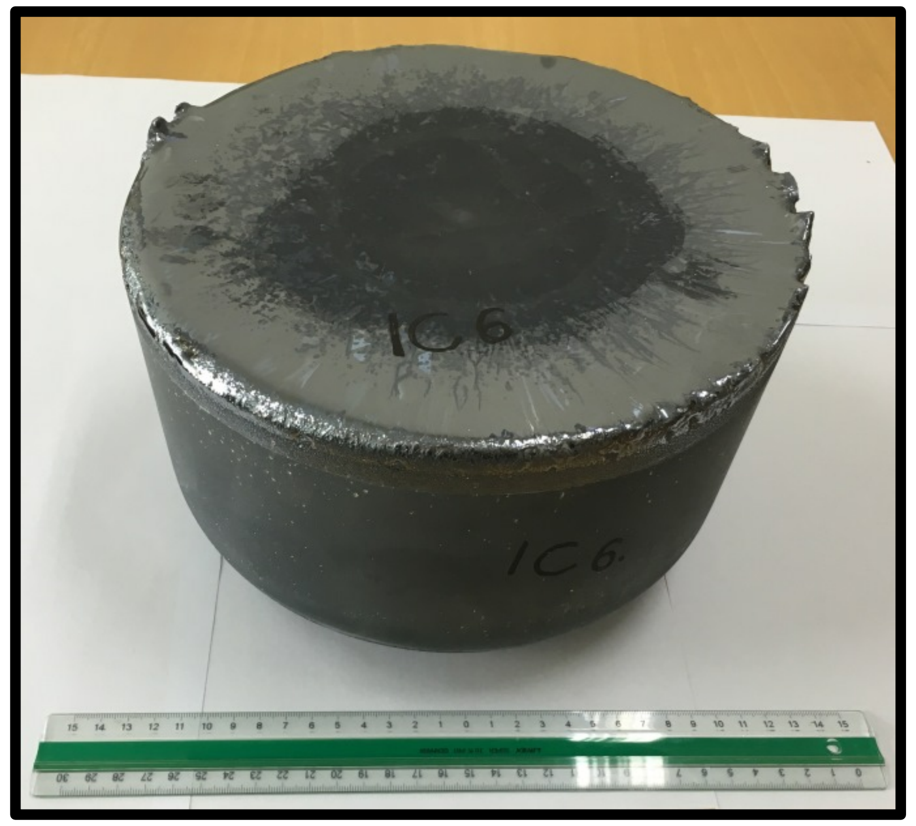
Results - crystallisation

After crystallisation

Ingot release from crucible

1st mc-Si ingot (~15kg)



2^{nd} run

3^{rd} run

4^{th} run

5^{th} run (not analyzed yet)

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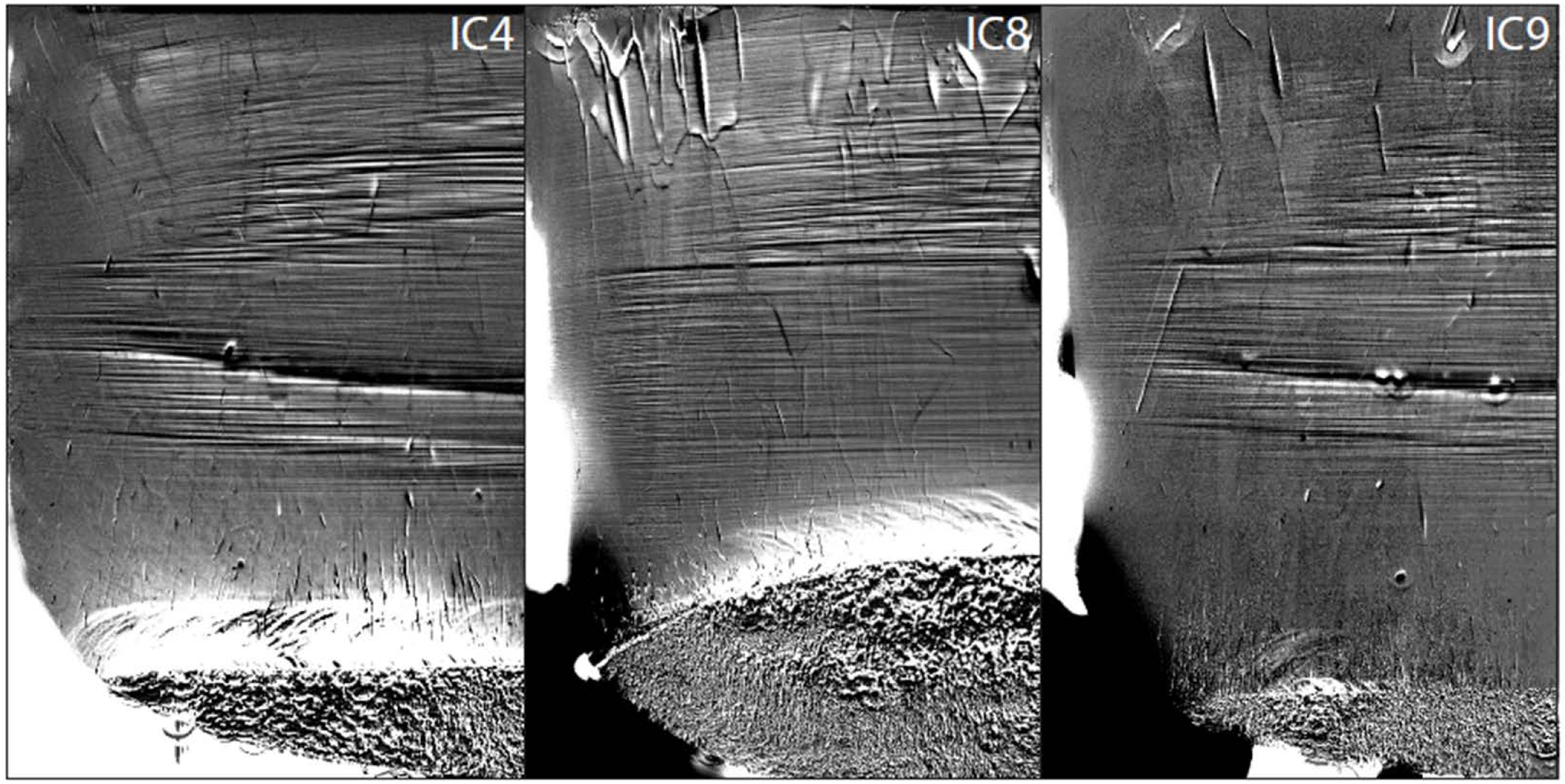
Results – solid/liquid interface shape



- Seeding layer is clearly visible
- No clear difference between using Si_3N_4 or SiO_2 crucibles can be found

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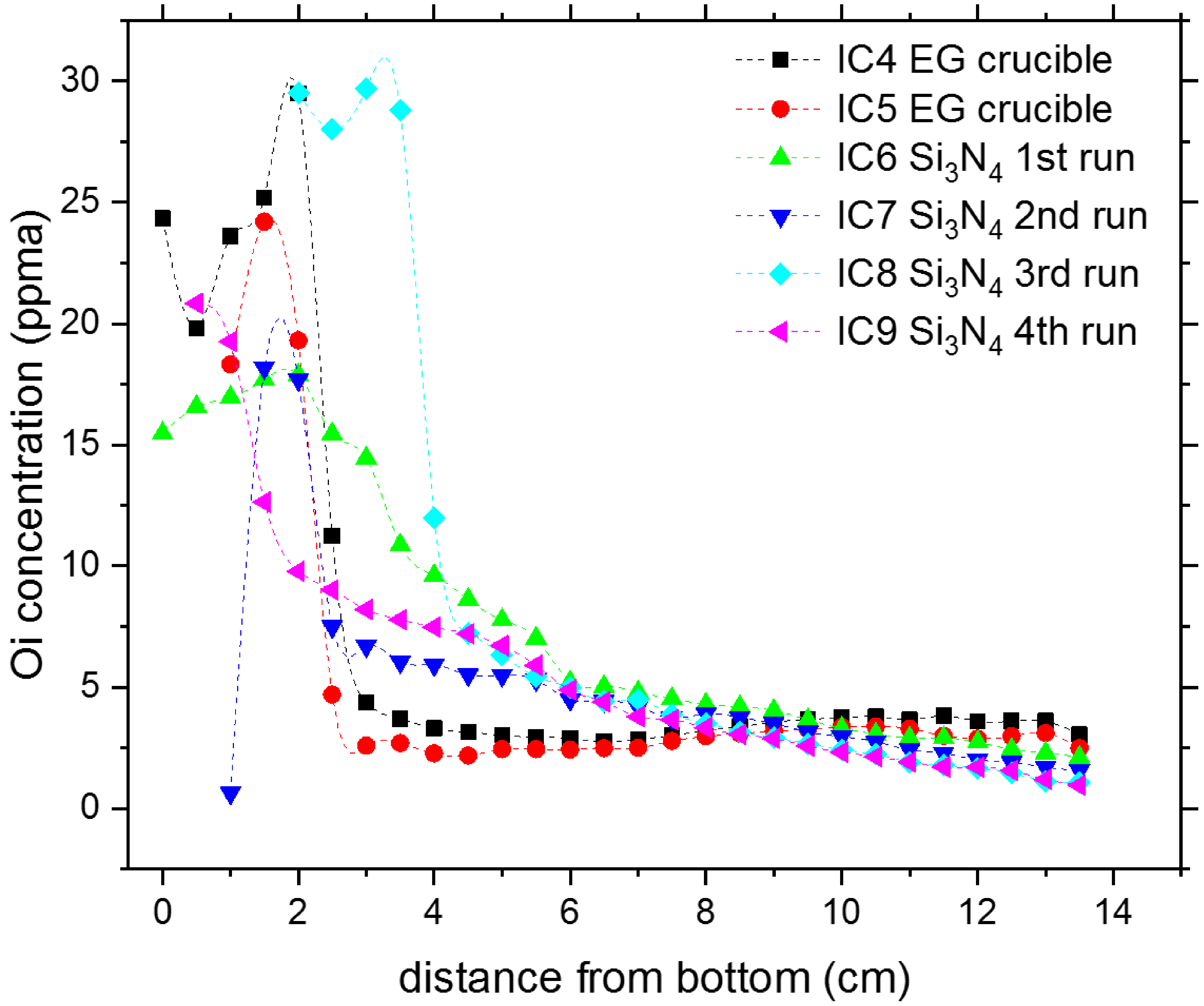
Results – interstitial oxygen



- Oi concentrations are relatively stable for the ingots grown in SiO_2 crucibles
- Clear reduction towards the top in the ingots grown in the Si_3N_4 crucible
- Shift around 8cm suggests that Si_3N_4 crucibles can outperform traditional SiO_2 crucibles, especially for taller ingots
- Initial high oxygen: some oxidation of the precoated Si_3N_4 crucible is expected during burning, with formation of silicon oxynitride (SiOxNy)

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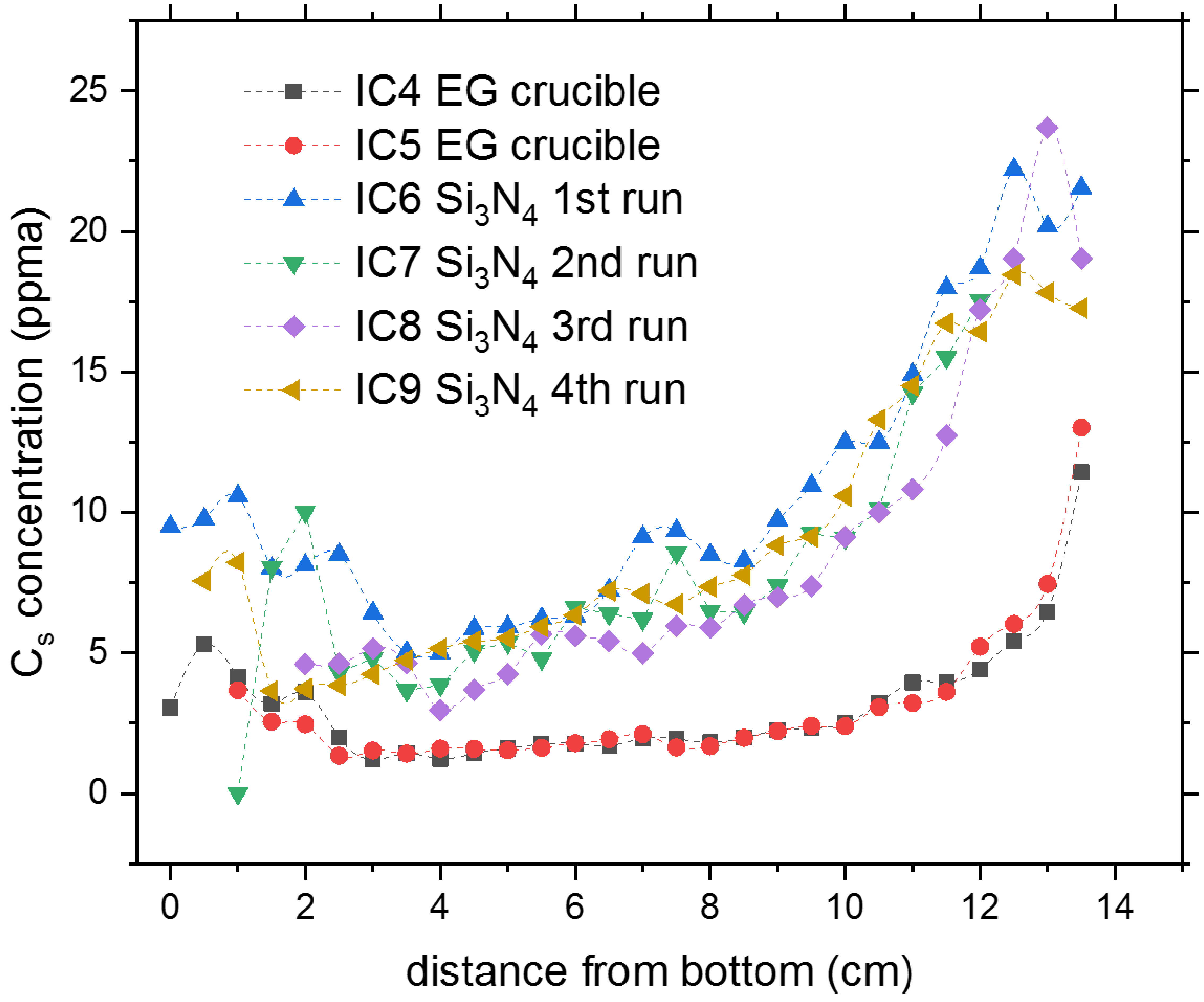
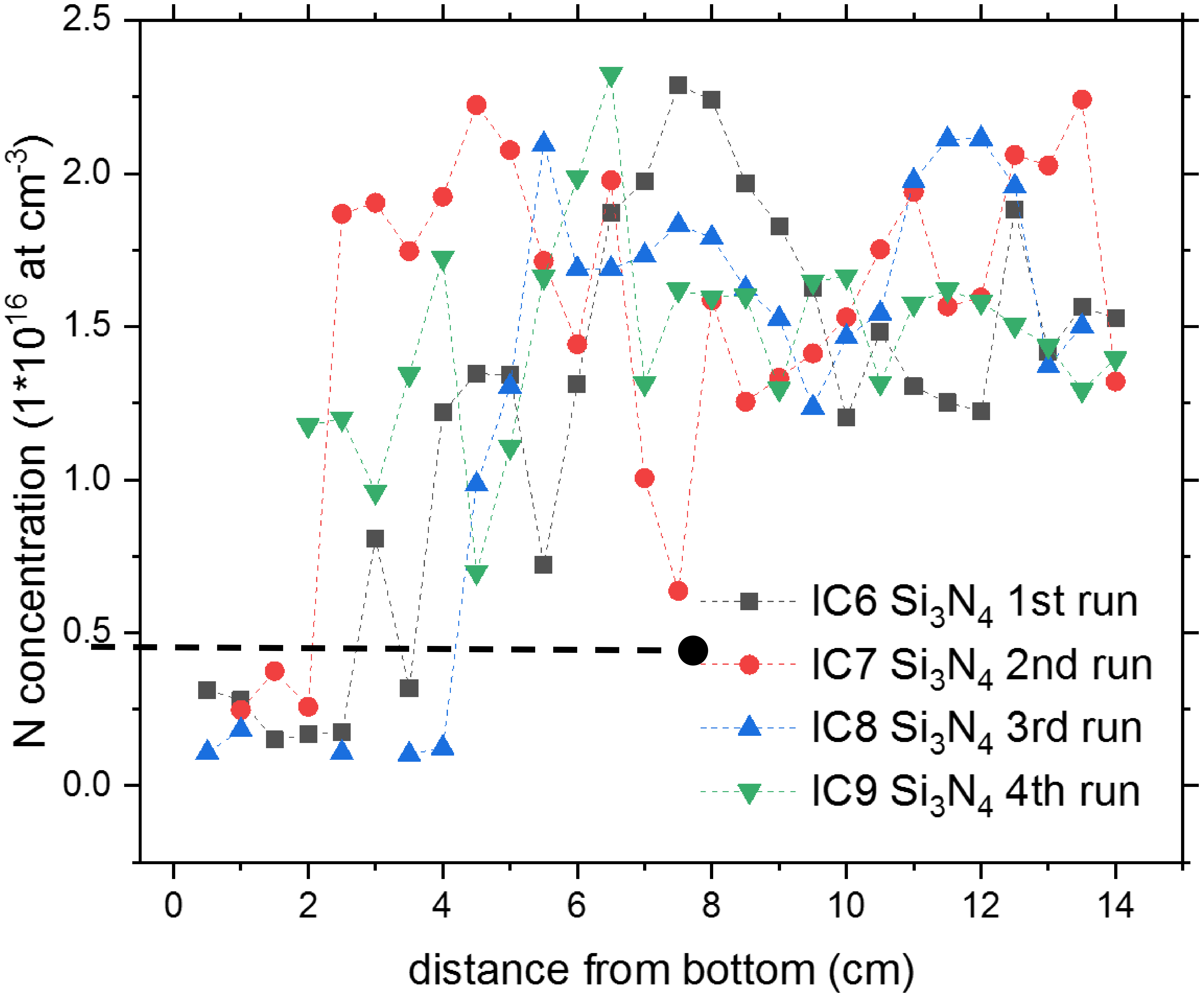
Results – substitutional carbon



The crucible contains small amounts of silicon carbide (SiC), and it is suggested that these particles act as the main contamination source.

Results – dissolved nitrogen (NN, NNO complexes)



Solid solubility limit of nitrogen 4.5×10^{15} at cm^{-3}

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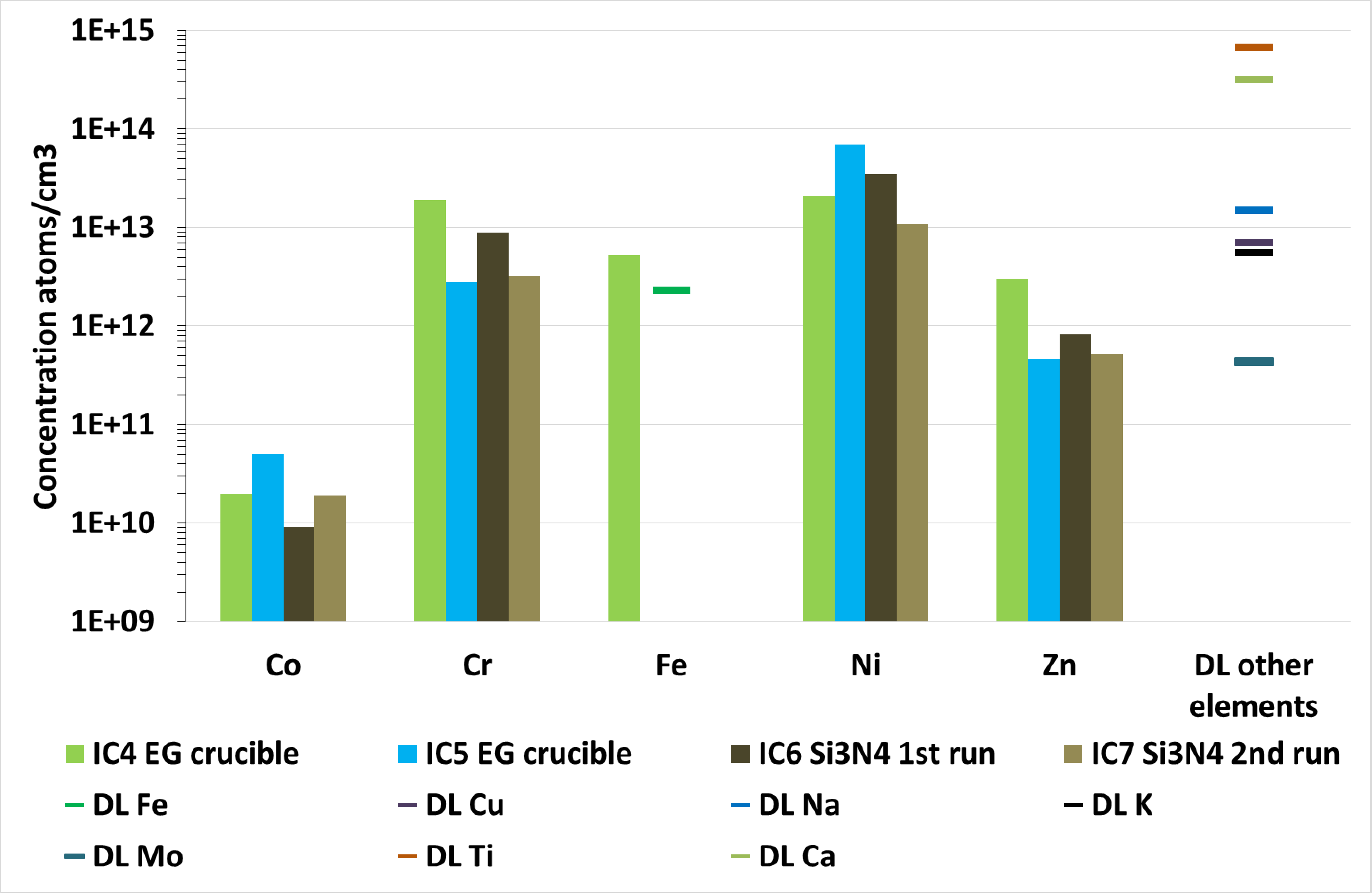
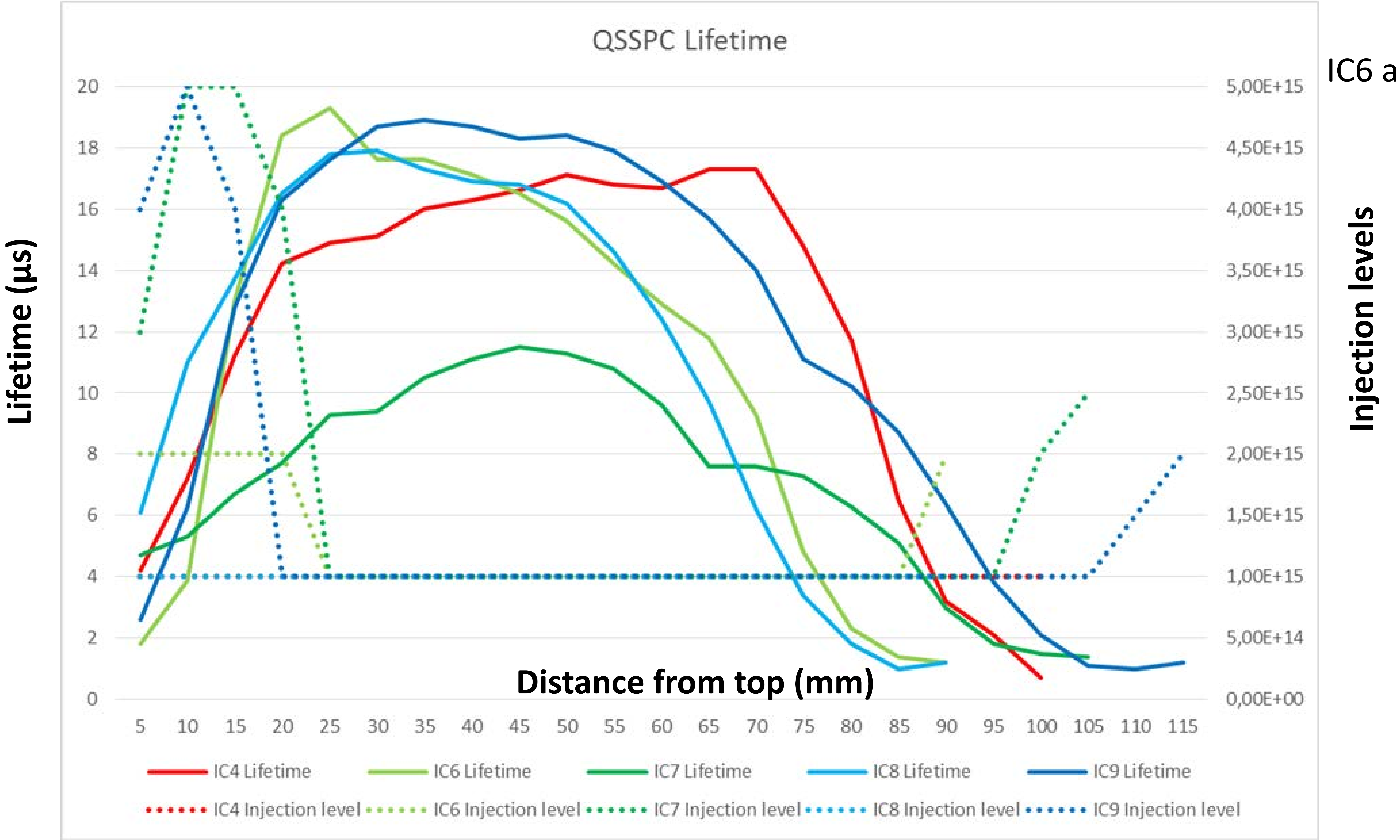
Results – metallic impurities



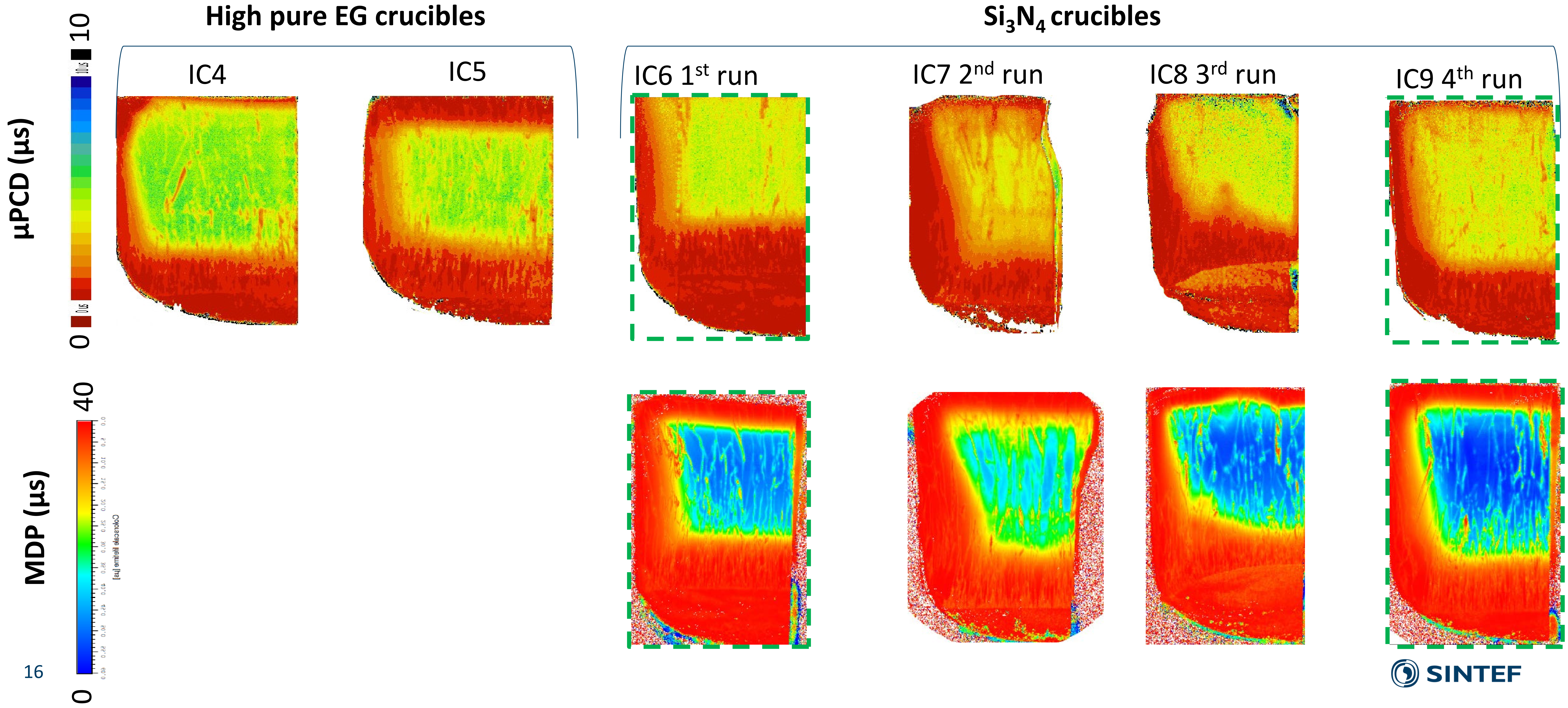
Same impurity levels as in reference material (EG-crucible).

Results – bulk lifetime



IC6 and IC9 with best performance

Results – carrier lifetime



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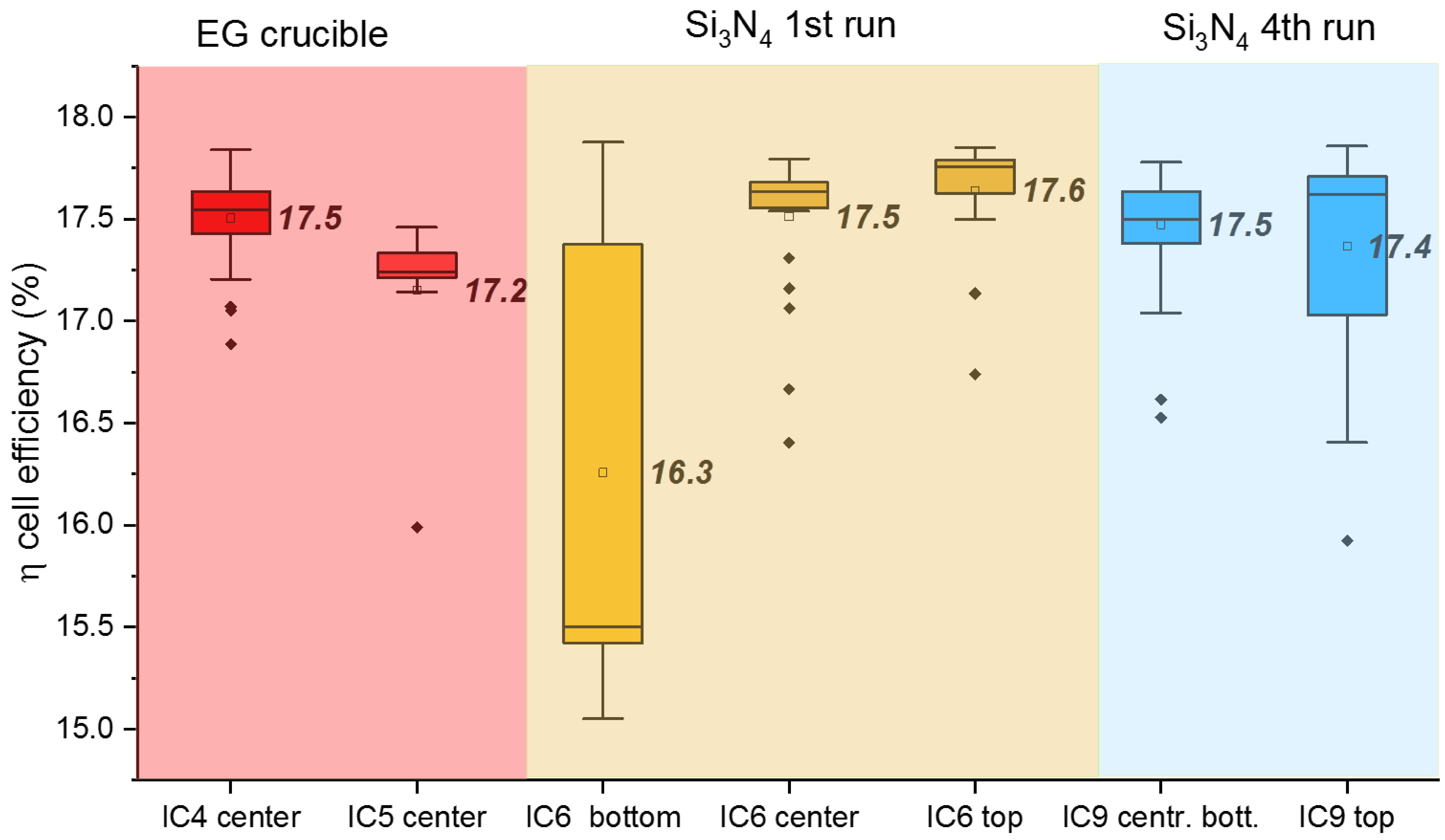
Results – cell efficiency



Summary and outlook

- Study suggests that the Si_3N_4 crucible can outperform traditional SiO_2 crucibles in terms of oxygen, especially for tall ingots
- 5 times use has been demonstrated
- SiC existing in the crucible material. Work is ongoing to eliminate the carbon.
- Material performance and cell efficiencies similar as reference material (SiO_2 crucibles)
- Upscaling to higher ingot dimensions

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Technology for a better society

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