# Readiness for industrial production: core equipment

## We have reorganized production premises

In 2015 R&D on electron beam silicon treatment technology and equipment design for these processes have been continued. **The first version of industrial furnace for feedstock rods of diameter up to 250mm production has been mounted and comissioned in March.**

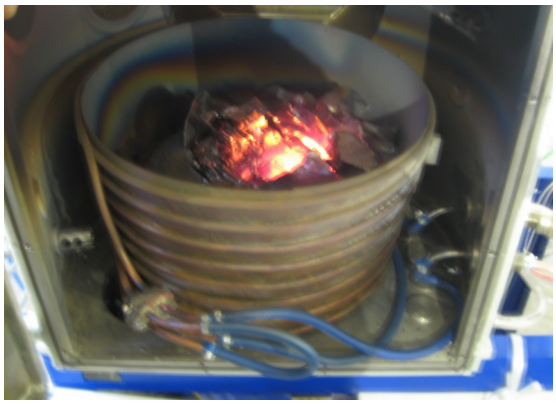
To mount the furnace building floors at 3.5m mark were strengthened and HV power sources of electron beam guns have been moved there:

The closest attention was paid to rod growth in technology development. In 2015 works on the project started in a collaboration with Institute of Electronics and Computer Science, Riga were finalised. As a result equipment management system has been upgraded and geometry of produced rods was enhanced. In a collaboration with Institute of solid state physics, LU, Riga the work on «Create the energy-efficient technology to produce polycrystalline silicon» project has been started in April. In the scope of the project a dislocation free single crystal with diameter 65-70mm and resistivity over 1000 Ohm*cm has beeen grown out of our rod at IKZ, Berlin. Detailed description of scientific and technological results is provided below.

# Readiness for industrial production: research equipment

## We do successfully sell our equipment and acuire new equipment

In July previously rented furnace was purchased and installed for research in electron beam processes, which shall enable a boost in a series of specific research tasks.



Work on production of laboratory furnace purchased by a european customer for growth of FZ feedstock rods with diameter up to 150mm has been finalized. The furnace has been dismounted and prepared for delivery to the Customer in November.

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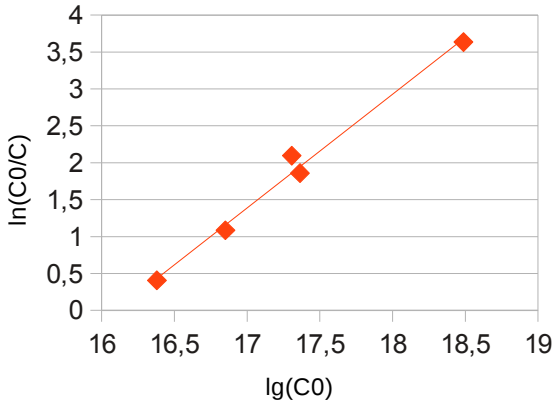
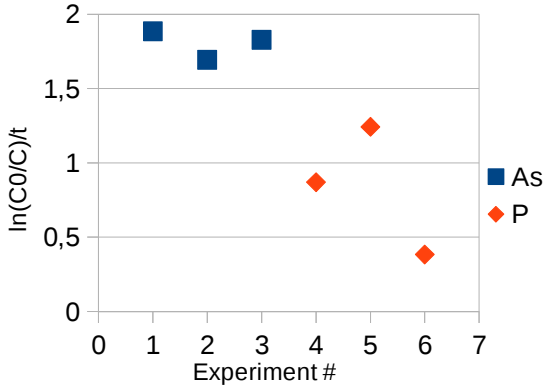
# Research on N-type dopants removal from silion

## Refinement processes for secondary silicon become more clear

Results of research in N-type dopants removal from silicon have been reported at conference in Germany.

During phosphorus removal a non-linear dependence between time and removal rate (relation of final concentration to initial) was observed.




At the same time a linear dependance between removal rate and initial phosphorus concentration.

As a result a hypothesis about impact of phosphorus evaporation in molecular form (e.g., as $P_2$ molecules) has been proposed and removal rates comparable to those reported by others authors have been calculated.

| Author | $k_P$, m/s | $k_{P2}$, m*at$^{-1}$/s*cm$^{-3}$ | Ref. |
|---|---|---|---|
| Hanazawa | 1-2x10$^{-4}$ | - | K. Hanazawa, et. al., Mat. Trans., V. 45, no. 3, pp. 844–849, 2004. |
| Suzuki | 1.8-2.1x10$^{-5}$ | - | K. Suzuki, et. al., J. Japan Inst. Metals, vol. 54, 1990, pp. 161–167. |
| Yuge | 1.3-2.2x10$^{-5}$ | - | N. Yuge, et. al., J. Japan Inst. Metals, vol. 61, 1997, pp. 1086–1093. |
| Our results | 1.5x10$^{-5}$ | 4.1x10$^{-23}$ | |

We plan to determine in the course of following experimnets if observed effect is due to limited diffusion of dopant to melt surface, furnace background impurity level accumulation during removal process, or bimolecular evaporation.

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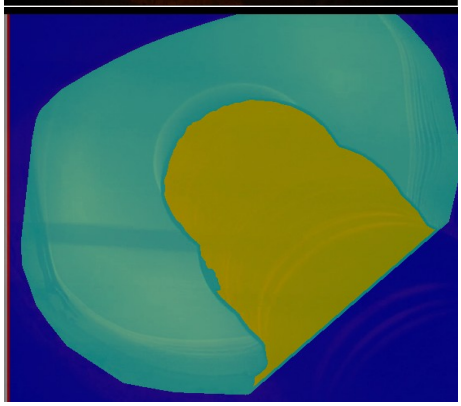
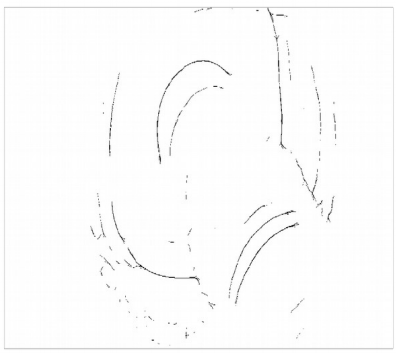
# Enhancements in rods shape and equipment control

## Diameter fluctuations in growing rods have been decreased to +/-3 mm.

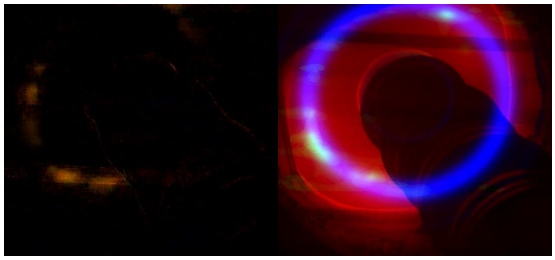
In order to optimize the growth process and to enhance growing rod diameter control with PID-regulation in the scope of collaboration with Institute of Electronics and Computer Science, Riga, significant amendments in image analysis were made.

Meniscus determination is now made in an automatically defined region of interest, meniscus itself is detected with the help of linear filtration:





To provide an uniform thermal field beam trajectory is controlled. An average of two consecutive frames is subtracted from frames, as a result the difference contains information on beam movement only. Summation of that information over a series of frames enables beams trajectory approximation.



As a result of new algorithms application quality of control over crystal diameter has improved.

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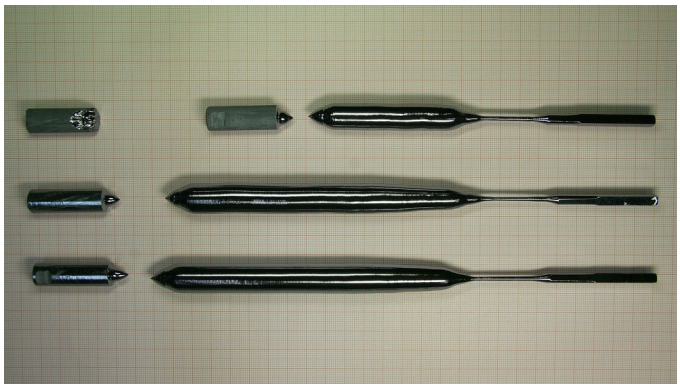
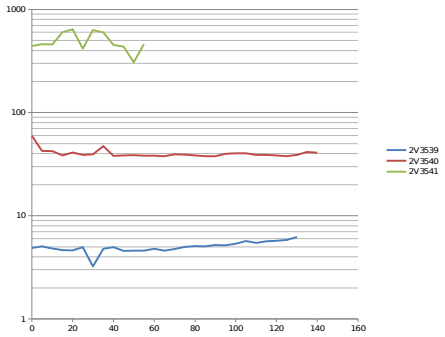
# Process purity

## Rods resistivity has reached hundreds of Ohm*cm

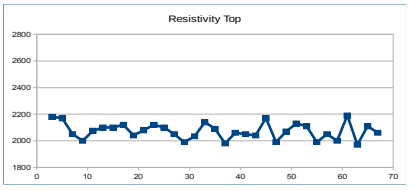
To investigate process purity rods originating from feedstock with different dopants content were pulled: Kepp 7-2V3539 from refined arsenic doped silicon, Kepp 8- 2V3540 from virgin poly doped with boron, and Kepp 9- 2V3541 from virgin poly. Samples were cut from the rear parts of rod and recrystallized with FZ method:

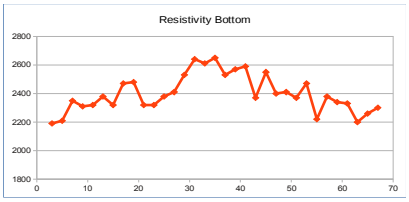





Further enhancement of hot zone and modifications in crystal pulling technique enabled us to obtain a series of rods grown from virgin polysilicon with resisitivity more than 450 Ohm*cm. A rod recrystallization with FZ method in IKZ, Berlin yielded in dislocation free single crystal with diameter 65-70mm and resistivity over 2000Ohm*cm. Ingot was transferred for additional processing to produce power devices from it.

| | 50/1 | 51 | 52 |
|---|---|---|---|
| Type | P | P | P |
| R, Ω*cm | 900-1200 | 500-1100 | 450-1600 |
| L, mm | 670 | 420 | 310 |



# Publications

[1] R. Fuksis, M. Pudzs, Al. Kravtsov and An. Kravtsov, "Measuring the Radius of Meniscus Ring During the Growth of Silicon Rods", in Image Analysis: 19th Scandinavian Conference Proceedings, SCIA 2015, Copenhagen, Denmark, 2015, pp. 462-471.

[2] R. Fuksis, M. Pudzs, Al. Kravtsov and An. Kravtsov, "Diameter control for silicon rod growth" in 5th International Workshop on Computer Science and Engineering: Information Processing and Control Engineering, WCSE 2015-IPCE, Moscow, Russia, 2015.

[3] R. Fuksis, M. Pudzs, Al. Kravtsov and An. Kravtsov, "Electron beam melting with digital image processing in obtaining float-zone silicon rods - an advanced material for high - performance solar panels", EuroNanoForum 2015, Riga, Latvia, 2015.

[4] An. Kravtsov, Al. Kravtsov, R. Fuksis and M. Pudzs, "Ingot pulling with electron beam heating: Process enhancements," Photovoltaic Specialist Conference (PVSC), 2015 IEEE 42nd, New Orleans, LA, 2015, pp. 1-4.

[5] An. Kravtsov, "New Steps in the Electron Beam Pulling of Silicon Rods for the FZ Silicon Single Crystals", in 31st European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, Germany, 2015, pp. 567-570.

[6] Al. Kravtsov and An. Kravtsov, "Phosphorus Removal in Batch Silicon Refinement by Electron Beam", in 31st European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, Germany, 2015, pp. 564-566.