

半導体バルク材料の結晶成長研究 (融液成長)

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太陽エネルギー変換材料研究ユニット

(兼) 結晶物理学研究部門

各種半導体材料

単元素半導体

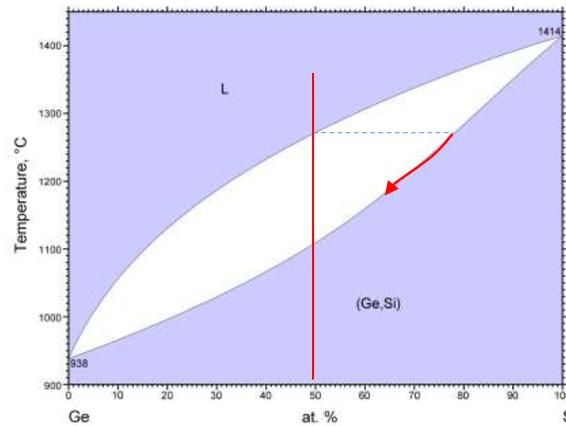
Si, Ge,



大阪アサヒ商事 (株) Web site

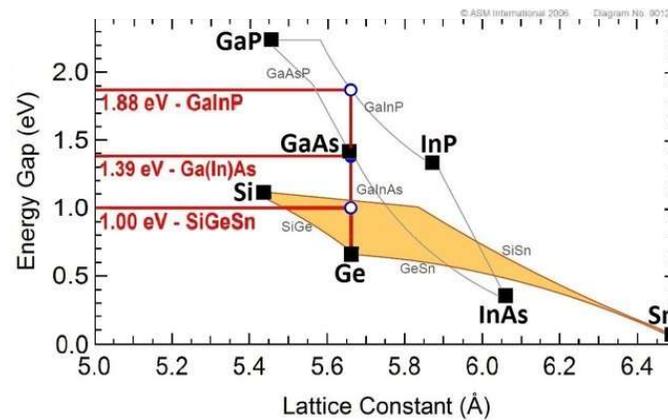
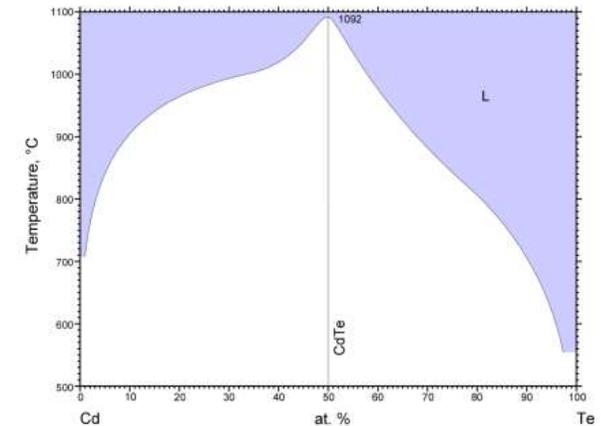
混晶半導体

$\text{Si}_x\text{Ge}_{1-x}$, $\text{In}_x\text{Ga}_{1-x}\text{As}$, , , ,



化合物半導体

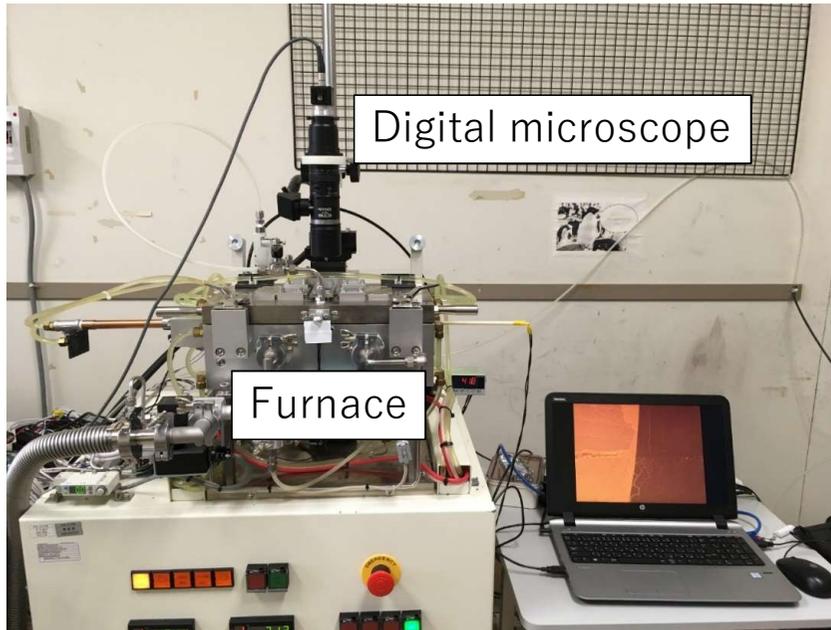
GaAs, InP, GaN, SiC,
GaSb, CdTe, AlN, , ,



Pablo Caño *et al.*, 2017 Spanish Conference on Electron Devices (CDE)

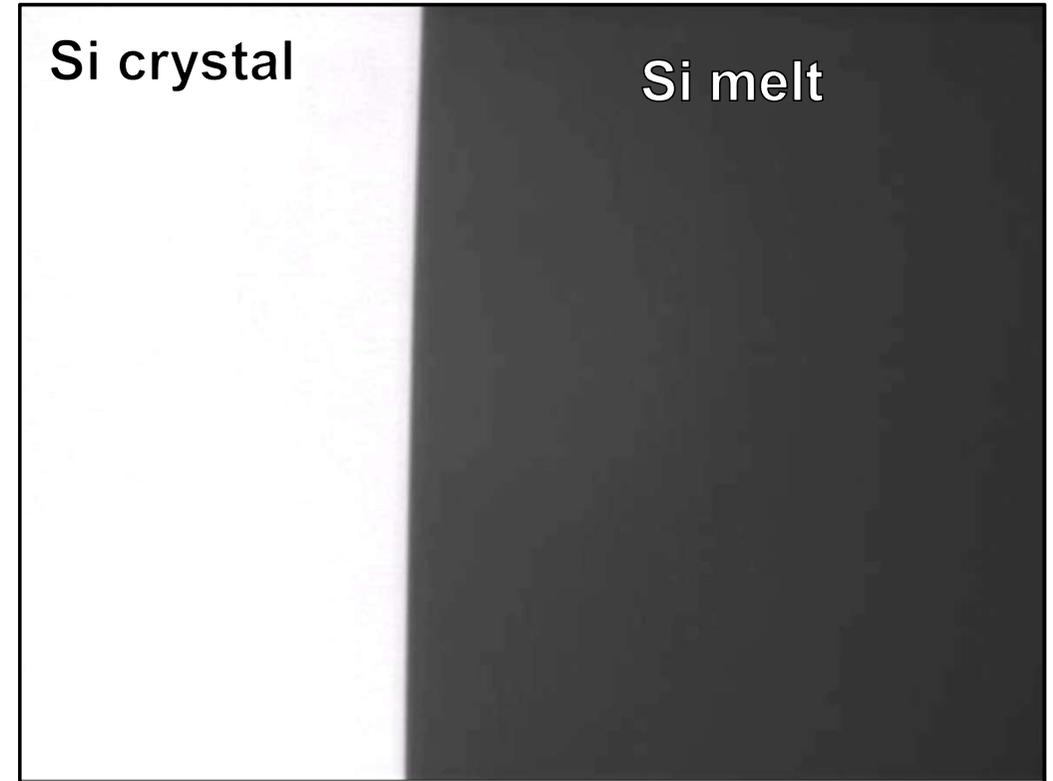
高速動作、高耐熱性、低消費電力、発光、、、

融液成長過程における固液界面のその場観察



J. Crystal Growth **262** (2004) 124.

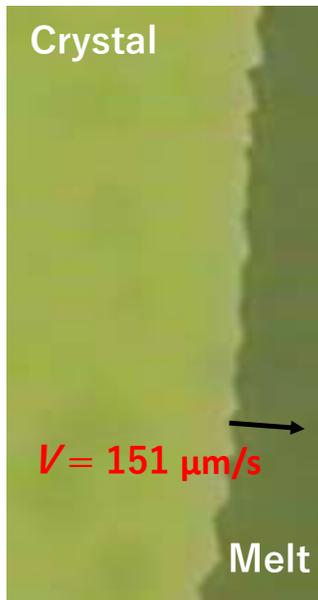
Single crystal



混晶半導体($\text{Si}_x\text{Ge}_{1-x}$)の固液界面不安定化

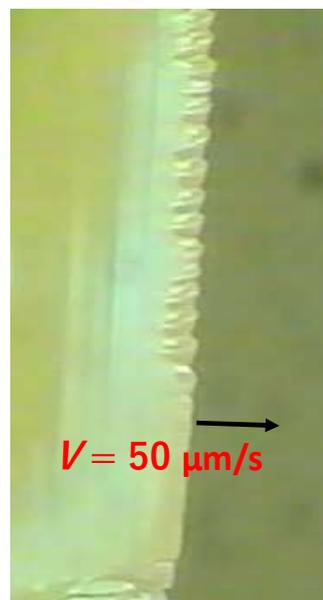
$\text{Si}_x\text{Ge}_{1-x}$ 混晶

Pure Si



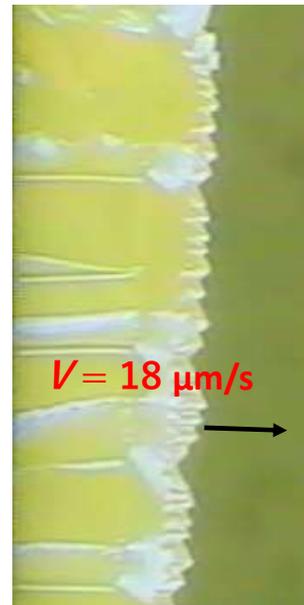
100μm

Ge = 0.65 at%



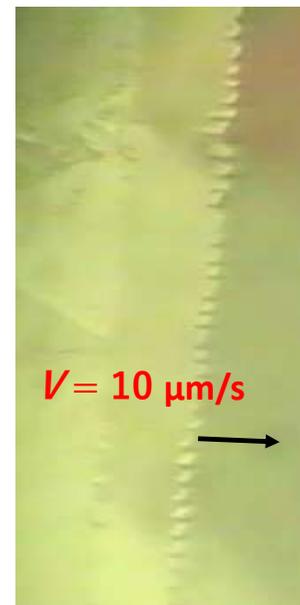
0.5mm

Ge = 2 at%



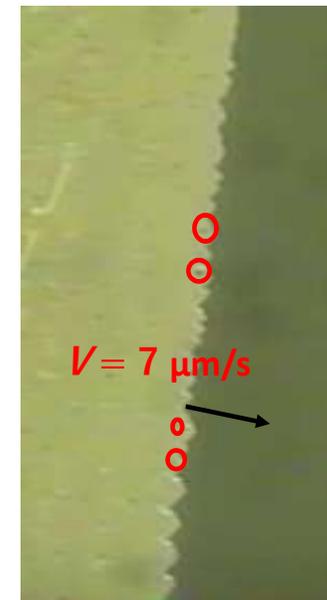
0.5mm

Ge = 5.5 at%



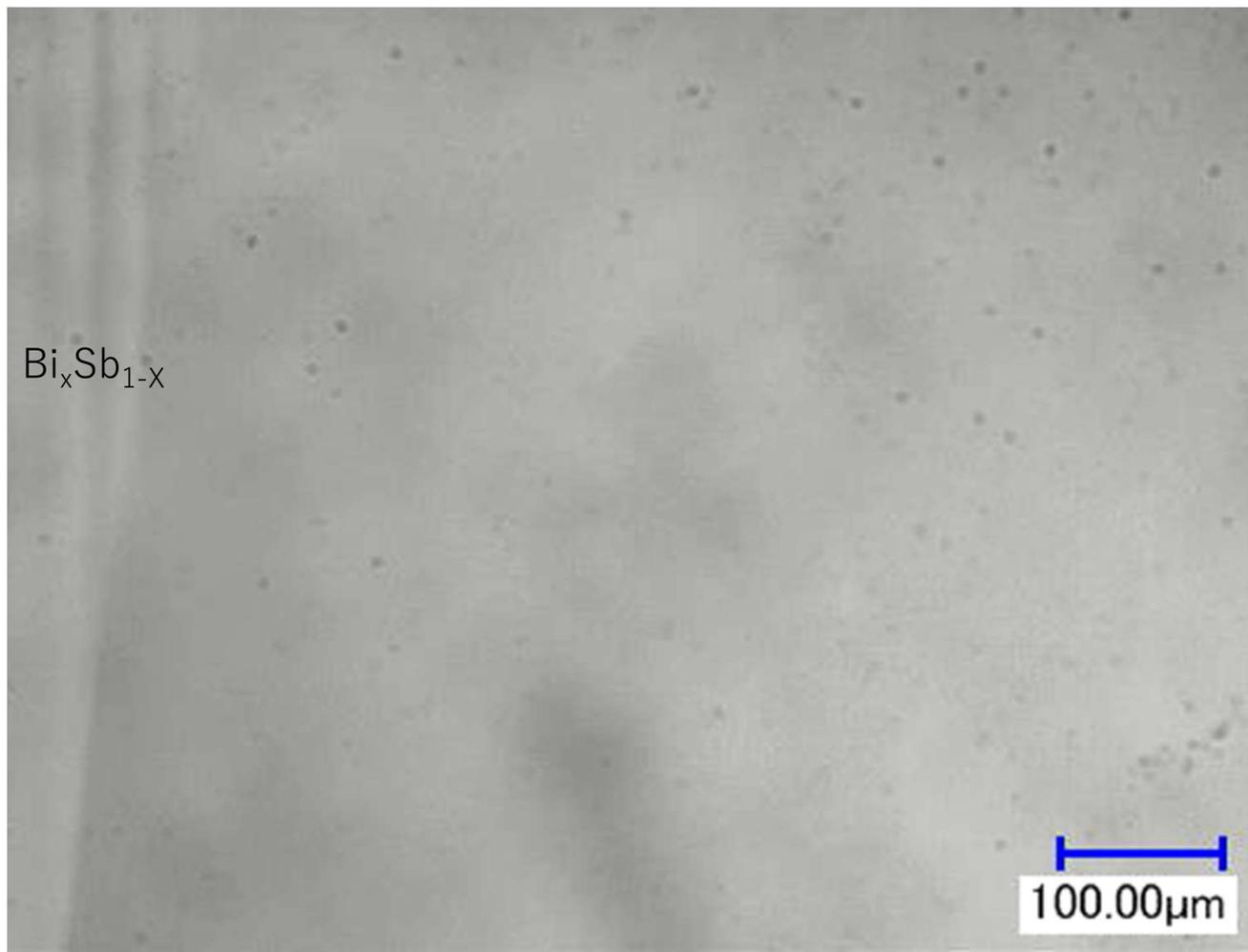
0.5mm

Ge = 11.6 at%



0.5mm

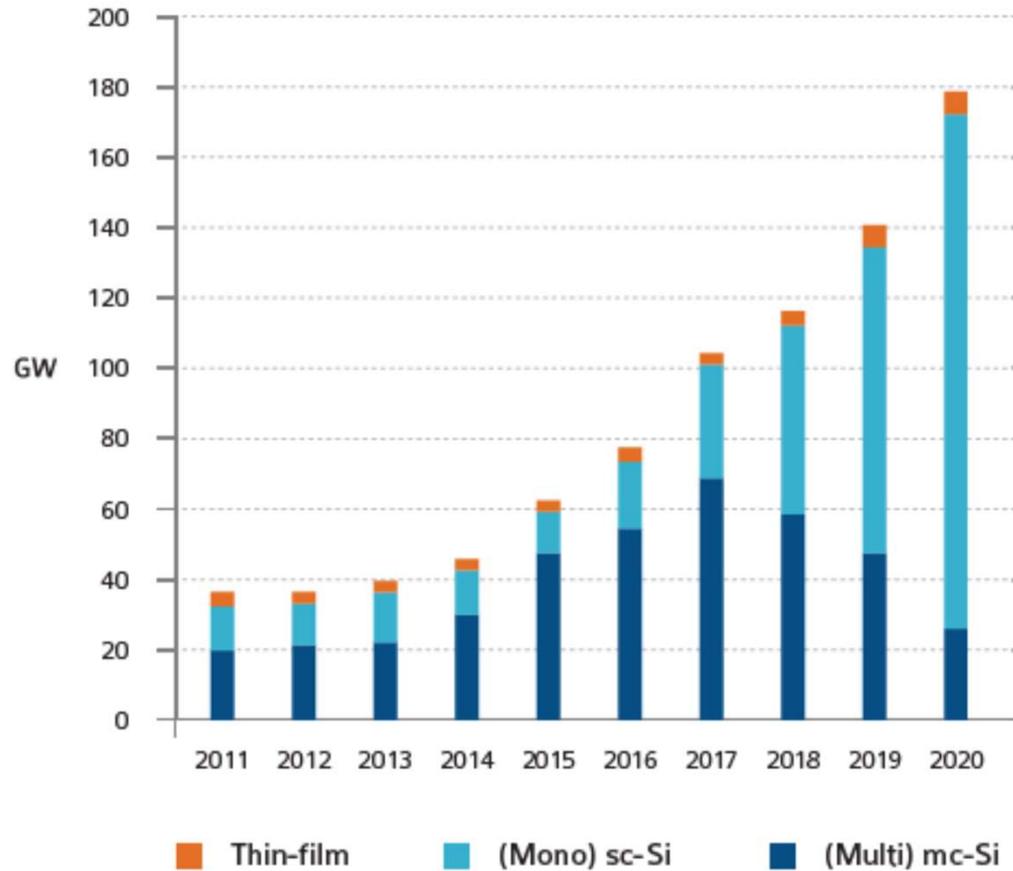
混晶半導体($\text{Bi}_x\text{Sb}_{1-x}$)の固液界面不安定化



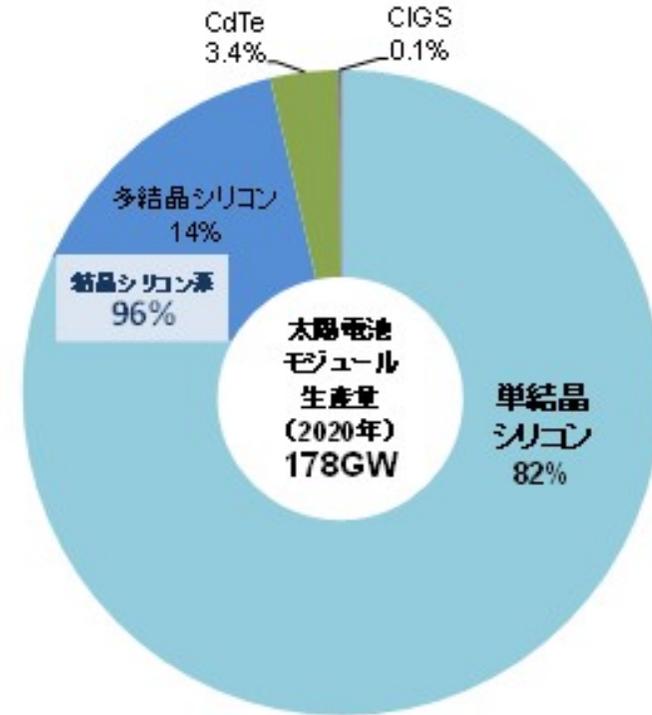
半導体材料の固液界面現象の基礎研究



実用太陽電池の生産量と材料内訳



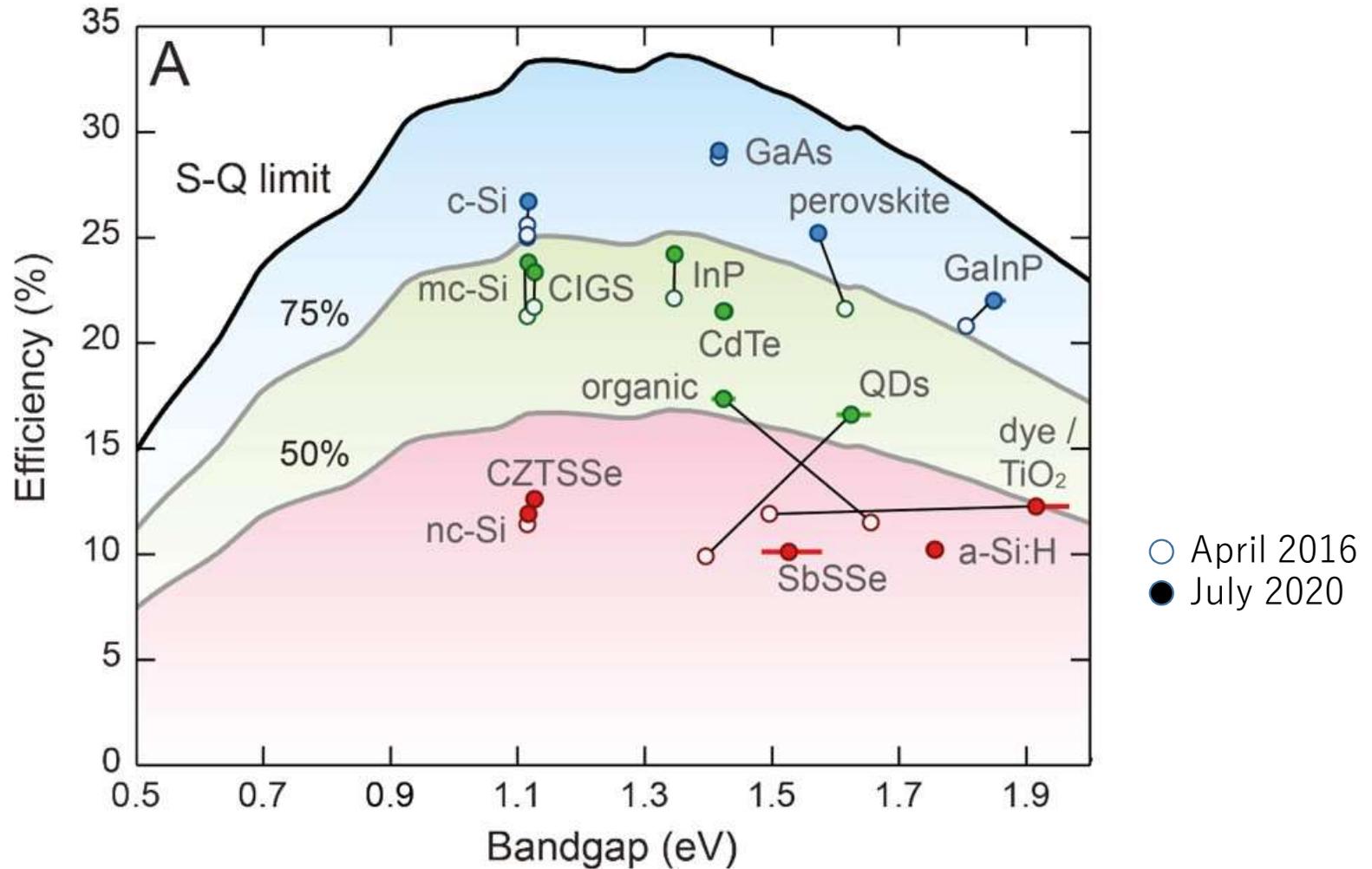
IEA PVPS TRENDS 2021 IN PHOTOVOLTAIC APPLICATIONS



出典：(株) 資源総合システム web site

多結晶シリコンは更なる高品質化結晶成長技術の開発が求められている

各種太陽電池の変換効率



理論限界値 (Shockley-Queisser limit)

B. Ehrler *et al.*, *ACS Energy Lett.* 2020, 5, 9, 3029-3033

各種太陽電池パネルの変換効率

TABLE 4 Confirmed terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m²) at a cell temperature of 25°C (IEC 60904-3: 2008, ASTM G-173-03 global)

Classification	Effic., %	Area, cm ²	V _{oc} , V	I _{sc} , A	FF, %	Test Centre (Date)	Description
Si (crystalline)	24.4 ± 0.5	13177 (da)	79.5	5.04 ^a	80.1	AIST (9/16)	Kaneka (108 cells) ⁴
Si (multicrystalline)	19.9 ± 0.4	15143 (ap)	78.87	4.795 ^a	79.5	FhG-ISE (10/16)	Trina Solar (120 cells) ⁵⁴
GaAs (thin film)	25.1 ± 0.8	866.45 (ap)	11.08	2.303 ^b	85.3	FhG-ISE (11/17)	Alta Devices ⁵⁵
CIGS (Cd free)	19.2 ± 0.5	841 (ap)	48.0	0.456 ^b	73.7	AIST (1/17)	Solar Frontier (70 cells) ⁵⁶
CdTe (thin film)	18.6 ± 0.5	7038.8 (da)	110.6	1.533 ^d	74.2	NREL (4/15)	First Solar, monolithic ⁵⁷
a-Si/nc-Si (tandem)	12.3 ± 0.3 ^f	14322 (t)	280.1	0.902 ^f	69.9	ESTI (9/14)	TEL Solar, Trubbach Labs ⁵⁸
Perovskite	11.6 ± 0.4 ^g	802 (da)	23.79	0.577 ^h	68.0	AIST (4/18)	Toshiba (22 cells) ¹⁹

M. A Green *et al.*, *Prog. Photovolt. Res. Appl.* **27**, 565-575 (2019).



CdTe薄膜の多結晶組織

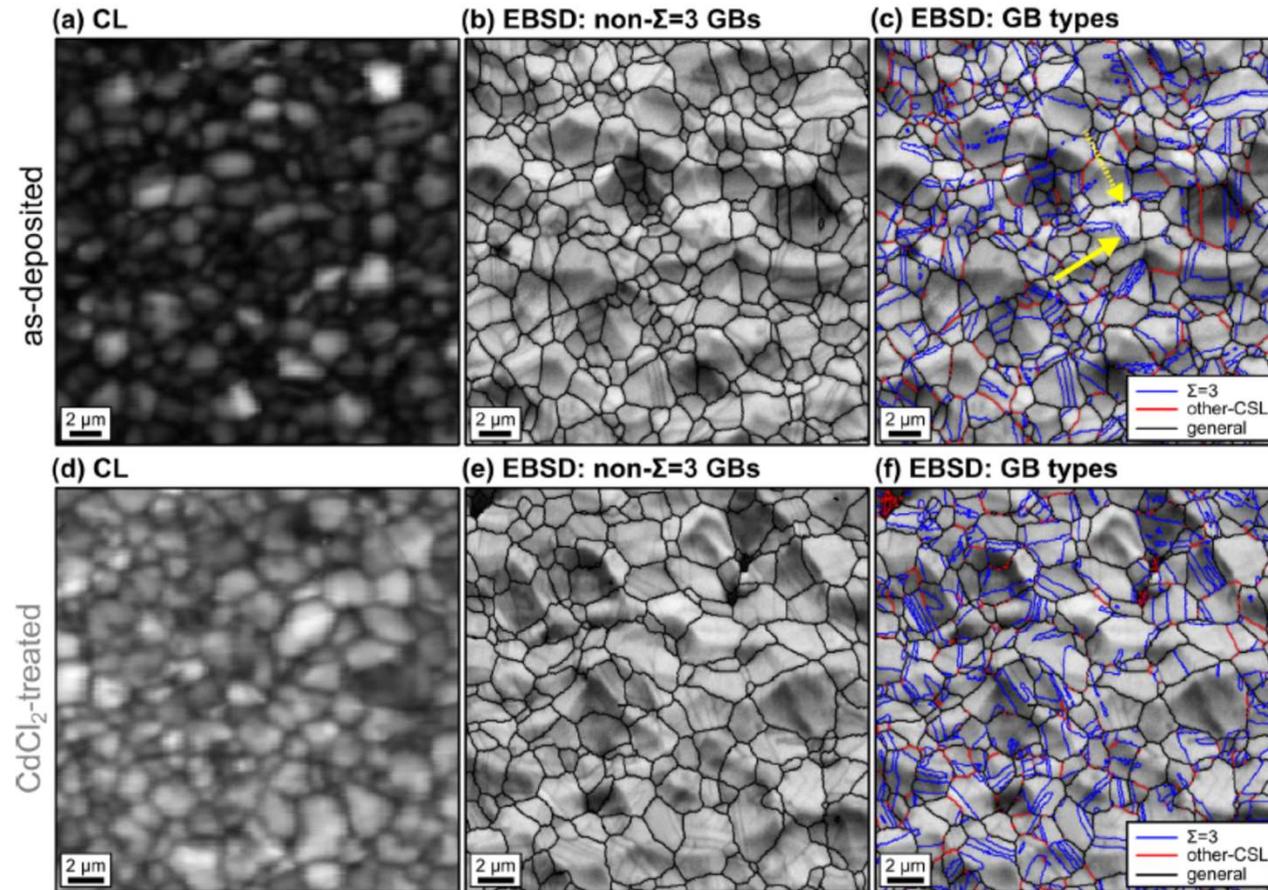
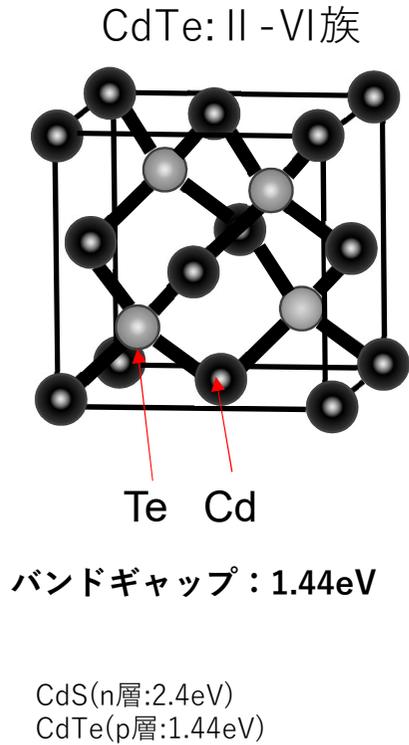


FIG. 3. The top row [(a)–(c)] and bottom row [(d)–(f)] correspond to CL images and EBSD maps for the as-deposited and CdCl₂-treated films, respectively. (a) and (d) are total intensity CL images; (b) and (e) are EBSD GB maps showing non- $\Sigma=3$ GBs in black; and (c) and (f) are EBSD GB-type maps showing $\Sigma=3$, other-CSL, and general GBs. We cataloged the CL intensity at the GBs by type.

CdTe薄膜の多結晶組織

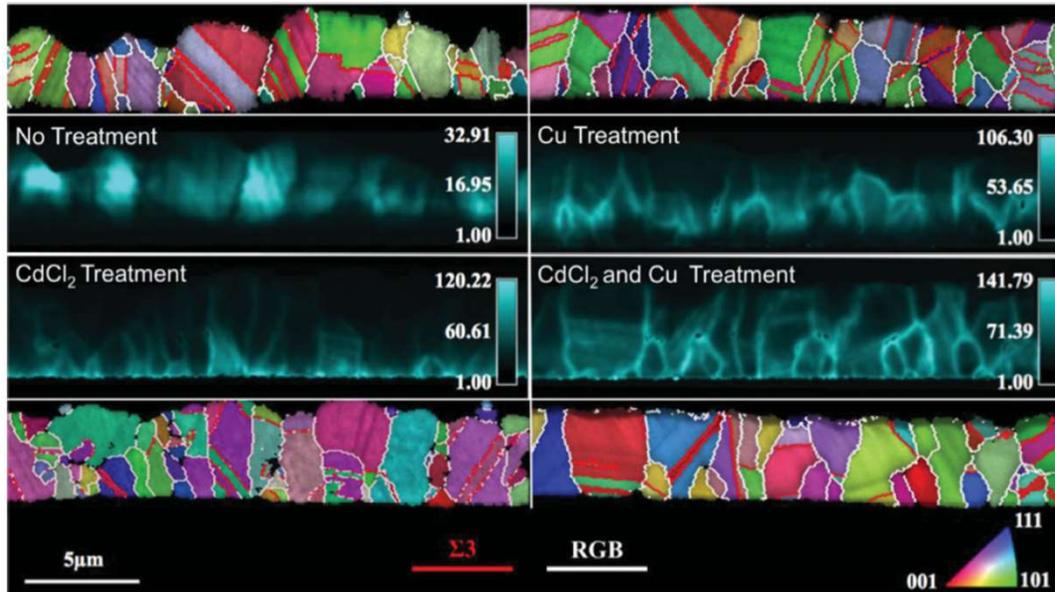


Figure 7. EBIC and EBSD maps of untreated, CdCl₂ treated, Cu treated and CdCl₂/Cu treated CdTe solar cells. Reprinted, with permission, from [75].

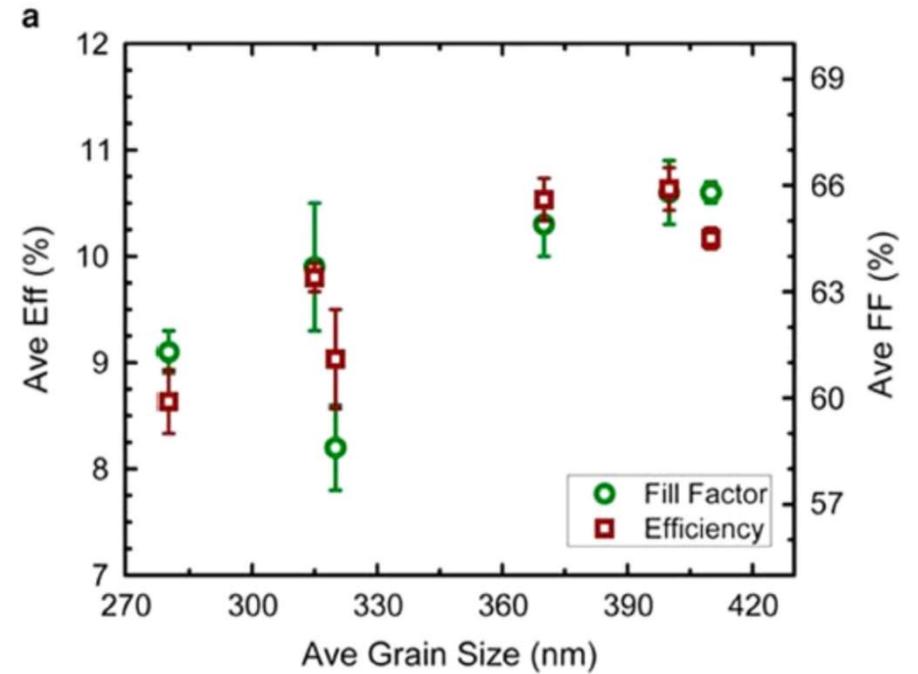


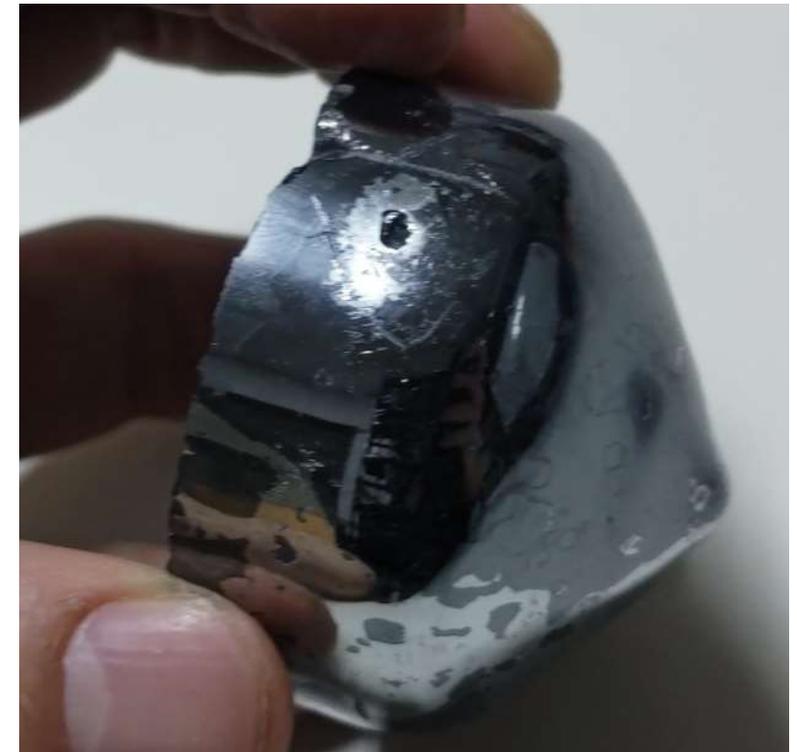
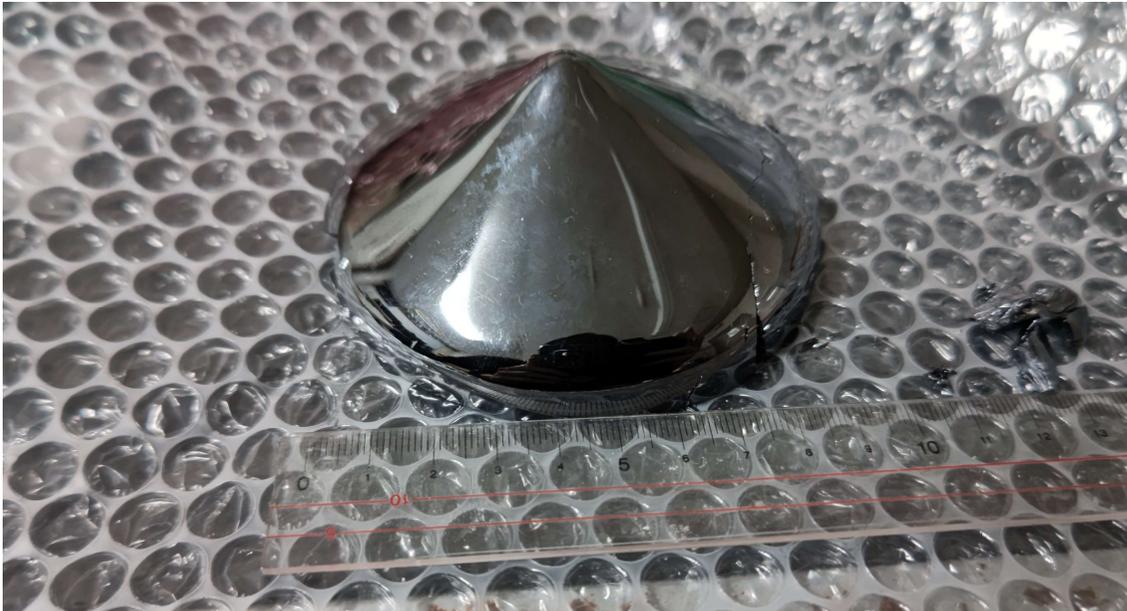
Figure 12. (a) Average efficiency and FF versus nontwin-corrected average grain size for CdCl₂-treated samples. (b) Average efficiency and FF versus twin-corrected grain size for CdCl₂-treated samples. Reprinted with permission from [152], Cambridge University Press.

J. D Major, *Semicond. Sci. Technol.* **31**, 093001 (2016).

融液成長によりCdTe多結晶の粒径を大きくすることができる

高品質CdTe単結晶インゴットの成長技術開発

当グループのCdTe結晶



大型CdTe結晶の成長技術開発
CdTe多結晶の融液成長メカニズムの基礎研究

東北大医学部、歯学部
静岡大 との共同研究

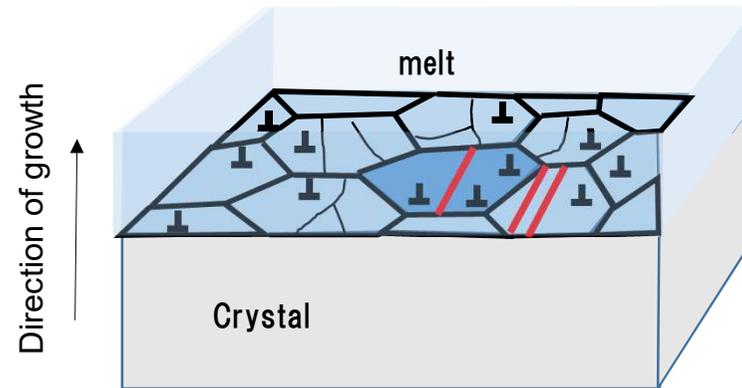
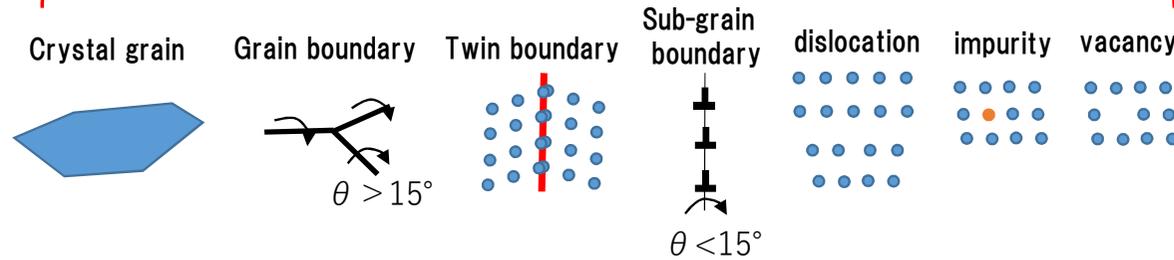
多結晶の組織と固液界面

Microstructural elements of polycrystalline structure

Mc-Si wafer



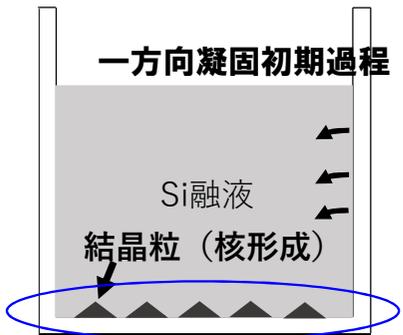
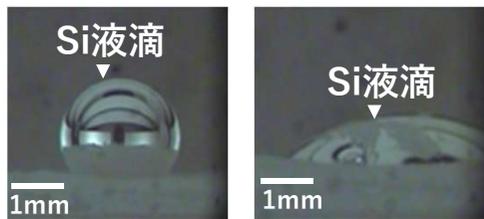
15.6cm□



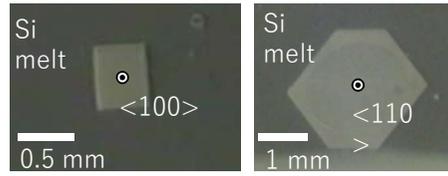
- ・多結晶組織を形成する各構造成分が固液界面現象に及ぼす影響？
- ・固液界面における多結晶組織の形成メカニズム？
- ・固液界面エネルギー、粒界エネルギー、粒界の熱伝導率？

Si多結晶の融液成長メカニズムの研究

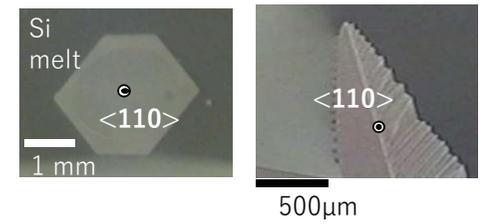
ルツボとの濡れ性制御



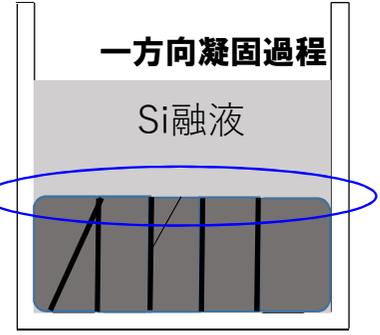
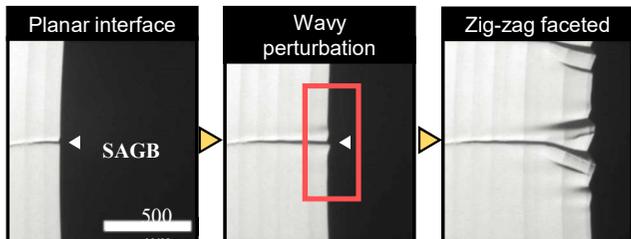
配向性制御



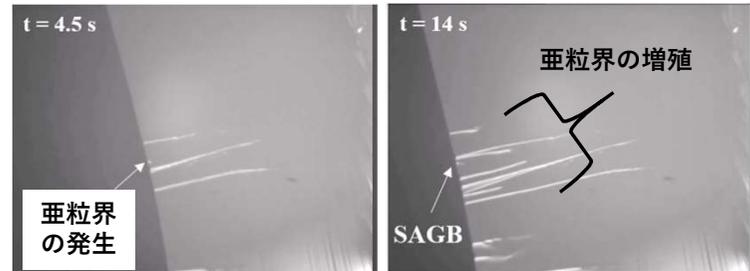
成長モード制御



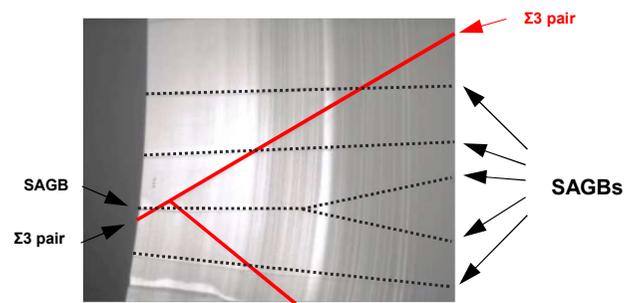
多結晶の固液界面形状制御



固液界面における亜粒界発生の制御

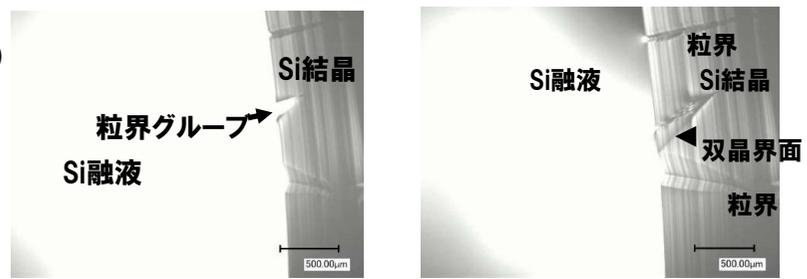


粒界による亜粒界増殖の抑制

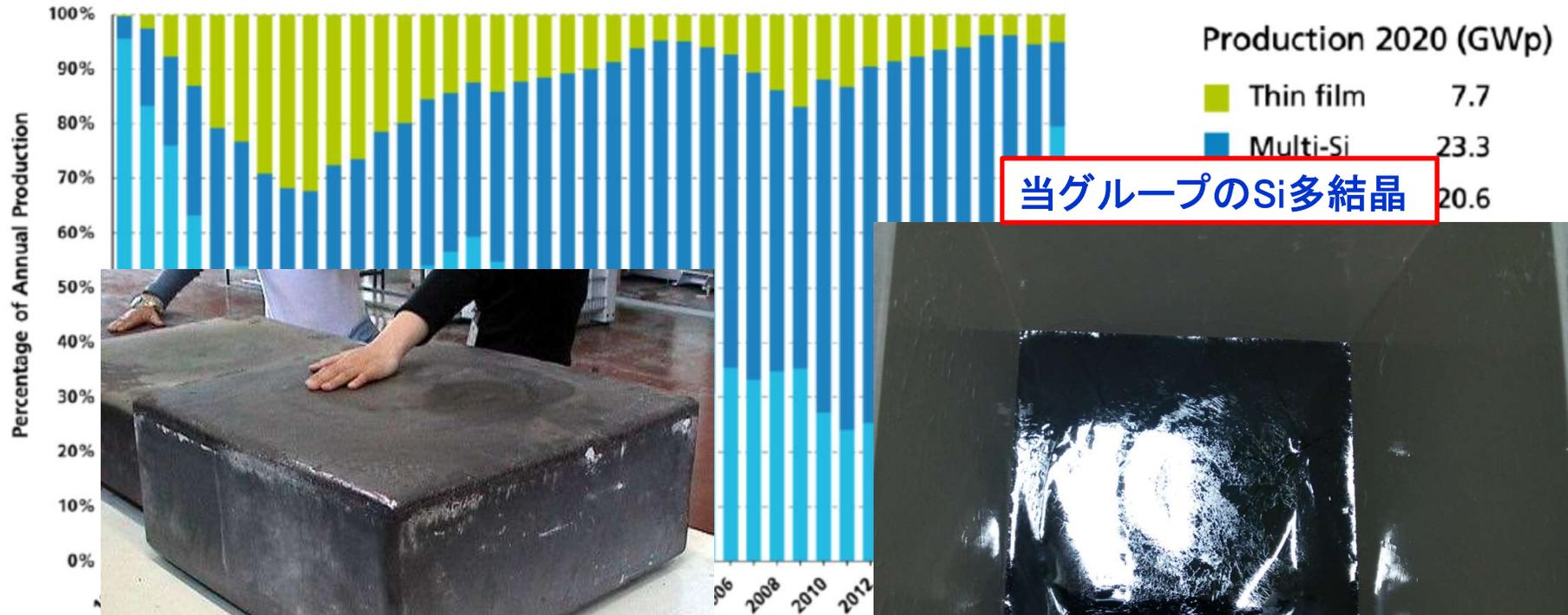


Im2np (マルセイユ大学)
IKZ (ドイツ)
大阪大学などと研究協力

固液界面における双晶界面形成制御



太陽電池用高品質Si多結晶インゴットの成長技術開発



今後の展開

各種半導体の融液成長メカニズムの基礎研究

太陽電池用多結晶材料（Si、CdTe）の高品質化

➡ 熊谷先生、ロディオン先生

Si, CdTe結晶基板を用いた新規機能発現

➡ 塚崎先生