Single crystal cells

silicon cells:

- basic design
  - fabrication
    - strategies for high efficiency
      - light management
        - minimising resistive losses
          - minimizing recombination losses

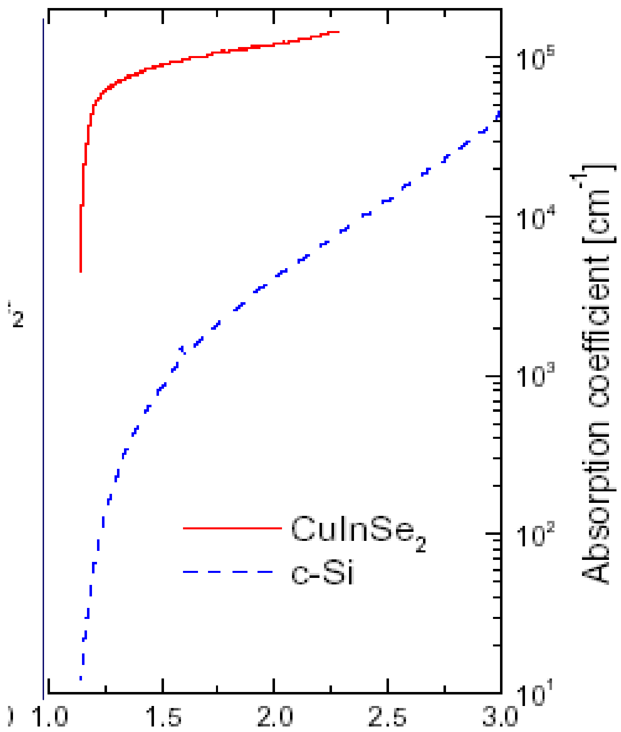
GaAs cells

- basic design
  - problems
    - special applications

Silicon cells

- ❑ single crystal: efficiency η up to 24.7% (module 22.7%)
- ❑ multicrystalline: η ~20 % (module 15%)
- ❑ a-Si: η~10%

indirect bandgap – poor absorption

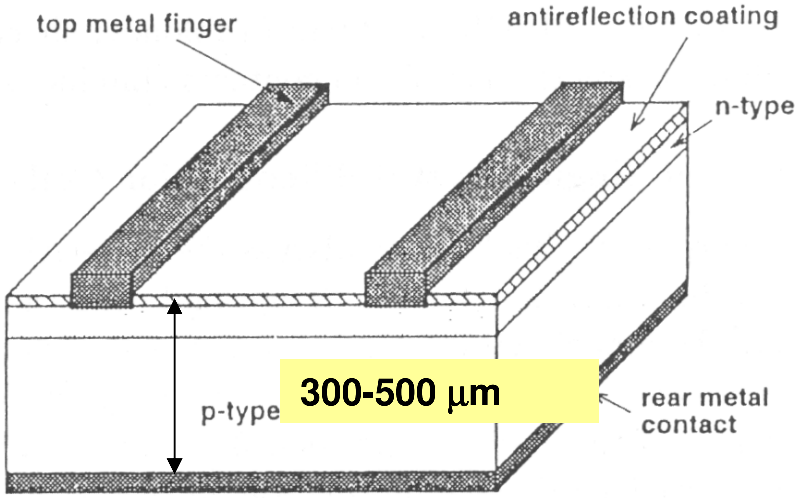


hν(eV)

exp(αd)>>1 for d>200 μm

photovoltaic-grade Si properties:
doping ~10^{16} cm^{-3}
mobility ~1000 cm^2/Vs
minority carrier diffusion length 100 μm
sheet resistance 0.1 Ωcm^2 (for d= 500 μm)

Monocrystalline silicon



standard

$\eta = 15 - 18\ \%$

fabrication steps:

sand

p-type crystal growth

Czochralski process, float zone process

slicing, etching

n-doping

(phosphorus diffusion, ion implantation)

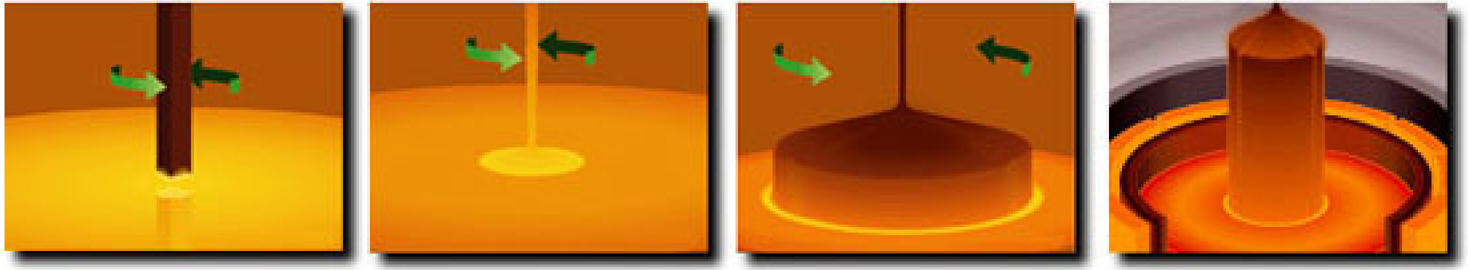
contacts

screen printing, electroplating

antireflection coating

(screen printing, sputtering)

Czochralski process of c-Si growth



boron-doped during growth

Single Crystal Silicon Ingot

d ~15 cm

CZ Crystal Pullers
(Mitsubishi Materials Silicon)

Typical Si cell parameters

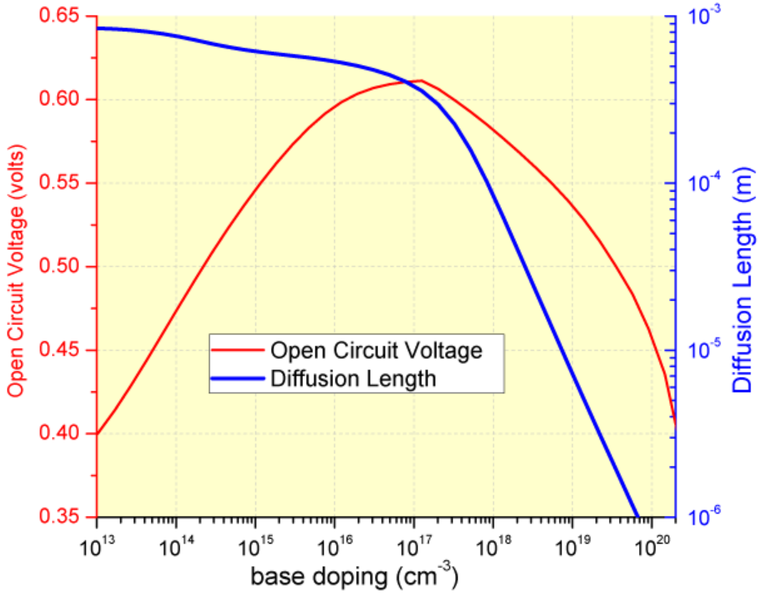
	emitter **n-type**	**base** **p-type**
thickness	0.5 μm	300 μm
doping	10^{19} cm^{-3}	10^{16} cm^{-3}
minority carrier diffusion length	14 μm	140 μm
minority carrier lifetime	10^{-6} s	$5x10^{-6}$ s

Problems:

- poor absorption of long-wavelength photons
- rear surface recombination
- series resistance

Optimisation of the cell design

doping vs recombination losses



Optimisation of the cell structure:

low series resistance ⇒ high doping of emiter ⇒ low diffusion length in the emitter

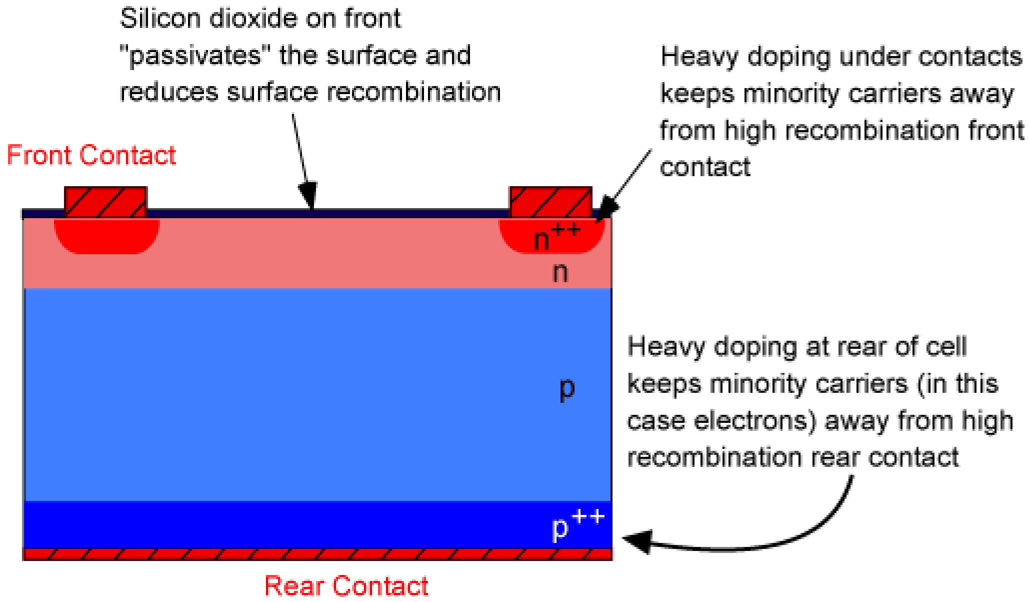
⇓

shallow junction neccesary to avoid „dead layer” effect

⇓

reduction of the front surface recombination neccesary

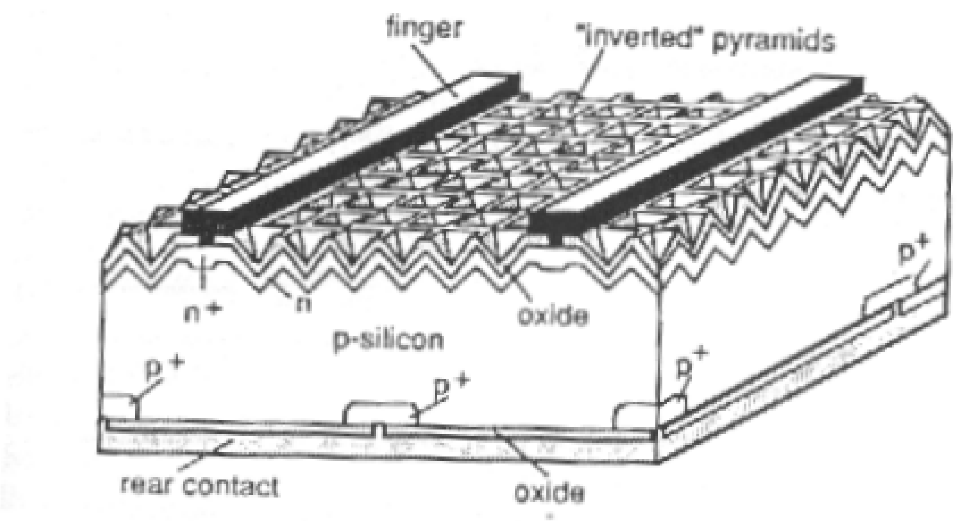
Reducing recombination at front and back electrode



passivation of the front surface (oxides, nitrides)
high doping close to the electrical contacts

Strategies for high efficiency

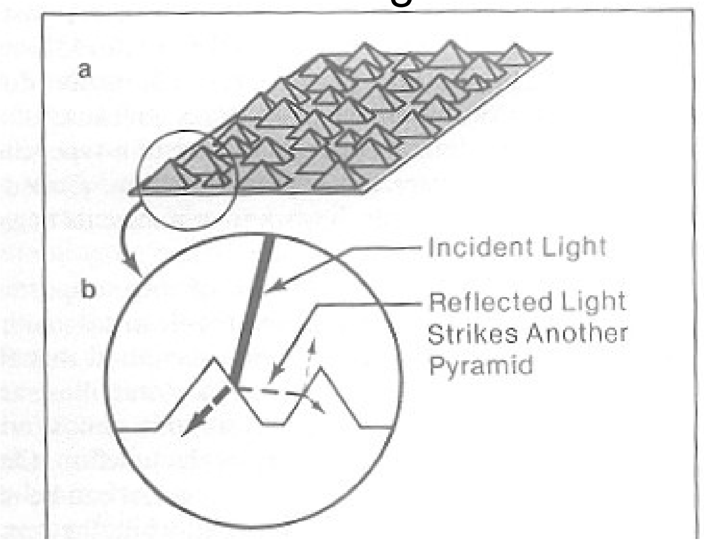
- enhance absorption – antireflective coating, texturing
- contacts optimization - buried contacts
- reduce surface recombination - back surface field, passivation of front and back contacts, rear point contacts

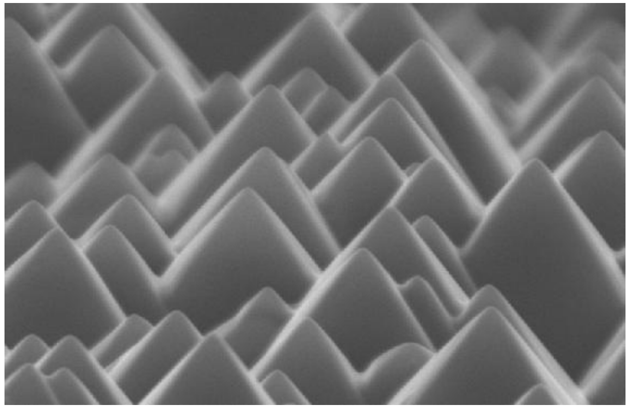


PEARL cell *(Passivated Emiter, Rear Locally-Difused)* $\eta = 24,4\ \%$

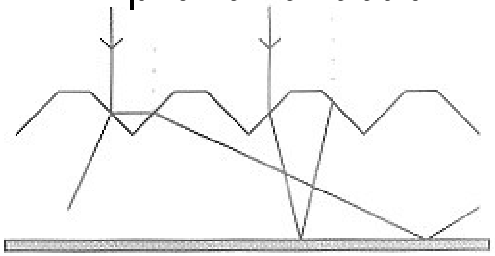
Maximise absorption - texturing

etching

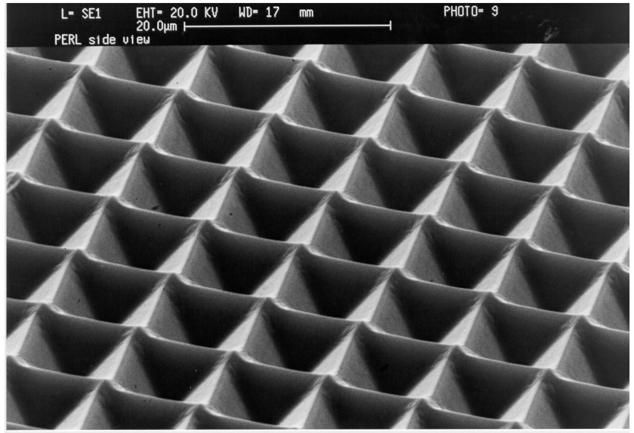




inverted pyramids
– improve reflection



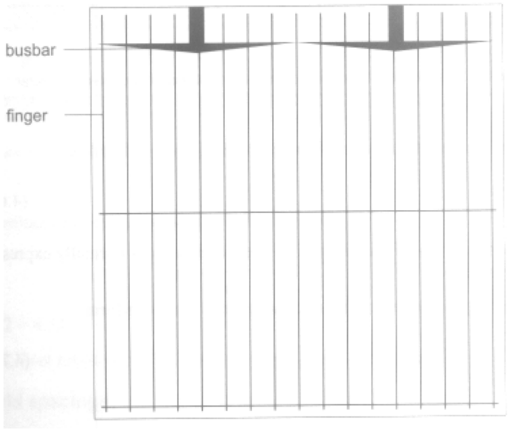
(a)

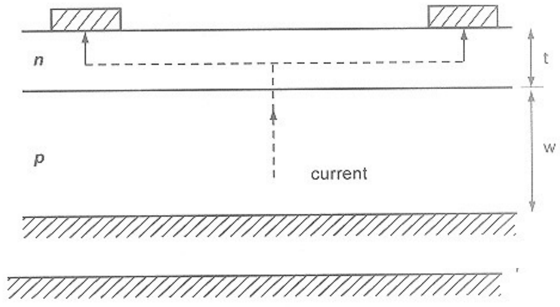


Light trapping

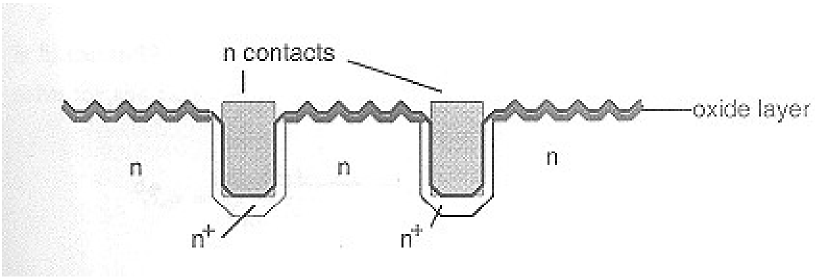
Maximise absorption and minimise series resistance

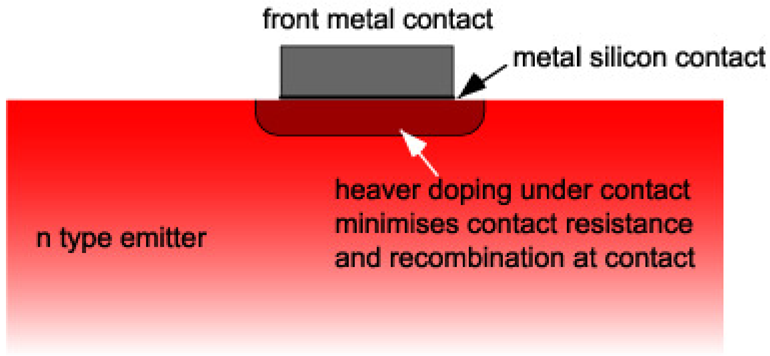
optimisation of grid fingers





Important: sheet resistance ρ/t
grid spacings

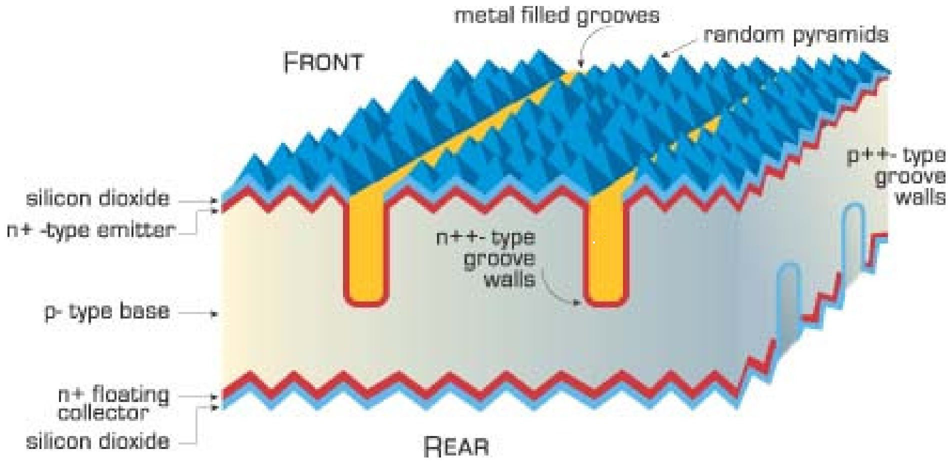


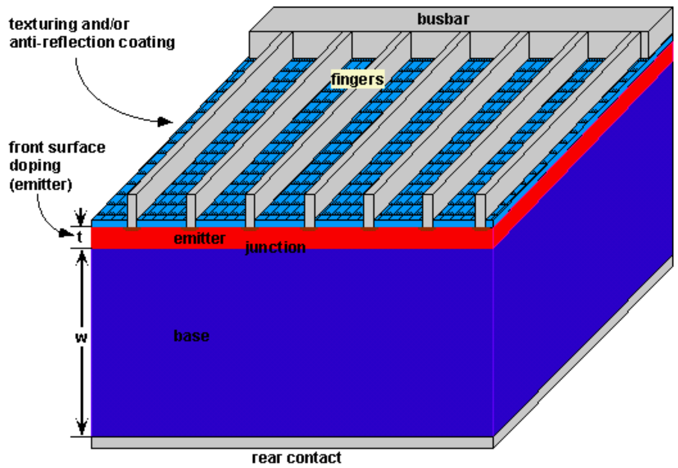


„buried contacts" : minimised shaded area, large contact area

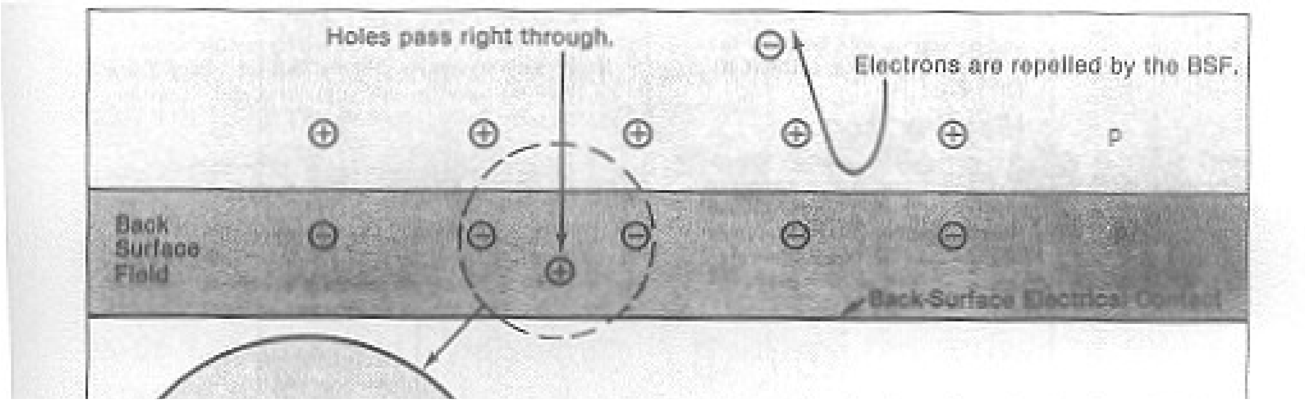
Costs!

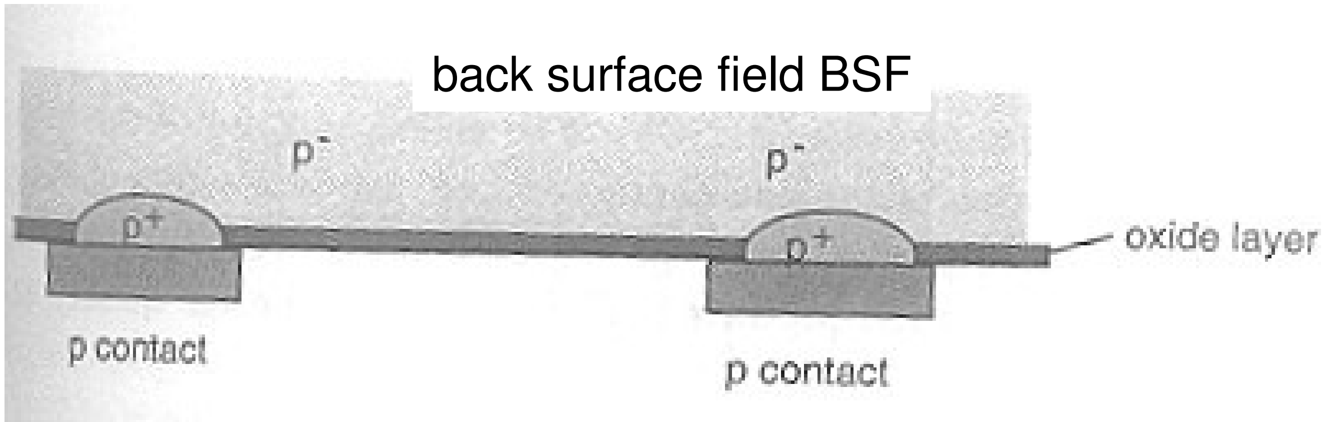
buried contacts cell





Minimise back contact recombination





rear point contact cell

✓**passivation of the back surface with oxide**

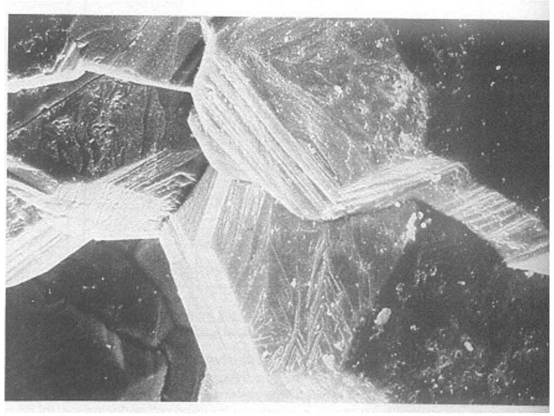
✓ **differential doping close to contacts**

Polycrystalline and multicrystalline Si – cost reduction

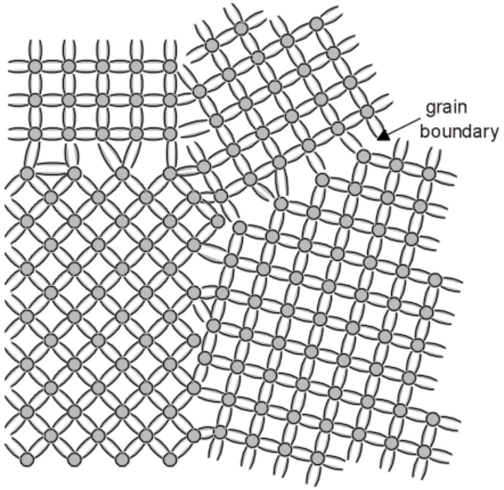
Multicrystalline

grain size ~ layer thickness (mm)
2-3% less efficiency,
80% costs

Methods:
casting
ribbon growth
thin film deposition …



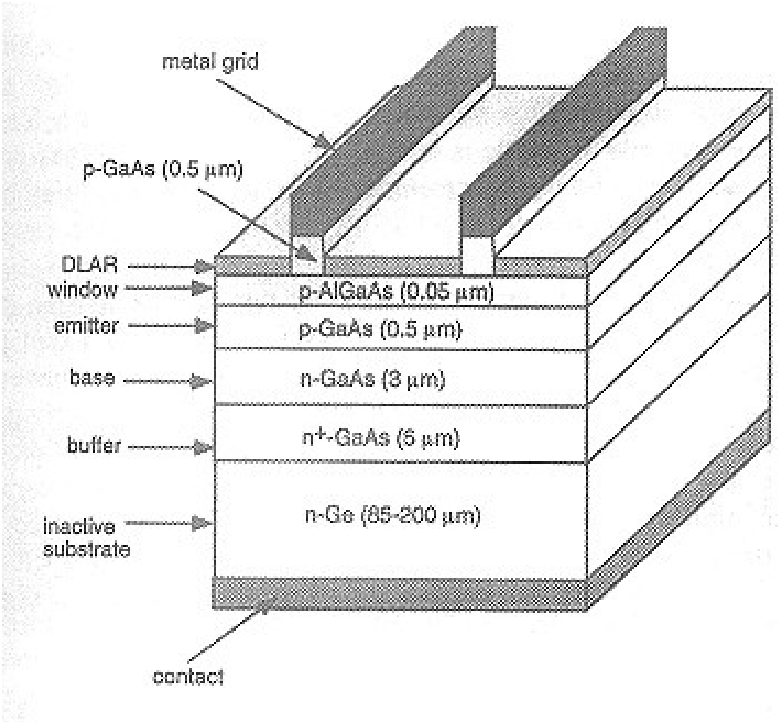
Polysilicon Ingots



Policrystalline:
recombination via grain boundaries important

Single crystal GaAs cell, η up to 25%

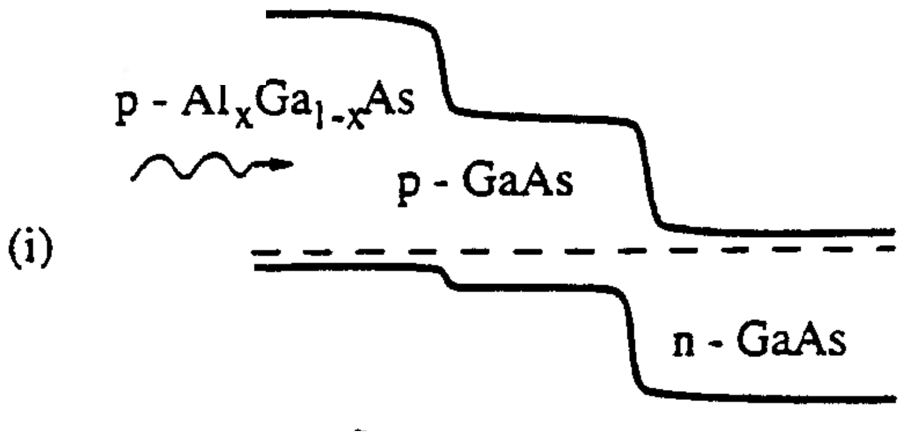
Space applications



Direct bandgap, Eg=1.42 eV closer to optimum
absorption α ~10-100 x higher than in Si

much thinner layer

COSTS!



Higher bandgap in the emitter ⇨ reduced surface recombination

Applications of GaAs-based cells

✓ Space applications:

lightweight,

more radiation-resistant

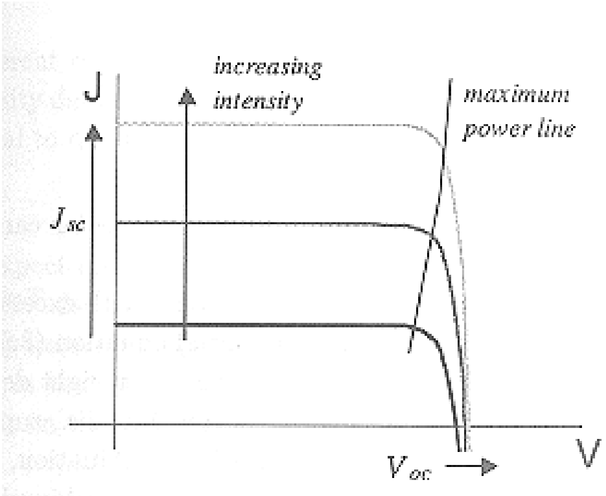
✓ Under concentrated light:

lower probability of Auger recombination

better thermal coefficient

	Emitter n-type	**Base p-type**
thickness	0.5 μm	4 μm
doping	10^{18} cm^{-3}	10^{17} cm^{-3}
minority carrier diffusion length	1.4 μm	3 μm
minority carrier lifetime	10^{-9} s	10^{-8} s

Efficiency increase under concentration

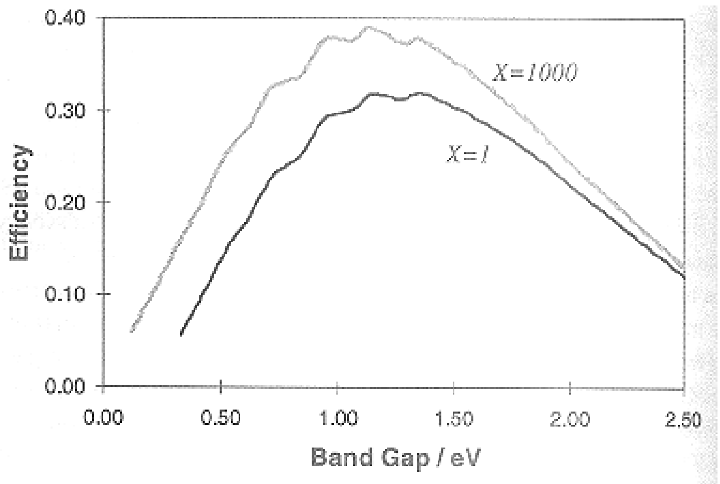


record cells

GaAs 27.6% under 255 suns

Si 26.8% under 90 suns

under concentration optimum bandgap is lower



GaAs is still better than Si:
1.lower thermal coefficient
2. lower probability of Auger recombination
under concentrated lignt