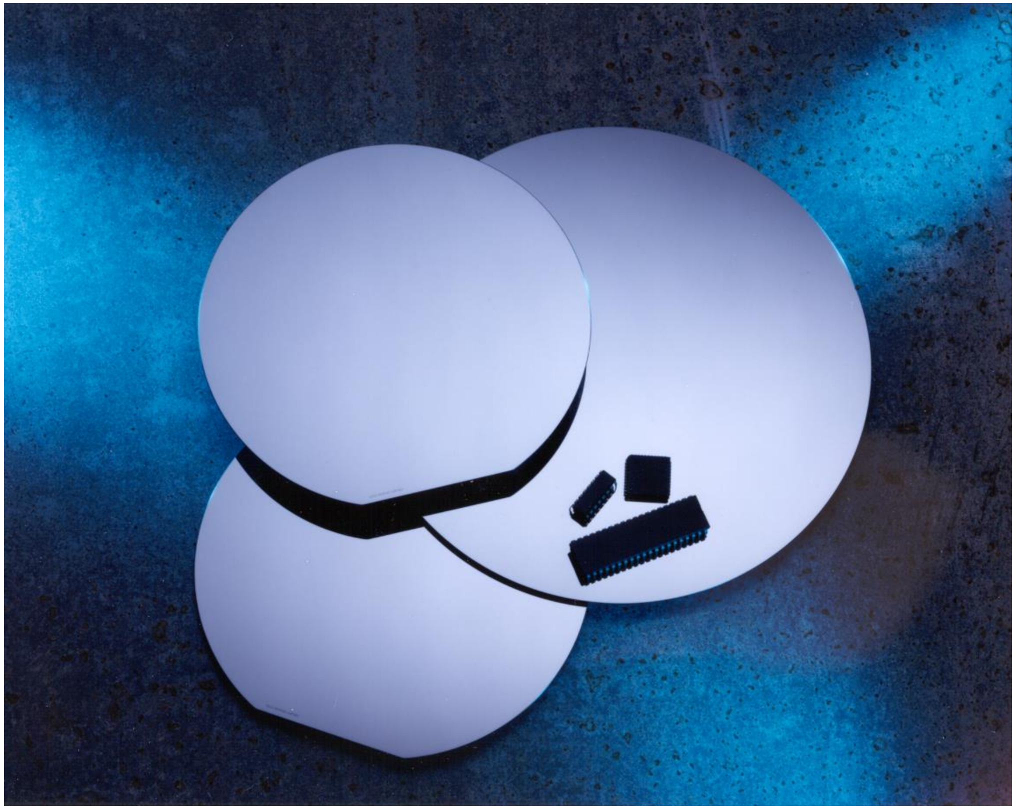
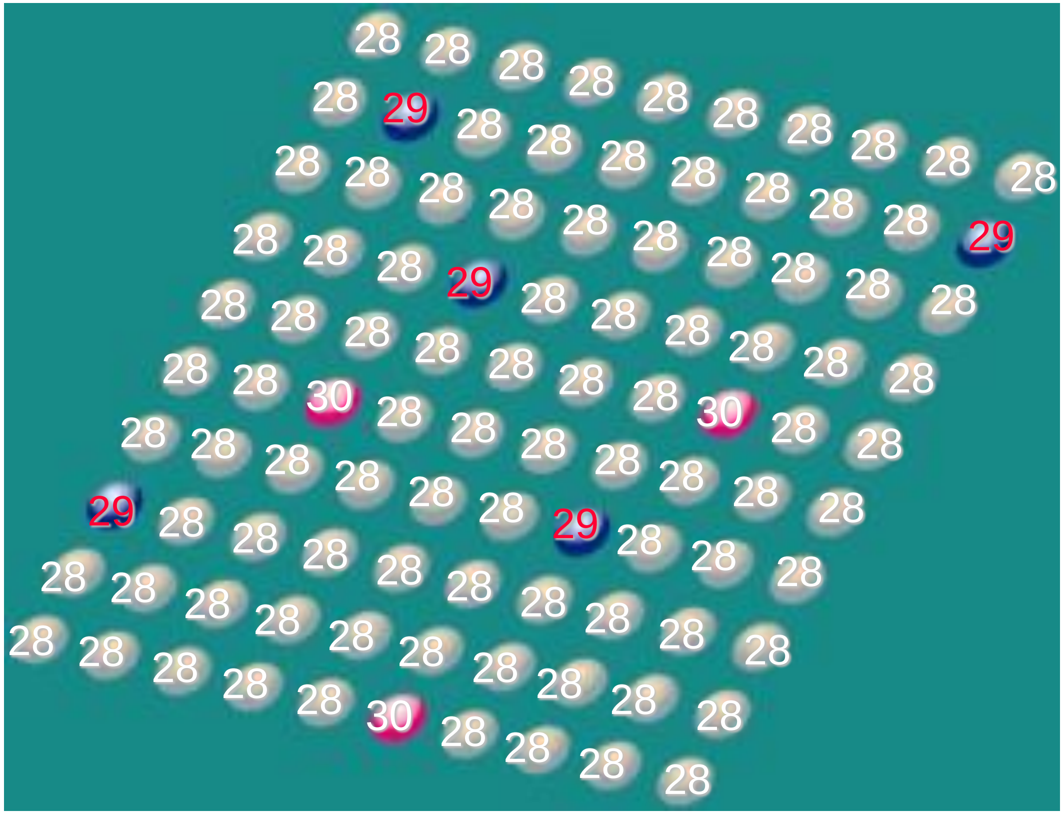
Silicon-28

Next Generation Material for Semiconductors



What is Isotopically Pure Silicon ?



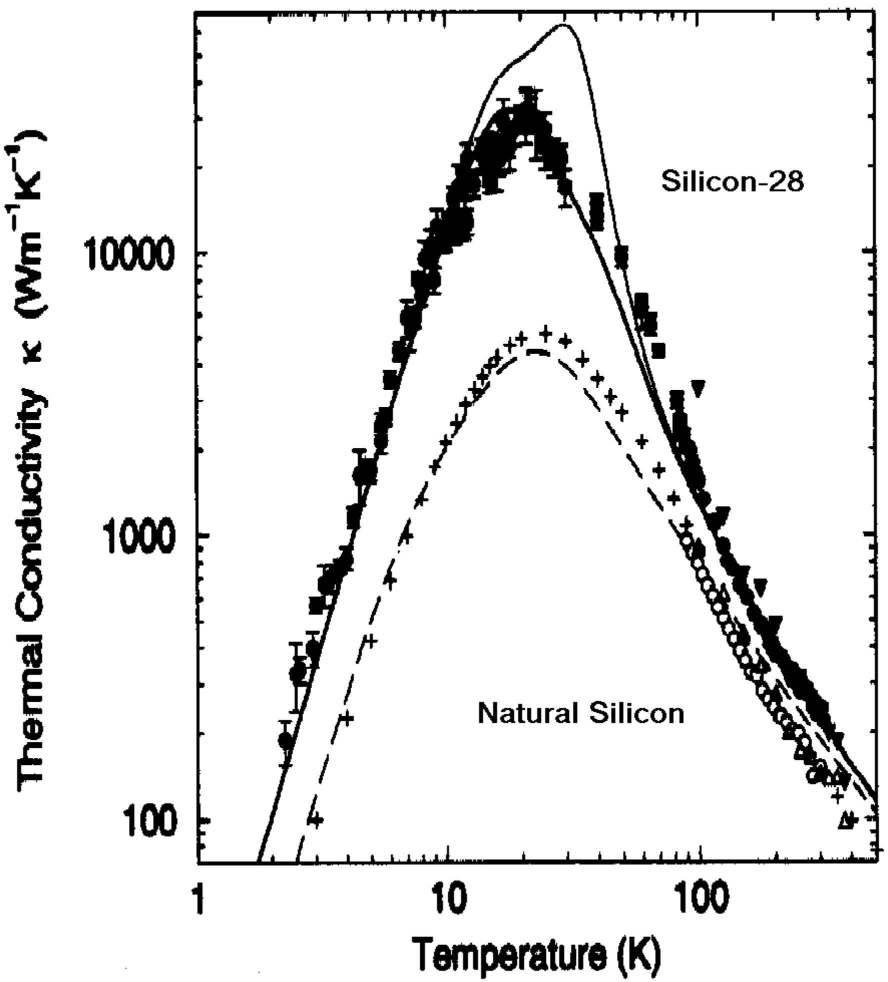
	Natural	**Purified**
Si-28	**92%**	**>99.9%**
Si-29	**5%**	**<0.1%**
Si-30	**3%**	**<<0.1%**

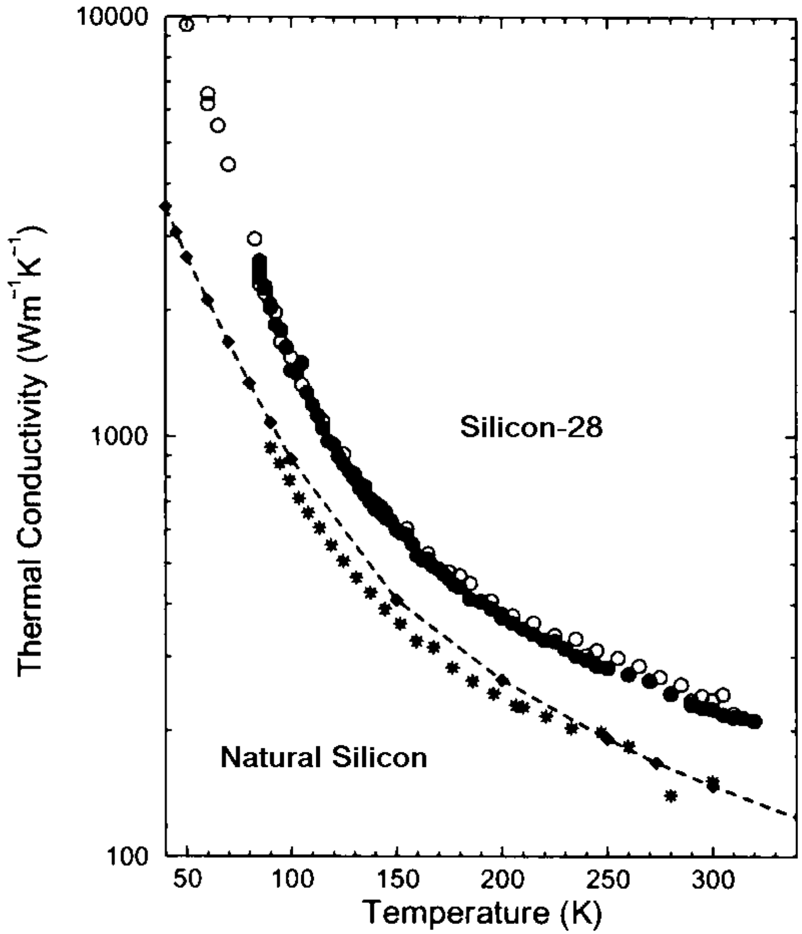
Available Forms

SiF_4

TCS

Thermal Conductivity of Silicon



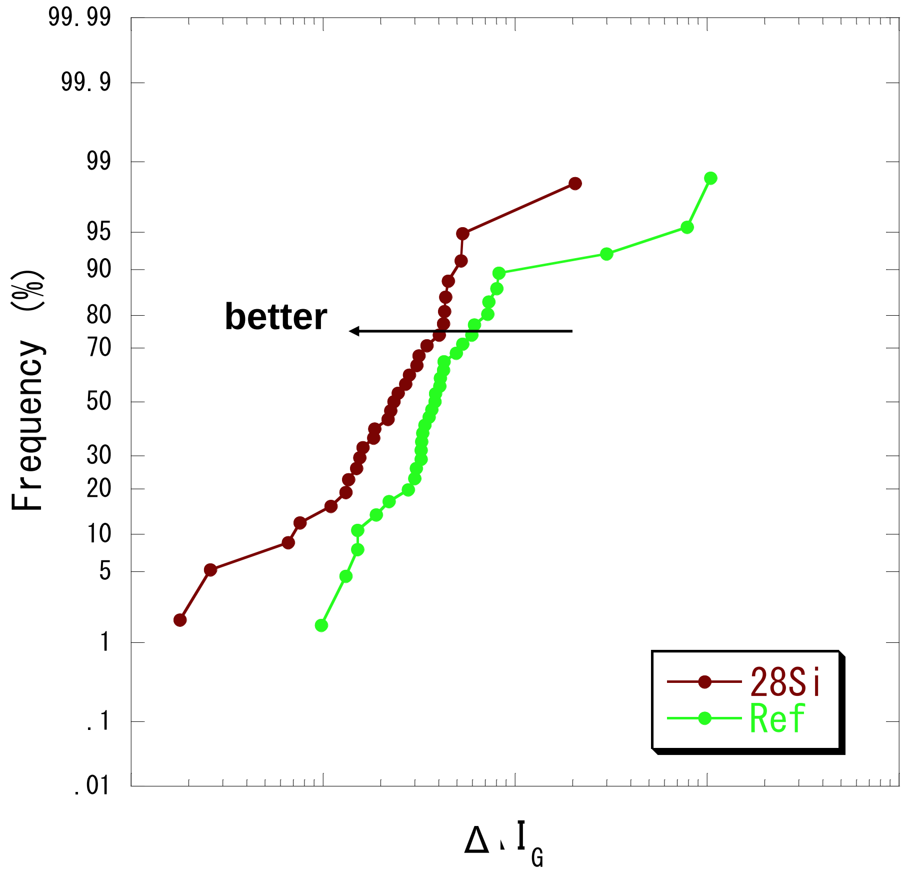


Si-28 Gate Oxide Integrity

90 nm Technology

200mm epi wafers

2μ epi layer



$\Delta I_G = I_G$ (after stress: 2.7V,2000s) - I_G (initial) = SILC (stress induced leakage current)

Thermal Images of 60W Power Amplifier

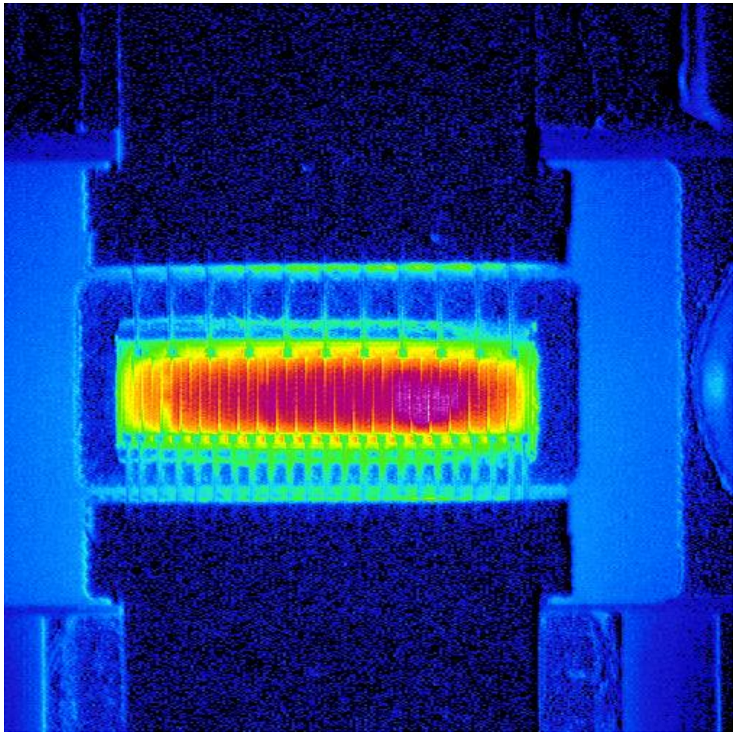
Actual Die size – 5.5 mm x 1.5 mm
50 microns thick
CuW package/heat sink

Junction Temp Tj=125.3 C

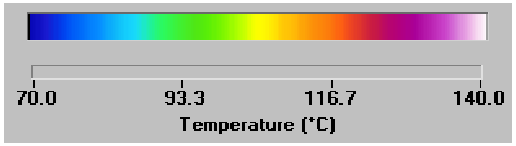
Temp =0.94 C/W

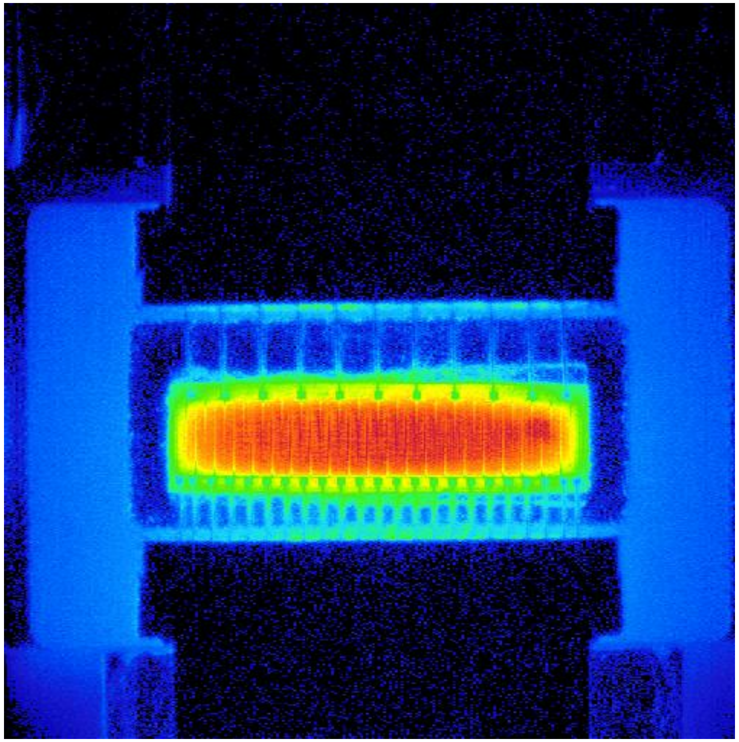
Junction Temp Tj=120.4 C

Temp =0.84 C/W



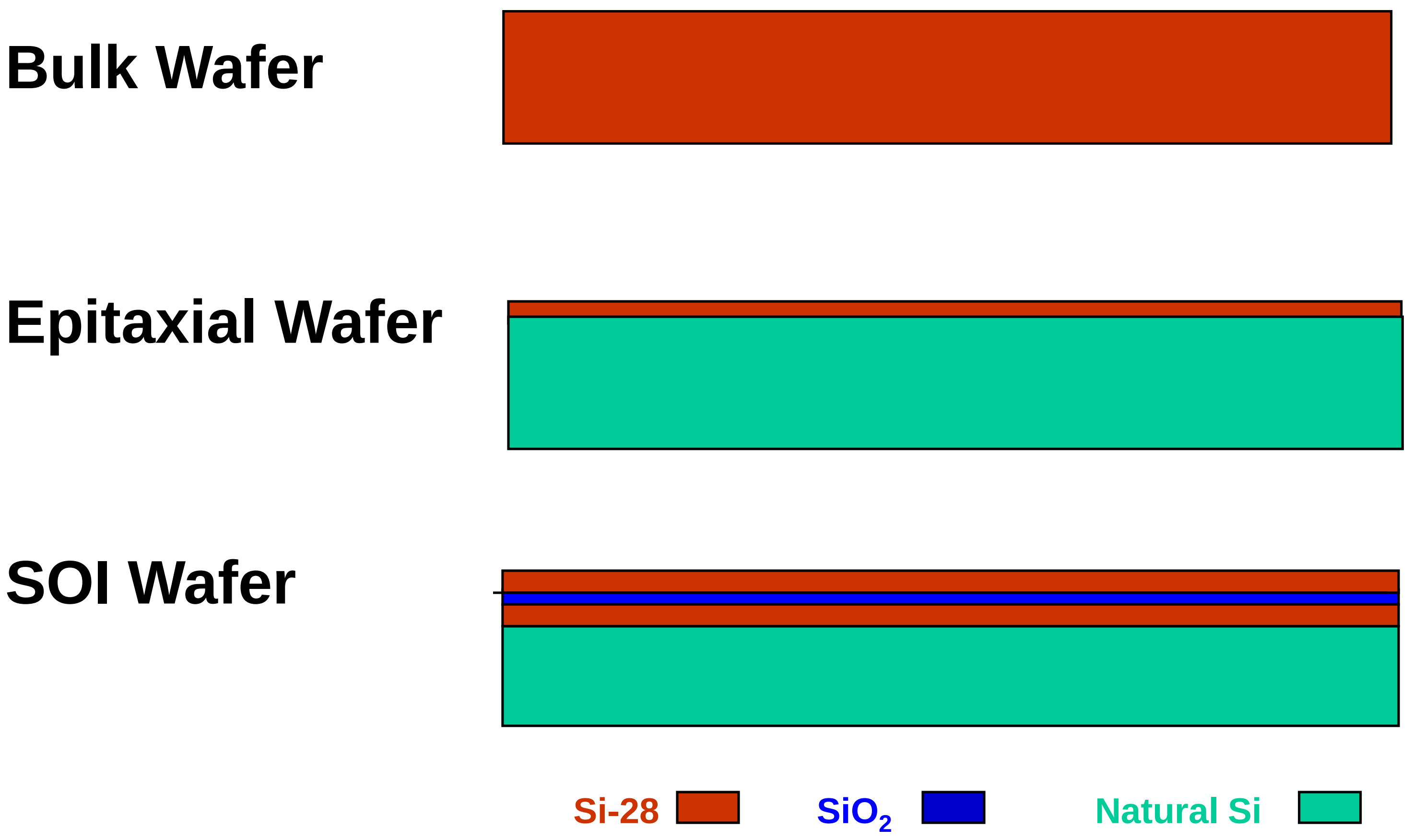
Natural Silicon





Silicon-28

Silicon-28 Wafer Types



Summary of Epi Wafer Testing

- **Thermal benefits documented for epi wafers**
  - **12- 15^{o}C <u>peak</u> temperature reduction at $\geq$ 50 microns**
- **5-7^{o} average reductions seen for transistor junction temperatures in CMOS & SOI wafers**
- **GOI improvements seen in CMOS devices**
  - **Improved reliability**
- **Carrier lifetime increased >100%**
- **Isotope effects hold for silicon carbide - $^{28}Si^{12}C$**

Potential Markets

- **Microprocessors**
- **Power Semiconductors**
- **Telecommunications**
  - **RF, microwave**
  - **SiGe**
- **High Speed Memory**

Cooling Cost Comparison

	Cost per die
Cryo-cooler	$150 +
Thermoelectric cooler	$35
Fan & heat sink	$10 to 20
Liquid cooling	$100 - $150
Chip thinning	$2 (est)
Si-28 epi wafer	$0.10 to $2 [1, 2]
Si-28 bulk wafer	$2 to $25 [1]

[1] Incremental to natural silicon wafer
Assumes 200 die/wafer

[2] 10μ epi thickness

Isotopically Pure SiC Characterization

- Brooklyn College Scanning Thermal Microscope measurements.
- Increase in thermal conductivity with isotopic purity observed.
  - 99.95% $^{28}Si^{12}C$ best was 3.62 W cm^{-1} K^{-1} (average 13 pts, 1mm sep.)
  - 95.54% $^{28}Si^{12}C$ (natural abundance) best was 3.23 W cm^{-1} K^{-1} (average 12 pts, 1mm sep.)
  - Cree measurement of TC in a high purity, SiC wafer yielded 3.3 W cm^{-1} K^{-1} (Tsvetkov et al., ISCRM '97).
- Increase is 12% (best) instead of expected 50%.
- Average TC from all isotopically pure samples and all natural samples yields 8% average increase. Sample data:

Sample	T (um)	Isopure?	Doped?	Tc max
Y021800A	7.0	Yes	Undoped	3.36
Y071200A	9.5	Yes	Undoped	3.29
Y052400A	9.0	Yes	Undoped	3.44
Y071000A	9.5	Yes	Undoped	3.62
Y073100A	9.5	Yes	N, 8E16 cm2	3.31
Y072500A	9.5	Yes	Undoped	3.34
Y062200A	9.0	No	Undoped	3.23
Y041300A		No	N, 5E16 cm2	3.03

Silicon Isotope Production

- Gas Centrifuge – Russia/Europe
  - Proven technology for SiF_4
  - Current Capacity ~100 kgs/yr, expandable to > 5 ton/yr
- Advanced Centrifuge – South Africa
  - Pilot plant in operation for silane
- Other Technologies
  - Laser – Silex (AU)
    - Unproven technology
  - Chemical Exchange (US, Rep. of Georgia)
    - Currently used for Boron isotopes
    - Proven Si enrichment to 98.8% with SiF_4
    - no technical barriers to 99.9%
    - Est. lower cost than centrifuge
  - Gas Chromatography (Isosilicon)
    - Lab scale

Silicon-28 Future

- **Multiple sources of isotope production**
- **Isosilicon main producer of SiH_4/TCS**
- **Silicon-28 precursor sales to wafer manufacturers**
- **10% of silicon wafer market could be silicon-28**

$1 Billion wafer potential

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