Current Die Thinning and Bonding Technologies for Solar Sails -An Overview

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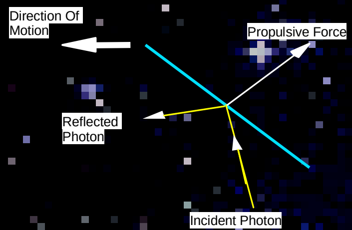
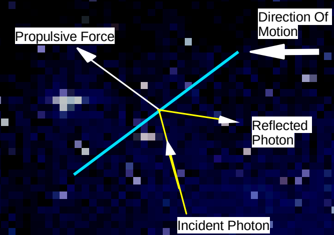
Introduction

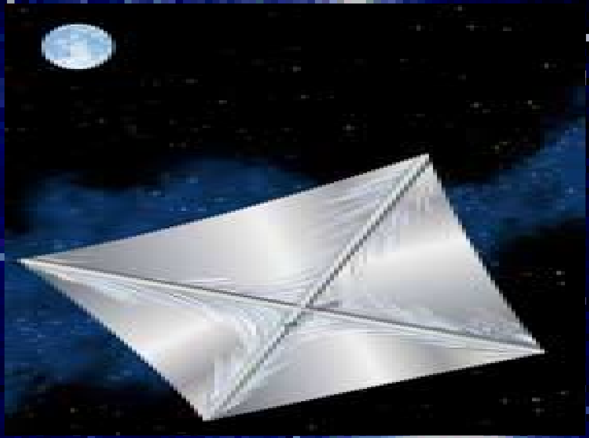
Basics of Solar Sails

Basics





• Solar sails are large ultra-light mirrors which use light from the sun (or a laser) for low-thrust propulsion.
• Photons bounce off the sail surface.
• Change in photon momentum transferred to sail.
• A mirror will be pushed twice: on impact and on reflection
• Sun/sail orientation controls orbital velocity

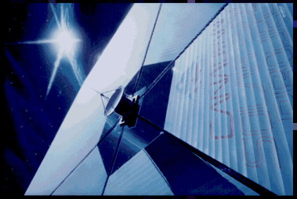


Advantages

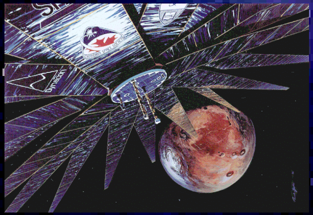
No need to carry onboard propulsion system or fuel.
• Reduced mass allows greater payload capacity and much shorter trip times for high energy missions.
• Constant low thrust counteracts gravity to enable unique non-Keplerian orbits and new vantage points.
• Sails that use laser energy beamed from Earth may enable rapid access to the interstellar environment.

Types

Square



Circular

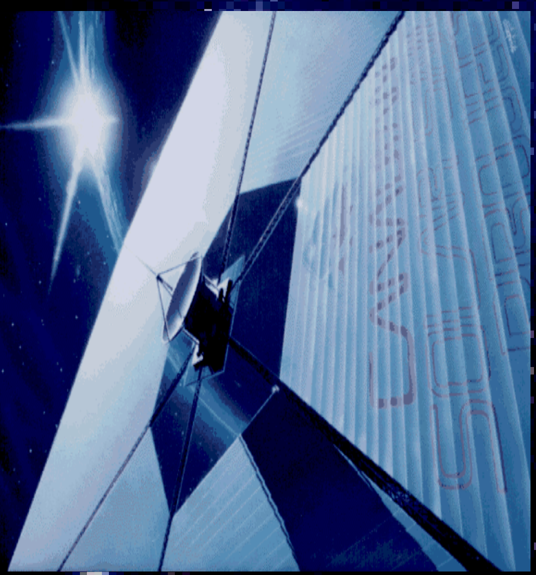


Heliogyro

Blade Sail

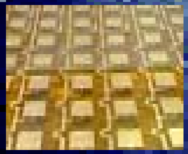
Introduction
Future Solar Sails

- *Highly-integrated solar sails consist of thin membrane partly populated with multifunctional patches.*



Sensors

Thin Film Photovoltaics

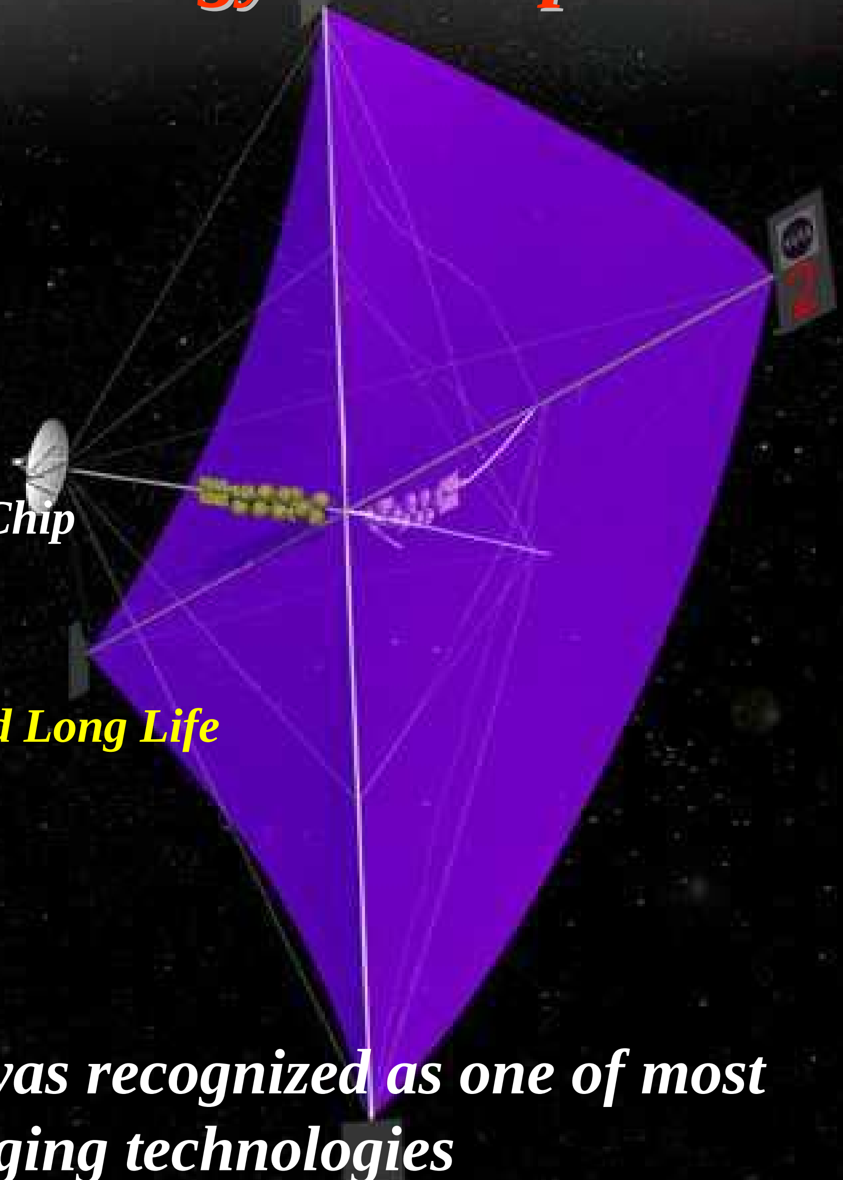


Phased Array Elements

Flexible Electronics

Solar Sails
Areas of Technology Development

- *Architecture and Planning*
- *Sail Development*
- *Advanced Packaging*
  - *Thinned Die on Film*
  - *Instruments & Sensors-on-a-Chip*
  - *Wireless / Distributed Systems*
- *Large Structure Environments and Long Life*
- *Large Lightweight Structures*



Thinned dies on film was recognized as one of most important and challenging technologies

Overview Objectives

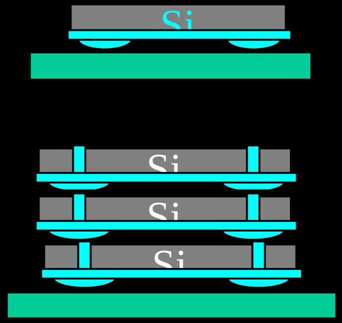
- Perform a review of the current technologies for thinning of silicon die and bonding onto membranes.
- Find out if existing technologies are applicable to solar sails
- Outline study's conclusions and recommendations for possible follow-on activities.

Die Thinning/Bonding Requirements

- Silicon based die
- Ultra-light weight
- Thickness: as thin as possible (microns)
- Flexible/high bending capability
- Attachable to polymeric membrane
- Long term high reliability (> 10 years)
  - Mech./thermal/electrical functionalities
  - High/low temps resistant
  - Thermo-mech. cycling resistant
  - Space radiation resistant

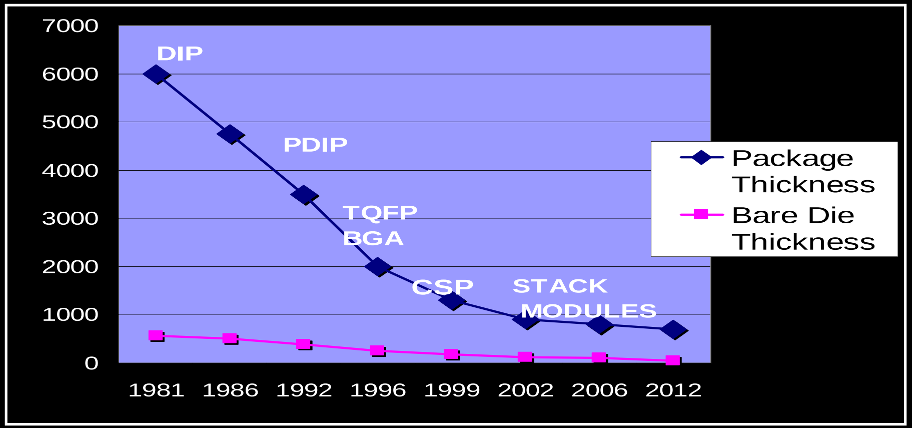
Die Thinning
General Trend

- *Historically wafer thinning has been used:*
  - *Achieve a uniform thickness*
  - *When heat was a problem*
  - *For most applications wafers were not thinned*



Number of components in 3D space would double every 18 – 24 months

- *Today, that is changing*
  - *New miniature packages and applications*
  - *Needs for higher I/O, increased performance & speed*
  - *Demands for high packaging density*



* Tru-Si Technologies

- *Solution: vertical miniaturization*
  - *Die thinning (t < 250 μ)*
  - *Thinned 3D stacking (thickness ~ 0.4 mm)*

IC packaging "smaller is better – thinner is better"

Die Thinning Advantages/Applications

Advantages/Benefits

- Smaller package profile
- More flexible
- Increased performance
- Better reliability
- Smaller saw street dimensions

* 50 µm wafer (Tru-Si Technologies)

•Applications

- Space, military, commercial and medical
- Numerous handheld, portable and miniature applications
- Memory cards, smart cards, small disk drives, cell phones, portable computing and other consumer electronics

Die Thinning
Current Techniques

- ***How to thin a silicon die/wafer***

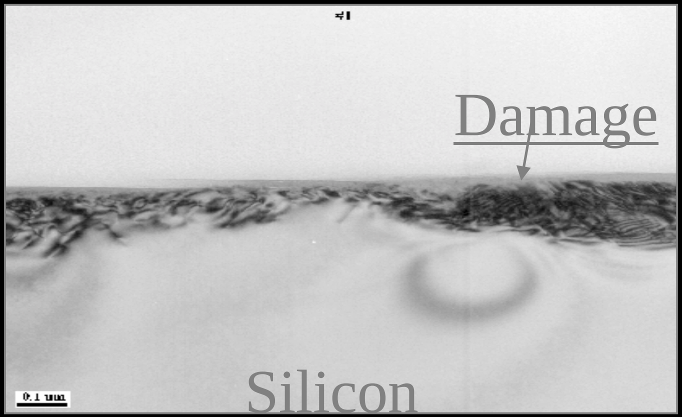
    - ***Mechanical grinding/polishing***

    - ***Wet etching***

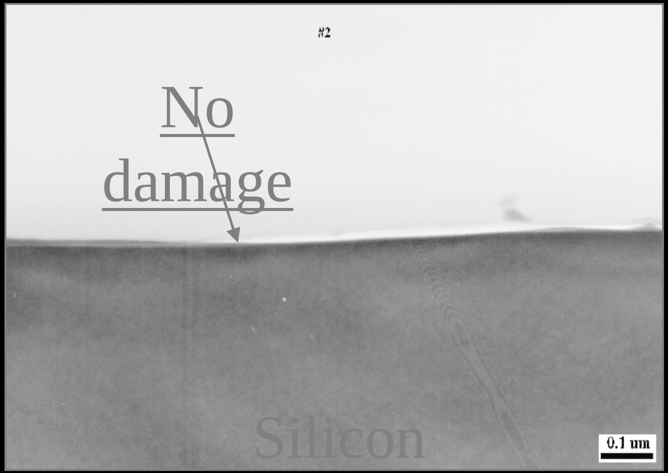
    - ***Dry plasma etch***

Die Thinning
Grinding

- *Efficient method at very modest cost and high throughput for thickness > 250 μ*
- *First step of thinning*



- *Grinding drawbacks*
  - *Introduces micro-cracks, residual stress and surface roughness*
  - *Causes structural damage and lattice disclocations*
  - *Creates a warpage and bow*
  - *Reduces mechanical and electrical properties*
  - *Need a front side protection*



- *Damage shall be removed by other thinning methods*
- *Numerous improvements*

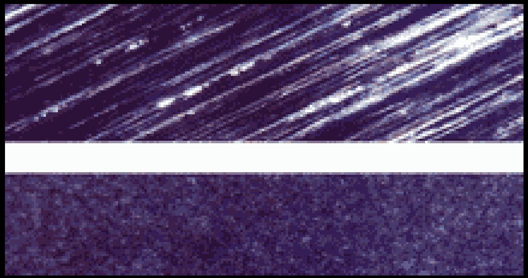
*** Tru-Si Technologies**

Die Thinning
Wet Etch

- *Follows the grinding step*
- *Can be used to remove the damage layers*

- ***Benefits***
  - *substantially reduces the stress level*
  - *reduces the warpage*
  - *removes micro-cracks and lattice disclocations*
  - *results in a much stronger wafer/die*

- ***Drawbacks***
  - *requires a protection of front surface*
  - *not practical with bumped wafers/dies*
  - *no good wafer/die thinning uniformity*
  - *increasing difficulty when a thickness < 250 μ*



Before and after etching

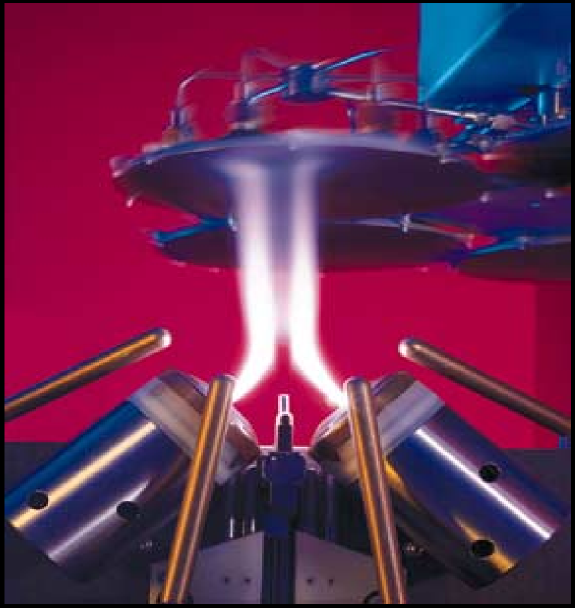
Die Thinning
Dry Plasma Etch

Conventional anisotropic low pressure systems :

- *operate in vacuum*
- *require sophisticated vacuum systems*
- *slow process and low etch rates*

New Atmospheric Downstream Plasma (ADP) developed by Tru-Si Technologies:

- *operate at ambient pressure*
- *isotropic plasma-etch system*
- *higher etch rates*
- *design/controls eliminate potential overheating, contamination, etching, thickness non-uniformity, ESD etc*



ADP system

Die Thinning
ADP by Tru-Si Technologies

•Process description

- *Magnetically controlled, inert gas DC arc plasma discharge*

- *ADP brings reactant gas (FC_4) to the plasma region*

- *Gas is decomposed and available for reaction*

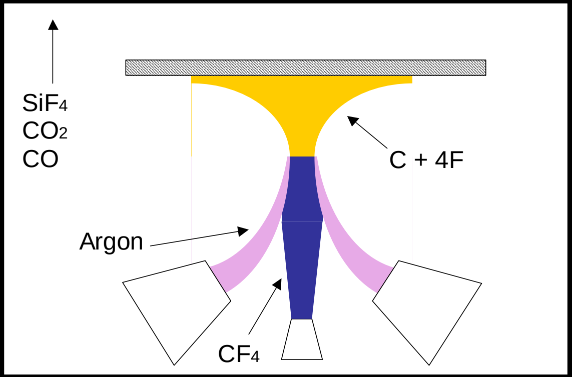
- *F reacts with Si and produces the etching*

- *C byproduct react with O_2 and is prevented from being deposited*

- *Charged particles recombine outside the plasma*

- *Lower power density*

- *Short & repeated exposures to the reaction zone*



Die Thinning
Atmospheric Downstream Plasma

Benefits

- operate at ambient pressure

- etch rates at least 20 x > vacuum plasma

- no surface/structural damage nor residual stress

- no front side protection

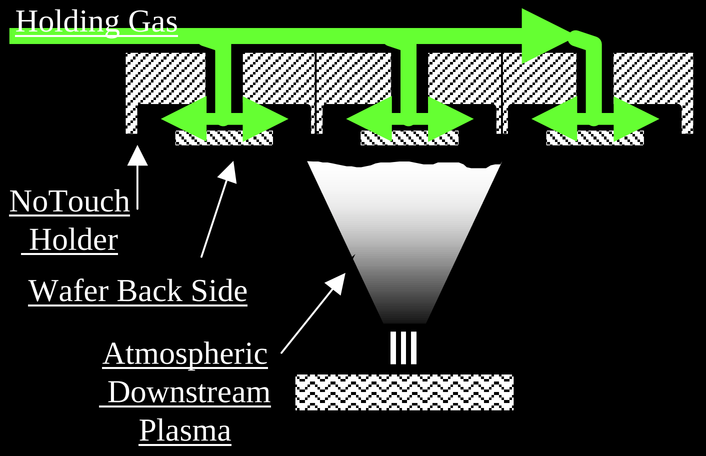
- isotropic and uniform etching

- control of plasma power density and location

- no overheating nor plasma contamination

- no electrical damage

- perfect for thinning of wafers/die with bumps



No Touch ™ holding

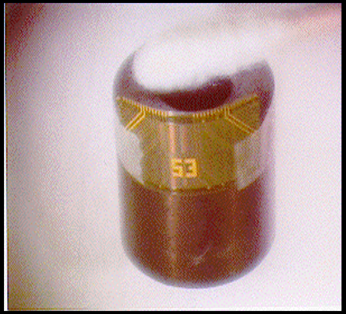
- surface temp. < 125^0C

- ideal for damage/stress removal and final thinning

Die Thinning
At Irvine Sensors Corp.

• *Proprietary multiple-step grinding/polishing*

- 4 and 16 Mb flash wafers were thinned to 25-35 μ
- Chip size was 419 x 449 mils

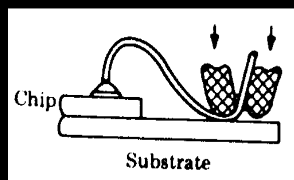


- 1 Mb SRAM wafer sections were thinned to 30-35 μ
- Chip size was 277 x 542 mils

- Kapton based flexible test vehicle has been used to test ultra-thin flash die.
- Thinned chips were smooth, flexible and electrically functional
- Residual stress too small to measure

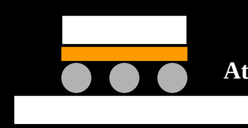
Die Bonding
Current Methods

- *How to attach a thinned die to flexible membrane*



- Wire bonding

- Direct attach



- Flip chip

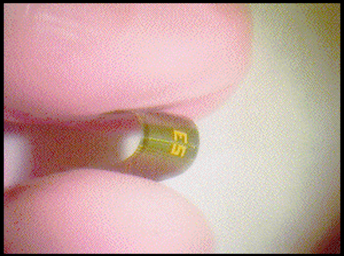
- Only a few organizations involved

Die Bonding
At Irvine Sensors Corp.

- *Three bonding methods had been investigated*

- *Wire & direct bonding failed*

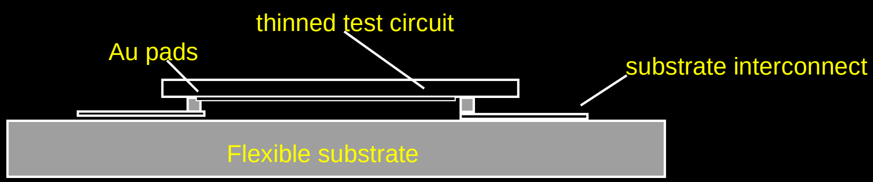
- *Flip chip bonding was successful:*
  - *- 25 μ thin Flash die face-down*
  - *- Z-conductive epoxy*
  - *- 25 μ Cu laminated Kapton substrate*
  - *- 2-3 μ Au pad*



Testing indicated good electrical and mechanical performance after repeated bending & thermal cycling

Die Bonding
At Irvine Sensors Corp.

- ***Reliability testing***



Test sample

Temperature cycling (+80 ^{0}C to –60 ^{0}C)

- No failure or change in resistance

- No structural degradation

Bending testing;

- 10 mm curvature

- 4 lbs uniaxial load

- 10,000 cycles

Post-testing evaluation:

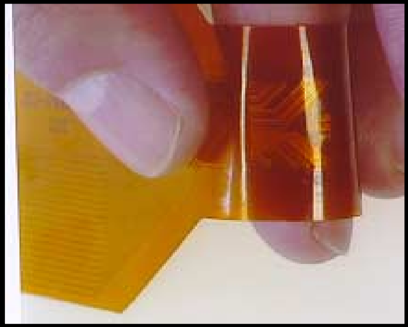
- Good structural integrity

- No change in reverse and DC leaking

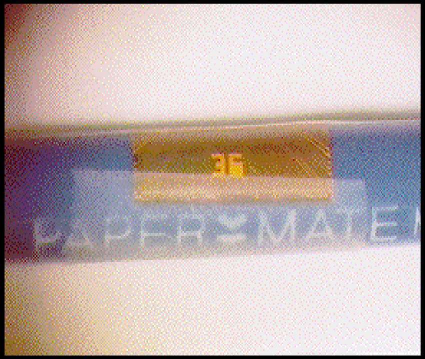
Bending of Flash die

Die Bonding At University of Arkansas

- *Integration of thin (20-35 μ) Si chip-on-flex membrane Demonstration in flip chip and face-up configuration*



- *Integration of chip carrying polymer patch-on-flex membrane*



- *Chip-on-membrane and chip carrying patch-on-membrane samples were successfully tested*

Conclusions/Recommendations

- *Preliminary studies indicate the feasibility of thinning of Si die to few tens microns and bonding it to flexible membrane.*

- *It appears thin chip-on-membrane systems can be made sufficiently reliable to satisfy solar sails requirements.*

- *There are several possible techniques to choose from.*

- *Further evaluation and verification of selected thinning/bonding technologies are recommended for specific flexible sensors and electronics for solar sails.*