Photovoltaic Power Generation

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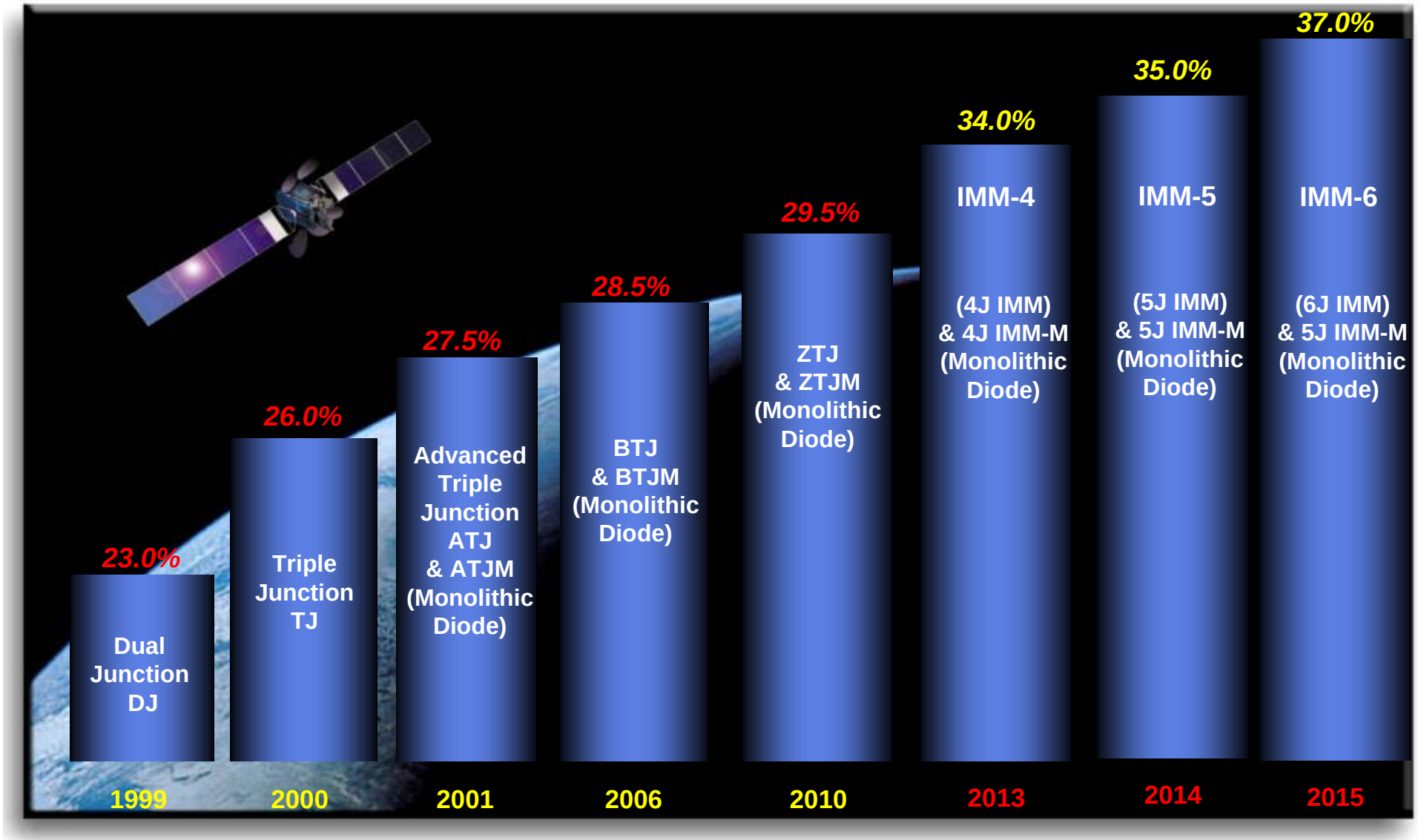
Background

- **Emcore:**
  - One of two US developers and manufacturers of high efficiency multi-junction solar cells and arrays for space applications
    - Spectrolab, a Boeing company, is the other
    - Internationally, Azur in Germany supplies Europe, and Russia and China are developing their capability
  - Photovoltaics division has been in existence since 1998
- **Sponsored R&D:**
  - Over the past 25 years there has been considerable support of space cell R&D through DOD
    - AFRL, AF Mantech, and others
  - Both evolutionary and revolutionary developments at cell level
    - Silicon to SJ GaAs on Ge - ~1989
    - SJ GaAs to multi-junction $GaInP_2$/GaAs/Ge - ~1995
    - $GaInP_2$/GaAs/Ge to IMM – current
  - Focus has been on cell efficiency improvements and transition into manufacturing

Emcore's Product Roadmap

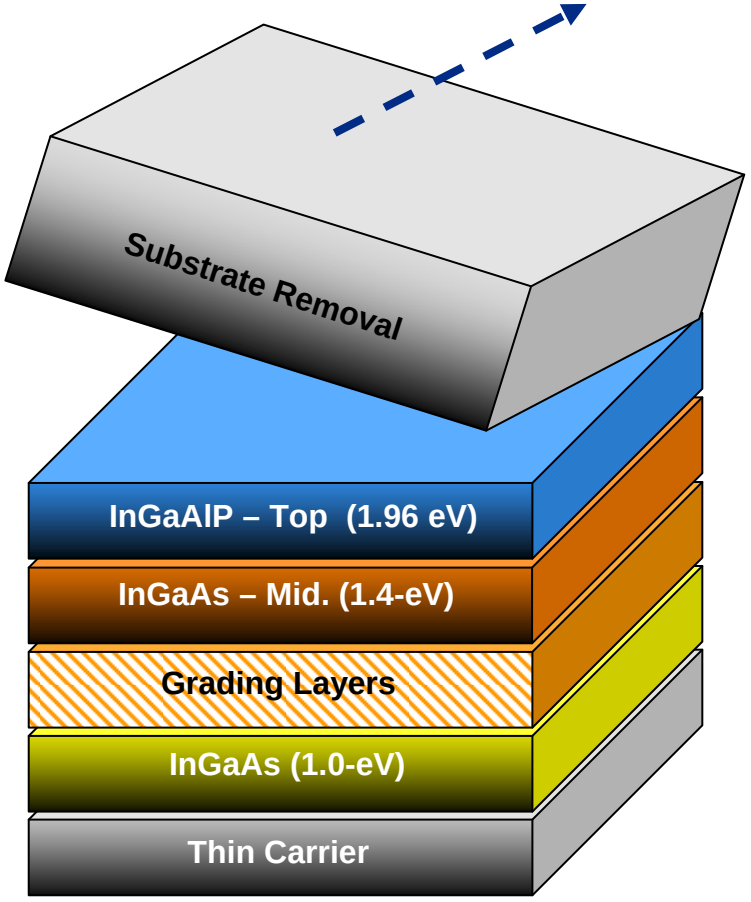


Technical Roadmap

- Continuous DOD funding over the past 25 years has resulted in steady increases in space cell efficiency
- Emcore product roadmap has reflected this emphasis on efficiency
- Minimal funding for cell integration/array development
- Often cell integration/array development is where reliability issues occur
- NASA programs benefiting from DOD funded cell performance improvements:
  - COTS-CRS, STEREO, LDCM, RBSP, GLAST, LRO, MSL, GPM, OCO, MMS, Starshine, & PSSC
- NASA programs that have supported cell development:
  - Messenger, Dawn, & SPP
- IMM cell technology is a revolutionary game changer

IMM Cell Technology

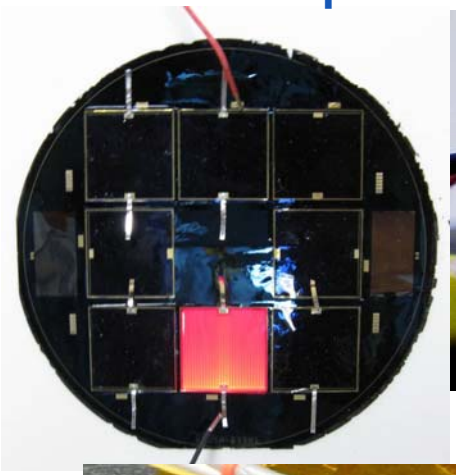
- **IMM cell is a revolutionary change for two reasons:**
  - **Performance:**
    - **Lattice matched $GaInP_2$/GaAs/Ge device performance has reached the peak – IMM is a way toward higher efficiency**
    - **34% achieved in laboratory, targeting 34% rad hard production cell**
    - **37% design in concept stage**
    - **Specific power of ~3,000 W/kg at bare cell level**
  - **Integration:**
    - **IMM enables novel panels and arrays**
    - **Integration of IMM-3 into FAST array - ~34.4% at ~12x**
    - **Drop in replacement for current array technology if rigid substrate approach taken**
    - **Flexible arrays possible**

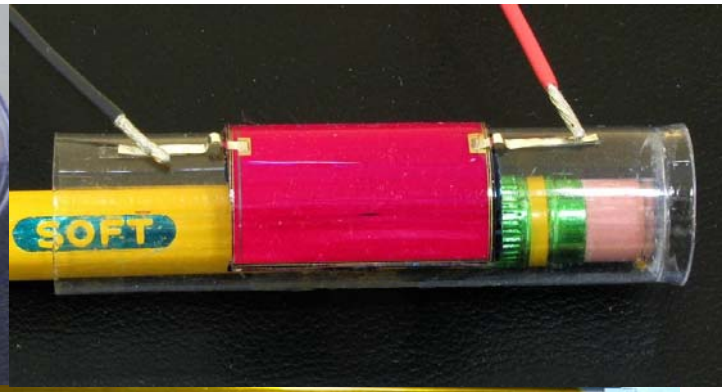


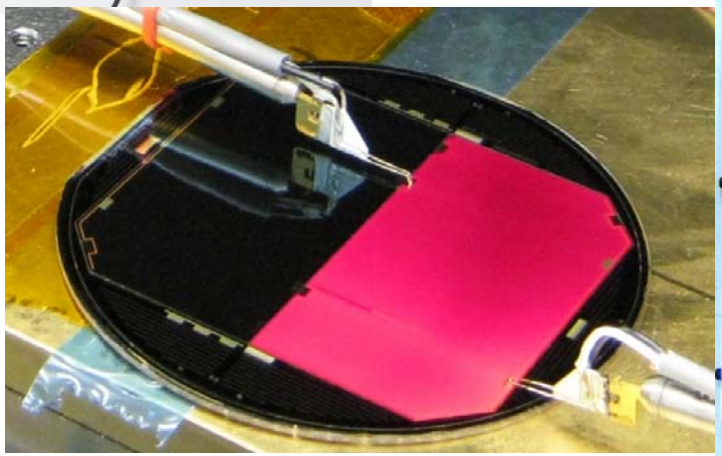
Final IMM – 3J Structure

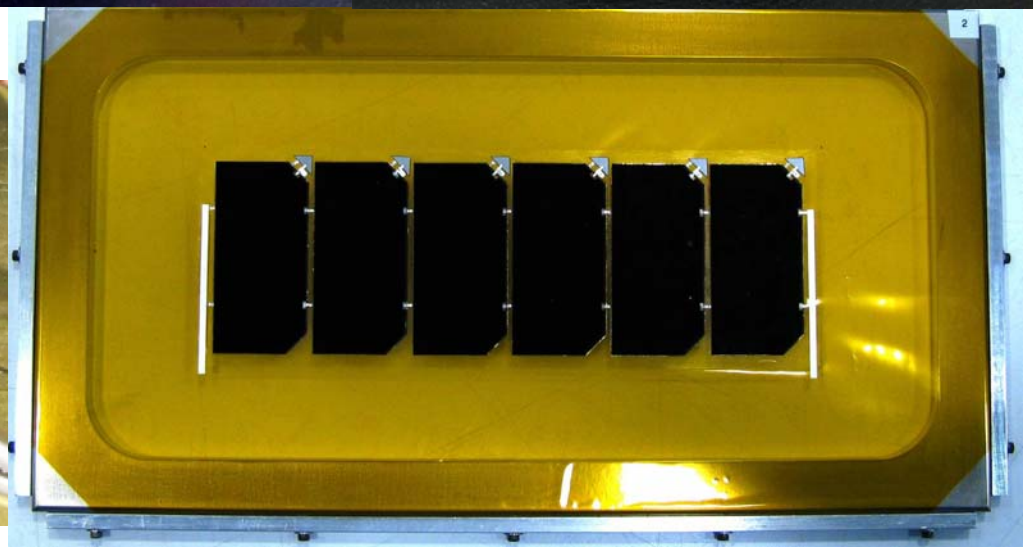
IMM Cell Technology - Arrays

- **IMM cell integration into arrays:**
  - **Traditional rigid panels**
  - **Flexible panels with minimal stowage volume**







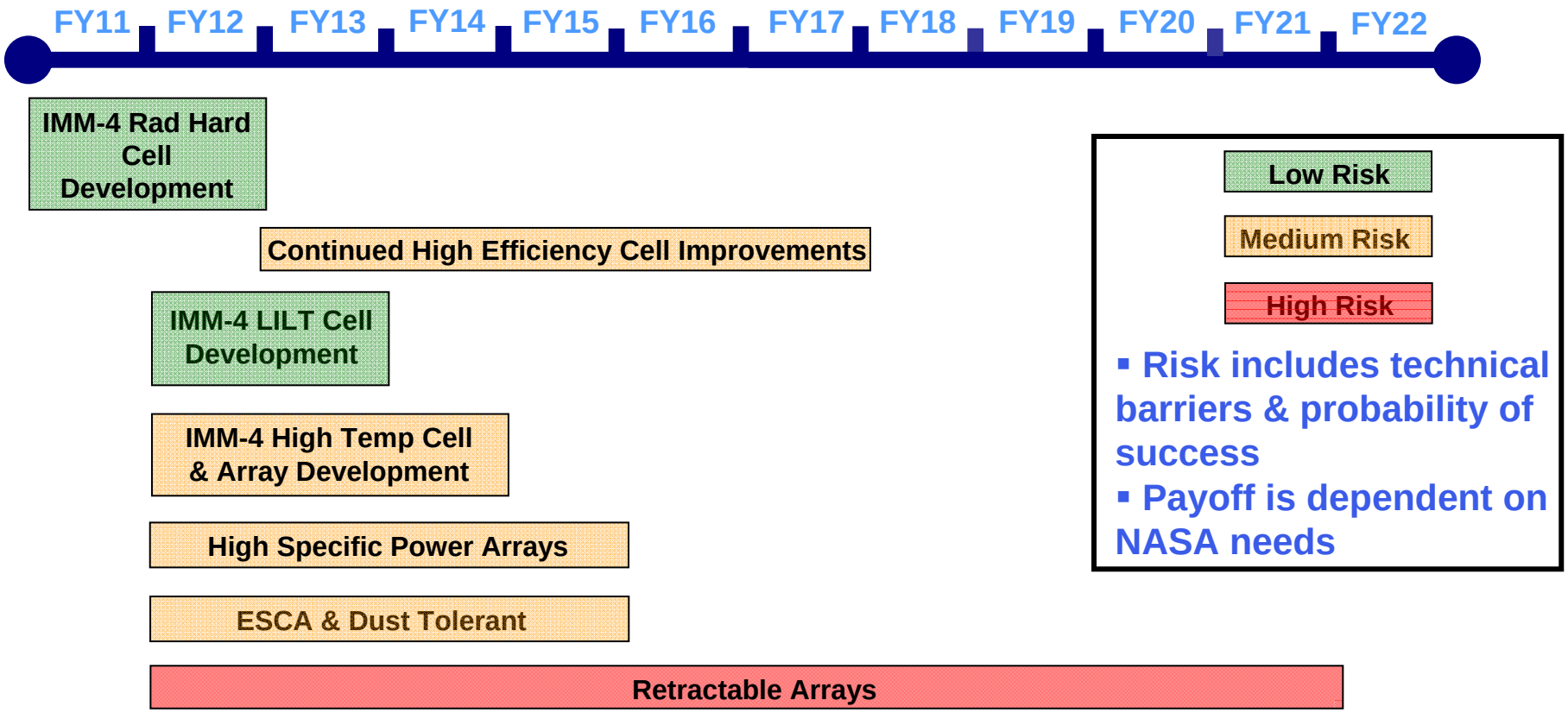


NASA Power Generation Roadmap

- **Solar Cells:**
  - High efficiency
  - Radiation tolerant
  - Designed for LILT conditions
  - Designed for high temperature operation (>200°C)
- **Arrays:**
  - High specific power (500 – 1,000 W/kg)
  - Electrostatically clean
  - Dust tolerant
  - Restowable
- **Leverage current IMM cell developments for NASA applications – both cell & array**
  - 34% radiation hard IMM-4 cell is near tipping point – 1 year to TRL5, 2-3 years to insertion into flight hardware provided the level of funding remains constant

Critical Technology Investments

- Invest to move IMM-4 cell technology to TRL6
- Invest in IMM cell integration and array technology



Recommendations

- Support development of IMM-4 cell to move past “tipping point”
- LILT & high temperature operation cells developed using IMM architecture
- Longer term support of IMM integration into panels and arrays, specifically high specific power arrays
- Continued longer term support for next generation cell development

* We have not discussed thermal photovoltaics & power beaming