Terahertz-Regime, Micro-VEDs: Evaluation of Micromachined TWT Conceptual Designs

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**THz regime: the last electromagnetics frontier?**

- Information technology
  - very high data-rate wireless comm
- Environment
  - atmospheric sensing
- Security
  - luggage scanning in airports
- Materials and materials processing
  - industrial process metrology and control
- Space science
  - THz astronomy, cosmochemistry
- Defense
  - chemical agent detection, digital and imaging radar
  - covert communication
    - space-space
    - short-range battlefield
- New compact source technology ⇒ new applications?

300 - 10,000 GHz

...the possibilities!
**THz regime: the challenge**

- The greatest obstacle to full realization of these applications is the lack of *compact* sources that are:
  - frequency agile
  - powerful
  - efficient
  - reliable, and
  - cheap

(Note: THz BWO’s are inefficient, and require bulky, heavy intense magnets)
Technology trade-offs

- Vacuum Electronics
  - efficient
    - spent beam collection
    - FEA cathodes
  - high power density
  - infinite electron mobility
    - no intrinsic frequency limit

- Solid State Electronics
  - precise miniature fabrication
  - devices made by patterning
    - replicate success
    - batch fab economy
    - good yields

= “micro-VEDs”
Micromachining

• Machining μm-scale 3D structures from 2D substrates
  – photo-lithography based
  – heights > 1 mm
  – exceptional wall quality
  – complex shapes possible

• Multiple techniques
  – LIGA (xray lithography molds + fill)
  – SU-8 (UV lithography + coating)
  – DRIE (etch silicon + coat/fill)
  – microEDM, microplasma machining

Come to the minicourse!
\( \mu \text{VEDs} \)

- Choose circuits amenable with 2D \( \rightarrow \) 3D
  - e.g., klystrons (Stanford, Leeds)
- Instantaneous bandwidth = TWTs

Folded Waveguide TWTs!
(Oscillators and Amplifiers)
**Fabrication**

- Etch serpentine as two halves in silicon wafer
- Coat walls with copper

**or**

- Electroform serpentine as two halves in PMMA mold (LIGA)

- Wafer-wafer bond
- High-resistivity Si for vacuum windows, lenses
- Arrays for higher power
Design and Analysis Tools

- Northrop Grumman Optimized Synthesis (OptSyn) Procedure
- Christine-1D (1D Parametric Code)
- TWA-3 (2.5D Parametric Code)
- MAFIA (3D PIC Code)
- Conceptual designs completed at 100 Ghz, 400 GHz, and 560 GHz
Oscillator Concept

- FWG TWT amplifier + feedback
- Reflected wave on serpentine too lossy
- Recirculate power through low-loss straight guide
Illustrative Example: 56 mW, 560 GHz

- Simulated
  - MAFIA (3D PIC)
  - CHRISTINE (1D disk)
560 GHz FWG TWT Forward Gain

1.8 mA + 6.6 mm long circuit

0.5 mA, 25 mm circuit
56 mW, 560 GHz FWG TWT Oscillator
(MAFIA, TWA3, Christine-1D)

~23 dB gain

2.5 cm

~ 1 cm

~5 dB loss

10.9 kV, 0.5 mA

56 mW, 560 GHz

η ~1%
**Planned and In-Progress Research**

- FWG oscillator experiments (UW&NGC)
  - Scaled (50 GHz)
    - what is the steady state?
    - vary feedback
    - compare with theory
  - High Frequency (~400 GHz)
- Circuit micromachining (UW, Argonne)
- Experimental studies of W-Band FWG
  - 100 GHz circuit characterization
  - Multiple Array FWG Circuit microfabrication
  - 100 W (CW), 85-100 GHz, 12 kV FWG Amplifier
- THz circuit characterization (UW)
Summary

• Opportunity: mmwave, THz-regime applications

• Challenge: 0.001-1 W sources at 300-1,000 GHz
  compact, efficient, low cost

• μVEDs: micromachined vacuum electron devices

• Folded waveguide TWTs
  amplifiers, oscillators (w/ recirculated feedback)

• Concept tests at 50 GHz (oscillator), 100 GHz (amplifier), 400 GHz (oscillator)

• 56 mW, 560 GHz, η ~ 1%