Commercial Application Aspects of QCL

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Are you the spirit that constantly denies?
Content

- Where do We Stand in MIR?
- Possible Replacement Markets
  - Consequences for QCL Designers
  - Immediate Action Proposal
- Can QCL Acquire the Quasi-Virgin Land of THz?
  - Technical Competition
  - Pros and Cons
- References
1. Where do we stand in the MIR?
Part 1: LASER COMPONENTS’ View

- LC: KISS principle, good compromise for many users
- Adressed commercial markets (no MIL/Space/Homeland Security/Telecom):
  - Gas Analysis
  - Divers
- No Imaging Applications
- Commercial: Prenatal phase
- How long will this pregnancy last???
1. Where do we stand in the MIR?
Part 2: Global diode laser sales

- MIR does not even exist in statistics...
- So far we target for microniches...
- Materials Processing seems small, but doubled

2005
2. Possible replacement markets

Figure 2. Worldwide nondiode-laser sales by application

- Materials processing
- Medical therapeutics
- Basic research
- Instrumentation
- Other
- Image recording
- Sensing
- Inspection, measurement, and control
- Entertainment
- Optical storage
- Barcode scanning

Sales ($ millions)

Figure 3. Worldwide nondiode-laser sales by type

- Solid-state lamp-pumped
- CO₂ flowing
- Er:YAG
- Solid-state diode-pumped
- Fiber
- CO₂ sealed
- Solid-state laser-pumped
- Ion < 1W
- HeNe
- Dye
- Ion > 1W
- HeCd

Sales ($ millions)
2.1. Consequences for QCL designers

- Proven Applications
  - Availability
  - Price
  - Lifetime
  - Current Tuning Rate
  - Noise Features

- Features for possible replacement markets
  - 1 mJ per pulse (few Hz)
  - 20 µsec, 50 W
  - TEM$_{00}$, low and symmetric Divergence
  - Microoptics (fiber coupling, stacks)
2.2 Proposal for immediate action of QCL designer community:

Self commitment for papers!!!

- Standardized measurement conditions for systematic data base
  - Power data only at TEM$_{00}$
  - No paper without far-field data
  - No paper without lifetime test at standardized preaging conditions
3. Can QCL acquire the quasi-virgin land of THz

- Thesis: The more people develop applications around THz QCL, the larger the future market share for this technology.
- How good are the chances?
- Remark: Spectral features in THz are theoretically not well understood. State of the art is phenomenology.
## 3.1 Technical Competition Part 1

<table>
<thead>
<tr>
<th>THz</th>
<th>Room Temperature</th>
<th>Compact</th>
<th>Cheap</th>
<th>Tunable</th>
<th>Speed</th>
<th>for User</th>
<th>S/N</th>
<th>Status Comm. Lab. Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp (FTS)</td>
<td>RT</td>
<td>sort of</td>
<td>THz-FTS components approx. 15T€</td>
<td>-</td>
<td>S (mechanics)</td>
<td>S (Golay D.)</td>
<td>0.1-10</td>
<td>C</td>
</tr>
<tr>
<td>Gas Lasers</td>
<td>RT</td>
<td>N</td>
<td>150 T€</td>
<td>hopping</td>
<td>S</td>
<td>C</td>
<td>(0.8-6.0)</td>
<td>C</td>
</tr>
<tr>
<td>Laser Diode Photomixer</td>
<td>RT</td>
<td>Y</td>
<td>May be</td>
<td>Y</td>
<td>M</td>
<td>C → S</td>
<td>0.01-4.0 (0.1-1.0)</td>
<td>L → C</td>
</tr>
<tr>
<td>TDS</td>
<td>RT</td>
<td>N</td>
<td>200T€</td>
<td>-</td>
<td>H (full spectra with ASOPS)</td>
<td>C (C → S fiber: P low)</td>
<td>0.1-4.0 (0.1-2.0 S/N: 10^3-10^6)</td>
<td>C</td>
</tr>
<tr>
<td>Pulse rectification (kHz)</td>
<td>RT</td>
<td>Y</td>
<td>ok (low f)</td>
<td>pricy (high f)</td>
<td>(limited)</td>
<td>M</td>
<td>S (low f) C (high f)</td>
<td>0.2-5 (up to 1.0)</td>
</tr>
<tr>
<td>Smith-Purcell Emitters</td>
<td>RT</td>
<td>sort of</td>
<td>May be</td>
<td>Y</td>
<td>S (mechanics)</td>
<td>C → S</td>
<td>&gt; 0.1</td>
<td>L → C</td>
</tr>
<tr>
<td>Germanium Lasers</td>
<td>quasi (cooler no liquids)</td>
<td>sort of (size limit cooler)</td>
<td>Y</td>
<td>(but +cooler costs)</td>
<td>Y</td>
<td>M,H</td>
<td>S</td>
<td>(1-4, pulse: 1W)</td>
</tr>
<tr>
<td>QC Lasers</td>
<td>quasi (cooler no liquids)</td>
<td>sort of (size limit cooler)</td>
<td>Y</td>
<td>(but +cooler costs)</td>
<td>Y</td>
<td>M,H</td>
<td>S</td>
<td>1-5 (some f, pulse: 10s mW)</td>
</tr>
</tbody>
</table>
### 3.1 Technical Competition Part 2

<table>
<thead>
<tr>
<th></th>
<th>Problems</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp (FTS)</td>
<td><strong>P:</strong> S/N bad</td>
<td><strong>A:</strong> easy to maintain and cheap</td>
</tr>
<tr>
<td>Gas Lasers</td>
<td><strong>P:</strong> gas handling (f coverage limited for gas phase samples)</td>
<td><strong>A:</strong> high power and multiple f with good coverage for liquid and solid samples</td>
</tr>
<tr>
<td>Laser Diode Photomixer</td>
<td><strong>P:</strong> S/N roll off at high f (electronics)</td>
<td><strong>A:</strong> compact, easy handling, wide f coverage</td>
</tr>
<tr>
<td>TDS</td>
<td><strong>P:</strong> S/N roll off at high f (electronics), expensive pump source: 100 T€</td>
<td><strong>A:</strong> wide f coverage at high speed with ASOPS, ps time resolution (chemical reactions)</td>
</tr>
<tr>
<td>Multipliers (x * 110 GHz)</td>
<td><strong>P:</strong> S/N roll off at high f (electronics), limited tuning, complex for high f &gt; 1THz</td>
<td><strong>A:</strong> compact, very stable, high power cw at f &lt; 1 THz</td>
</tr>
<tr>
<td>Smith-Purcell Emitters</td>
<td><strong>P:</strong> electron gun still too complex</td>
<td><strong>A:</strong> tunable from sub-THz to THz</td>
</tr>
<tr>
<td>Bloch Oscillators</td>
<td><strong>P:</strong> still at research level</td>
<td><strong>A:</strong> potentiell for high temperature operation</td>
</tr>
<tr>
<td>Germanium Lasers</td>
<td><strong>P:</strong> cooling required, He closed-cycle cooler and cryostat main investment: 80 T€</td>
<td><strong>A:</strong> high power and wide tuning range</td>
</tr>
<tr>
<td>QC Lasers</td>
<td><strong>P:</strong> cooling required, limited tuning (low yield for user frequency)</td>
<td><strong>A:</strong> compact, may be cheap (with cheaper 80K coolers)</td>
</tr>
</tbody>
</table>

**CW operation:** Typically needed only for applications in astronomy and atmospheric research (number of instruments may be 2 per satellite, rare cases of larger lots, mainly industry public relation and research level interest)

**Pulsed operation:** Higher power, therefore many applications conceivable but THz signatures of the application are needed and frequencies (if system not tunable) need to be tailored to each application!

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3.2 THz QCL Pros and Cons

- Direct and compact
- Reached threshold of usefulness for convenient imaging @ 10K (33 mW)
- Hope for parameter improvement

- Limited tunability
- Limited availability (especially @ 77 K and high power)
- TDS: Spatial and spectral resolution, therefore QCL-applications must be developed
Closing remark: Much progress at sources, but relative stagnation at detectors....
References


4. E. BRÜNDERMANN, private communication
