Generation of terahertz signals with optical microcavities

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Outline

- Applications of THz receivers
- Coherent sources of THZ
- THz generation with optical heterodyne conversion
- Issues
- Optical whispering gallery mode cavities
- The Torus
- Prospects
Applications of THz Receivers

- Most of the photons in the universe have terahertz (100 GHz to 1000 GHz) frequency (FIR wavelengths)
  - Interstellar medium (10-600 K, $f = kT/h$ at 200 GHz to 10 THz)
  - Terrestrial and planetary atmospheres
- Water and other molecules absorb/emit at THz
  - Remote sensing of living organisms
- Low energy light-matter interactions (phonons)
- Thermal imaging of cold sources
- Communications
Three-laser synthesizer for THz, Matsuura, et al., IEEE Trans. Microwave Theory and Technique, 2000
Microsphere -- a low-loss optical (micro)cavity

Whispering-gallery modes - closed circular waves under total internal reflection
(Term by J.W.S.Rayleigh, analogy to acoustic modes in the gallery of St Paul cathedral)

Sustained in any axisymmetric dielectric body with $R \geq \lambda$
low material loss (transparent material, e.g. fiber grade silica)
low bending loss ($R \gg \lambda$)
low scattering loss (TIR always under grazing incidence
+ molecular-size surface roughness)

| Quality-factor $Q = \lambda / \Delta \lambda_{\text{RES}}$ | up to $\sim 10^{10}$ |
| Photon lifetime $\tau = \lambda Q / 2 \pi c$ | up to $\sim 3 \mu s$ |

(cavity ringdown time)

Visualization of WG mode field by residual scattering in silica microsphere, $\text{V.S.Ilchenko et al, Opt.Commun. 113, p.133(1994)}$
Microsphere cavity

Two-level system in the evanescent field of WG mode
Coherent sources of THz Radiation

- **Frequency Multipliers with microwave tubes (Klysterons, Gunn diodes)**
  - Inefficient, bulky, can’t go beyond 1 THz

- **BWO (harmonics)**
  - Up to 1.7 THz, and tunable, but inefficient

- **Tunable FIR lasers**
  - Co2 with side-bands generated with Schottky diodes
  - Difference frequency with MIM diodes
  - Large, unreliable, power hungry

- **Optical Heterodyne conversion**
  - Use of low power laser diodes, and Low temperature grown GaAs (LTG-GaAs) detectors
Fiber-optic integration: a “pigtailling” method for microspheres

Maximum transmission at resonance ~23.5% (fiber-to-fiber loss 6.3dB); $Q_{load} > 3 \times 10^7$ at 1550nm; sphere diameter 405\(\mu\)m. Unloaded $Q_0 \approx 1.2 \times 10^8$. 
Microtorus: an ultra-high-finesse microcavity

Oblate spheroidal microcavity: ~100 fold reduction in the number of excited modes compared to typical microspheres.

Spectrum of whispering-gallery modes in spheroidal dielectric microcavity (D = 160μm; d = 35μm).
Free spectral range 383GHz (3.06nm) near central wavelength 1550nm.
Individual resonance bandwidth 23MHz (loaded Q = 8.5×10⁶). Finesse $F = 1.7\times10^4$
1. It seems indeed we can combine small size, ultra-high-Q with “nice” FP-like spectrum for true finesse $10^4 - 10^6$ -- in microcavities as opposed to “super”mirror FPs
2. Complete “mode cleaning” can be expected with higher eccentricities; higher Qs -- with refinement of fabrication
3. Potential applications may be diverse
Coherent THz Source

- Use WGM microcavity with laser diodes
- Use optical fibers for coupling
- Use fiber grating for mode selection
- Stabilize microcavity to external oscillator (if needed)
- Implement cavity tuning, (if necessary)

Future Challenges

- Increased efficiency of the photomixer (large area travelling wave mixers)
- WGM THz cavity
Coherent THz Source
Optical Set-up

Ref:
“Narrow Line-Width Diode Laser with a High-Q Micro-Sphere Resonator,”