Introduction to Optical Transition Radiation

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Introduction to Optical Transition Radiation

- **Basic**
  - We study E-beams
  - cannot directly observe
  - need indirect means....radiation

- **Transverse Diagnostic types and limits**
  - scintillators
    - phosphor
    - YAG
  - SR ~270 µm (for similar beam parameters as LLNL)
  - wire scan
    - need low beam jitter
    - need very thin wires
  - TR
    - very good resolution (near point source diffraction limit)
    - relatively simple
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Why OTR?
- TR is relatively flat to $\sim \omega_p$ of reflector
- strongly attenuated above plasma freq.
  - may have coherence effects in IR range
- most compelling...
  - optics and digital imaging devices invisible spectrum
    - readily available
    - cheaper
    - no shortage of photons within the typical spectral range of interest
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Theory

• Transition Radiation
  – TR created when charged particle crosses boundary of different dielectric constants
  – fields must reorganize and some can be shaken off as TR
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- Transition Radiation
  - Characteristic angular dependence
  - Energy dependence on shape

\[
\frac{d^2 I}{d\omega d\Omega} = \frac{1}{4\pi^2 c} \left| -e\sin\theta + \frac{e\sin\theta'}{1 - \beta\cos\theta} \right|^2
\]

- Relative intensity vs \( \omega \) (scaled to optical)
  - Demonstrates strong attenuation above \( \omega_c = \gamma \omega_p \)
  - Radiation at this frequency is absorbed by material
    - Dielectric constant...not constant \( \rightarrow \varepsilon(\omega) \)

\[
\frac{dI}{d\omega} \propto \frac{e^2}{6\pi c} \left( \frac{\omega_{cr}}{\omega} \right)^4 \quad \text{for} \quad \omega > \omega_{cr}
\]
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Optics

- linear beam optics (very brief)
  - focal length
  - magnification
    - $M = \frac{f_2}{f_1}$
- definitions
  - numerical aperture (N.A.)
    - Sine of angle between optical axis and marginal ray
  - working distance (WD)
    - Distance within first lens must be placed
  - $f/#$
    - Focal ratio
  - depth of field ($D_{field}$)
    - Range about which image is clear in object plane
    - Depends on N.A. of lens
  - depth of focus ($D_{focus}$)
    - Range about which image is clear in image plane

Infinity Correction System

$$N.A. = \frac{\phi}{2f}$$

$$f/\#= \frac{f}{\phi} \rightarrow \text{clear aperture}$$

$$D_{field} = \frac{\lambda}{2(N.A.)^2}$$

$$D_{focus} \approx M^2 D_{field}$$
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- **Irregularities**
  - chromatic aberrations
  - spherical aberrations
  - flatness
    - Given on orders of wavelength
  - scratch
    - Width of a reference scratch in ten-thousands of a mm
      - 80 scratch ~ 8µm
        (but not that precise)
  - Dig
    - Craters on the surface - defined as its diameter in hundredths of a mm
      - 50 dig = 0.5mm
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- LLNL Experiment
  - 50 MeV beam
  - Very small spot size
    - $\sim 20\mu m$
  - large jitter
  - Will utilize existing infrastructure
    - 6” cube
    - Polished aluminum target, angled 45 deg.
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• OTR experiment
  – motivated by a similar one at KEK
  – want diffraction limited optical system
    • Rayleigh criterion for point source (overlapping airy disks)
      – ~1 microns for 10x objective
      – ~2 microns for 5x objective

\[ d_{\text{min}} = \frac{.61\lambda}{N.A.} \]
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- Plan Apochromat Objective
  - "10x" (with 200mm tube lens)
    - focal length 20mm
    - W.D of 33.5 mm
    - NA of .28
  - "5x" (with 200mm tube lens)
    - focal length 40mm
    - W.D of 34 mm
    - NA of .14
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- Need to place objective very close to target
  - re-entrant design
  - thin window
  - differential pumping w/mylar?
- Recall magnification is $f_2/f_1$ so need 'long' focal length "tube lens" and 'long' tube
- Depth of field is only 3.5 microns for "10x" and 14 microns for "5x"
  - need to tilt the CCD to compensate for this
  - but depth of focus ~7.5mm and ~30mm respectively
- Will be difficult to do the initial focusing
  - maybe move target and rotatable mount for ccd
- Finally need to consider effects of spherical aberrations
  - window
  - tube lens
  - optics simulations needed
- Rough calculations with ½” CCD, 50x magnification & 100µm FOV
  - get ~0.2µm/pixel, defined by “circle of confusion” for this system
  - Beyond the diffraction limit, so its over designed (by linear theory)
  - Need to relax some parameters.
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Conclusions

• May be able to create a 'diffraction limited' optical system for OTR imaging

• Several parameters need to be defined by LLNL and PBPL prior to LVO

• Mechanical design issues need to be kept under consideration when defining parameters

• More work needs to be done to fully understand the optical system (simulations)