Possible consequences of high optical power on AdL optical coatings

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UF

Some numbers

Advanced LIGO Arm Cavities

- Design stored power is 800 kW
  - this is a lot of power
  - Compare LIGO 1 design: 18 kW
- For a 6 cm radius spot, intensity at mirror surface is 7 kW/cm^2
  - Defined by 1/e criterion
  - Compare LIGO 1 design: 0.5 kW/cm^2
  - This is actually not a very high intensity but it will be sustained over very long periods

Advanced LIGO Mode Cleaner

- Design stored power is 100 kW
  - Compare LIGO 1: 3.4 kW
- For a 2.1 mm radius spot, intensity (flat mirror surfaces) is 720 kW/cm^2
  - Higher intensity !
  - Compare LIGO 1: 42 kW/cm^2

Summary of Ignorance

- Advanced LIGO is in a new regime
  - » Very high average power and continuous wave operation
  - » Military work in this area, but hard to get information
- Numerous investigations of damage thresholds by pulsed Nd:YAG lasers (NIF, Nova, ….), but few studies of CW damage
  - » Damage mechanisms are different in pulsed and CW regimes
  - » Most information comes from vendor studies
  - » Typical reported CW damage threshold for Nd:YAG, 1064 nm is 1 MW/cm^2
    - – REO claims their coatings will handle higher intensities
- Some investigations of mirror contamination and damage for high average power synchrotron and FEL operation
  - » High vacuum, but EUV (even X-ray) operation and pulsed
  - » LLNL AVLIS program did some work on CW damage in the early 90's

Issues we would like to understand better

- Damage thresholds, mechanisms
  - » Powers and intensities are below typically quoted damage thresholds for CW laser damage, typically > 1 MW/cm^2
    - – Caveat #1: long term effects?
    - – Caveat #2: Contamination-assisted?
- Surface nonlinear processes
  - » Multi-photon surface bond-breaking
    - – Hydrocarbon contamination
    - – A nonlinear process, yet over years could be a problem
- Contamination
  - » Solid evidence for surface contamination in LIGO based on LHO, LLO experiences
    - – 19 ppm HR surface absorption measured on H1 ITM
    - – → 15.2 W of absorbed power when extrapolated to AdL
- Weird stuff
  - » Cosmic rays interacting with surface coatings?
  - » Charging of coated surface → hydrocarbon sticking → surface photochemistry?
  - » ???

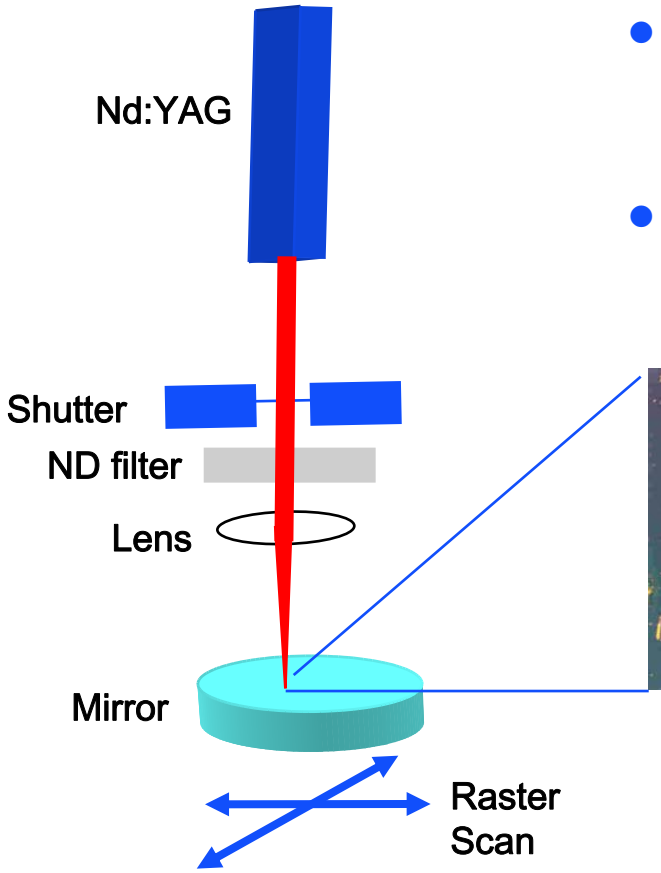
Recommendations I

- Talk to outside experts and collect information
  - » CW mirror characteristics under high power: Northrup Grumman, TRW, LLNL
  - » Contamination: we may be the experts in this field, but should talk to people at BNL, ALS, APS, JLAB, Stanford
- Experiment #1: Characterize damage thresholds of AdL optical coatings
  - » Raster scan, 1 and 100 s exposures, fixed spot size, increasing power
  - » Post-mortem microscopic examination
    - – Well-established methods for quantitatively determining threshold
- Experiment #2: Assessment of long term effects of AdL intensities over sustained periods (~year) on mirror coatings
  - » 10 W into a F=20000 cavity with 1 mm spots → 64 kW, 2 MW/cm^2
  - » 10^{-8} torr vacuum
  - » Monitor:
    - – Linewidth vs. time *in situ*
    - – Surface second harmonic generation (look for green light from the surface)
    - – Surface contamination vs time *in situ*
      - Spatially-resolved sum frequency generation
    - – Periodic surface inspections outside vacuum

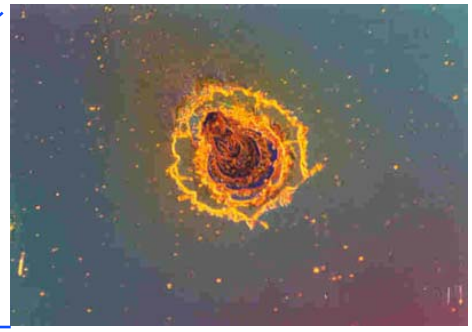
Recommendations II

- LIGO 1 mode cleaner could provide some information relevant to AdL arm cavities
  - » Worth doing a careful investigation of cavity properties now that 5 W is going into MC
    - – Monitor linewidth periodically and consistently
    - – Monitor MC REFL spot shape over time
      - Comparison with MELODY
  - » Next vacuum incursion into L1,H1,H2, visually inspect mirrors for problems
- Investigate possibilities for cleaning mirrors ?
  - » "Reversible laser damage of dichroic coatings in a high average power laser vacuum resonator" by Chow, et al.
    - – Near IR (55 kW/cm^2) and multi-line argon (1 kW/cm^2) irradiation
    - – Degraded performance attributed to loss of surface O atoms
      - Possible mechanisms for O depletion proposed
        - » All attributed to Ar (green) irradiation
    - – Irradiating degraded mirrors with 10 kW/cm^2 in 1-10 T O_2 restores performance by replacing O.

Damage threshold measurement



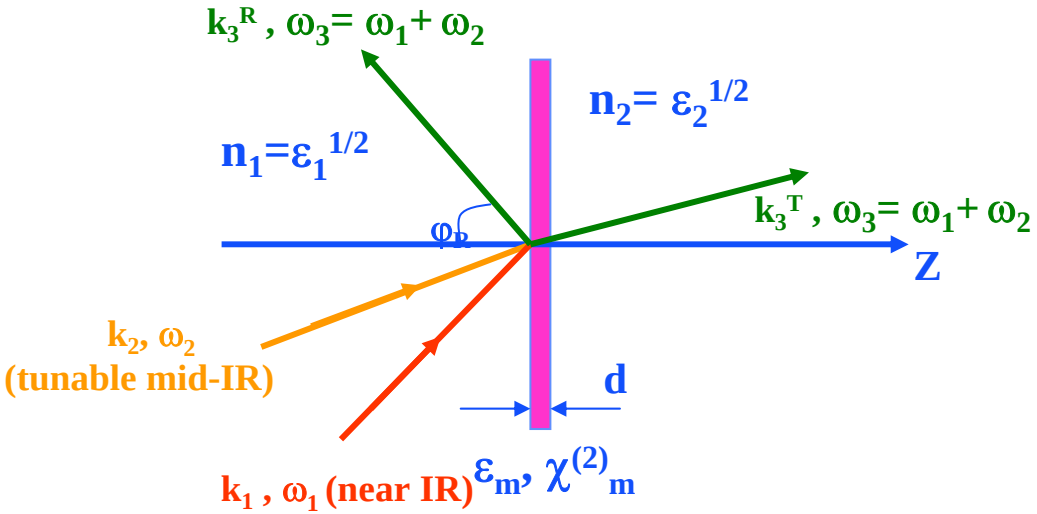
- **post mortem analysis using optical microscopy, Nomarksi contrast microscope to identify threshold**
- **statistics required (100 shots) per fluence**



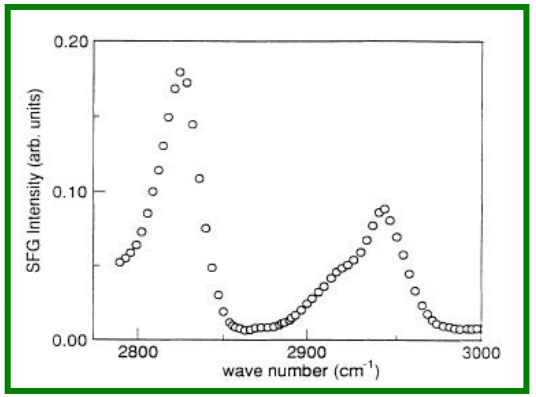
Graphic: Spica Optics

Surface Sum Frequency Generation

- **Resonant enhancement of SFG from chemical bonds of molecules present on surfaces**
- **Surface sensitive – $\chi^{(2)}$ contributes only at surface**
- **Non-contact, *in situ***
- **High spatial resolution**



CH stretch of methanol at methanol vapour/liquid interface λ_1= 532 nm, λ_2= IR



Surface Contamination Monitoring