

Polarization issue in PRC

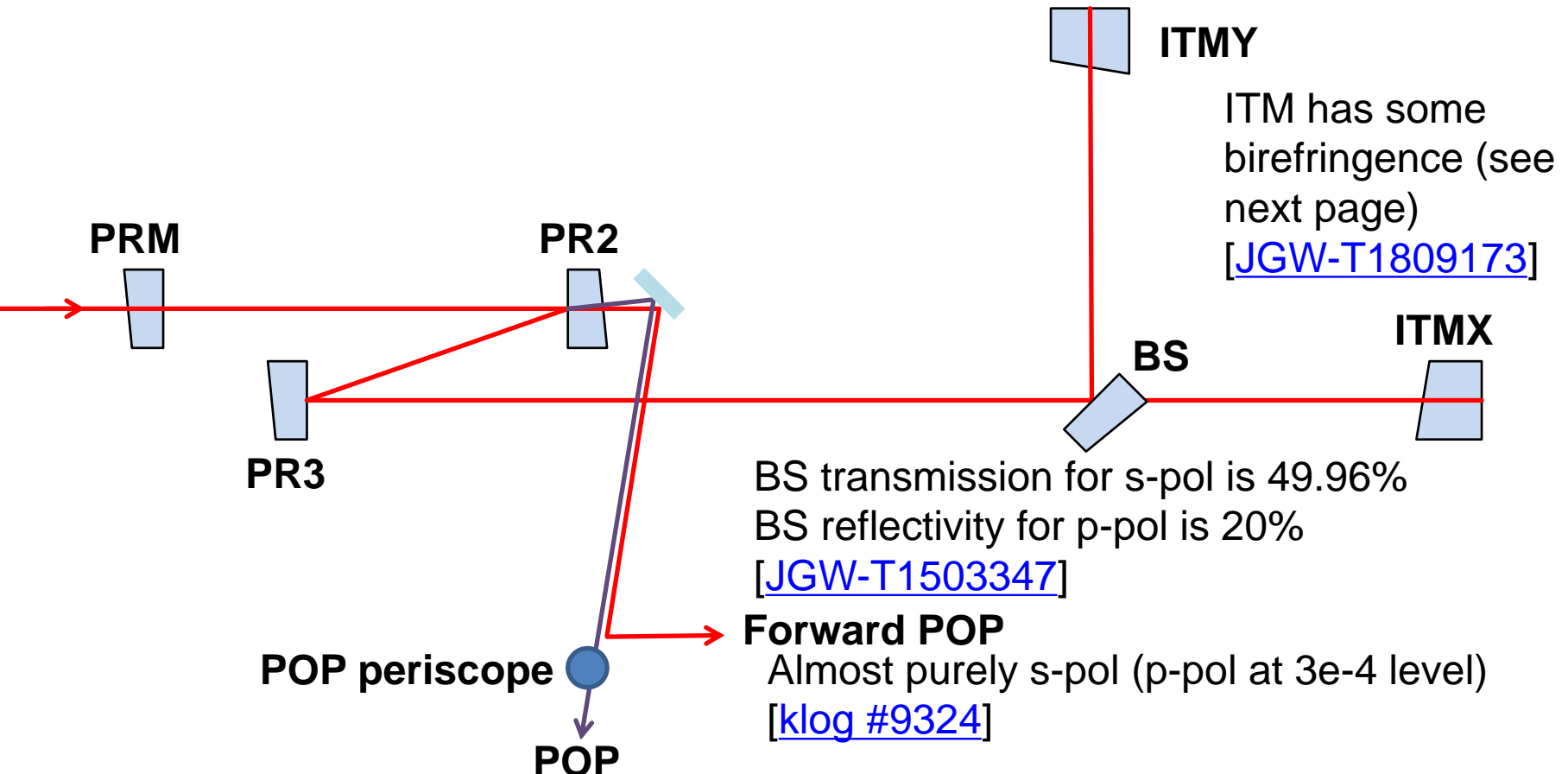
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The Situation

- ITM reflection has some p-pol, while forward beam is almost purely s-pol



9.4 % p-pol from ITMX single bounce

4.6 % p-pol from ITMY single bounce [\[klog #9314\]](#)

ITM Birefringence

- Vendor measured transmission wavefront error (TWE) with circular polarization, but TWE measured with s-pol was different

[JGW-T1809173](#)

	specification	vendor report	measured
ITMX	< 6nm	3.47	25.9nm
ITMY	< 6nm	4.07	30.1nm

Table 6. figure error of TWE at 140mm aperture

- This suggests that ITM has some birefringence
- Optical path length difference between two polarizations Δl_b gives phase difference of

$$\alpha = 2\pi\Delta l_b/\lambda$$

ITM Birefringence

- If we treat RMS linearly, Δl_b can be written as
$$\Delta l_b = l_o - l_{e'} = 2l_u - 2l_{e'}$$
where $l_{u/o/e'}$ are the optical path length measured with circular polarization (~ 5 nm RMS by vendor) and polarization aligned with o/e' axes (~ 30 nm RMS by Caltech)
- *Maximum* power loss due to s-pol turning into p-pol is $\rho = (1 - \cos 2\alpha)/2 \simeq \alpha^2$ (2 for round-trip in ITM)
- The power loss will be 7.0% for X and 9.5% for Y
- This corresponds to the power ratio at POP (p/(s+p)) of 9.6 % for X and 5.8 % for Y (note that BS reflectivity is different between polarizations)
- This seems to (amazingly) agree with the measurement (9.4% for X and 4.8% for Y)

Implications

- We need both uniform l_s and small Δl_b but this **cannot** be achieved by surface corrections
- Using ordinary and extraordinary refractive indices, Δl_b can be written as

$$\Delta l_b = dn_o(n_o^2 - n_e^2)\theta^2 / (2n_e^2)$$
 For sapphire @ 1064 nm
 $n_e = 1.747$
 $n_o = 1.754$

where θ is angle between c-axis and beam axis, [JGW-T0400030](#)
 and d is ITM thickness (15cm)

Note that they are different in cryogenic temperatures and there might be additional birefringence due to stress or something
- If we require loss to be smaller than a threshold,

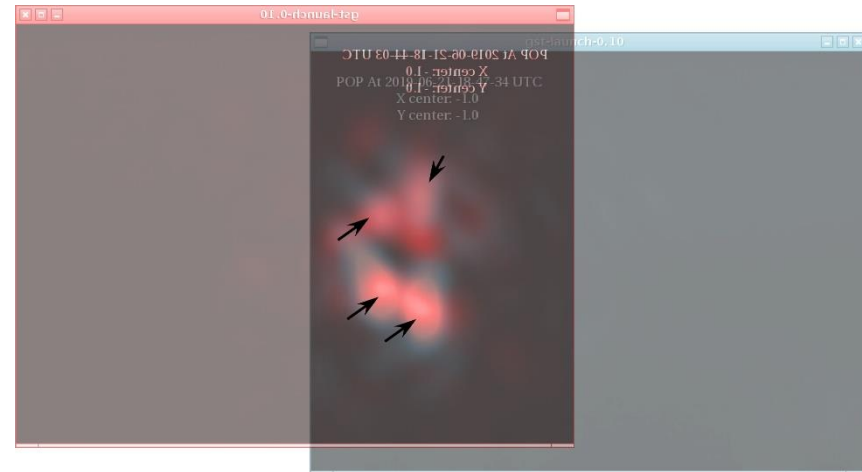
$$\Delta l_b < \sqrt{\lambda^2 \rho_{th} / (2\pi)^2}$$

$$\theta < \sqrt{\frac{2n_e^2 \sqrt{\lambda^2 \rho_{th} / (2\pi)^2}}{dn_o(n_o^2 - n_e^2)}}$$

For 10% (1000ppm) loss, these will be
 54 nm (5.4 nm) and
 0.41 deg (0.13 deg)

Other Possibilities

- The shape of p-pol beams from ITMX and ITMY seems similar which implies common p-pol generation? [[klog #9329](#)]
Common stress due to suspension?



- Beam height changes could create p-pol beam? (we have 1/300 inclination)
- Beam clipping creates p-pol beam somehow?
- Birefringence in ITM coating? (might be able to check by measuring the amount of p-pol at room temperature)

Sapphire Axes

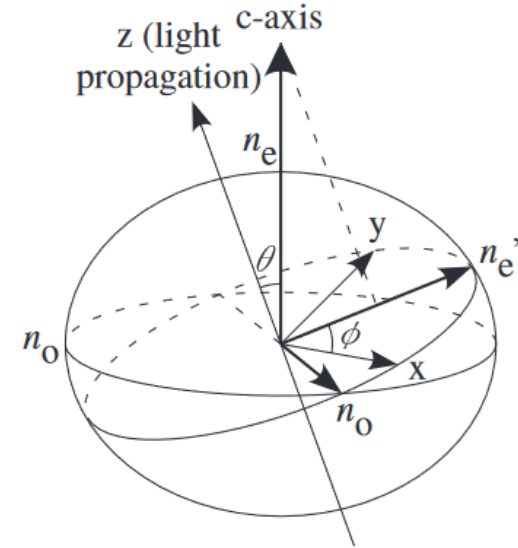
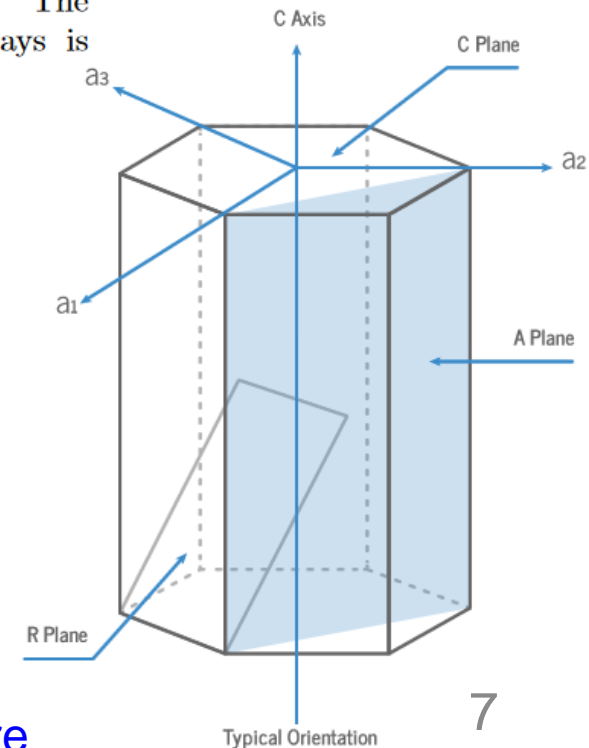


Figure 1. If the c-axis of the sapphire sample inclines by an angle θ from the z-axis, the phase speed of light propagating along the z-axis depends on the direction of its electric field vector \mathbf{E} . The phase speed of a beam whose electric field is parallel to the projection of the c-axis onto the xy-plane, which inclines by an angle ϕ from the x-axis, is c/n'_e and the phase speed of a beam whose electric field is perpendicular to the direction is c/n_o . The phase retardation between these two rays is given by Eq. 2.

Tokunari+, [JPCS 32, 432 \(2006\)](https://doi.org/10.1063/1.1753000)



Calculation Details

- Phase difference between o-axis and e'-axis

$$\alpha = 2\pi d(n_o - n_{e'})/\lambda$$

- p-pol power after ITM reflection

$$P_p/P_{in} = (1 - \cos^2 2\phi)(1 - \cos 2\alpha)/2$$

$$\leq (1 - \cos 2\alpha)/2$$

$$\simeq \alpha^2$$

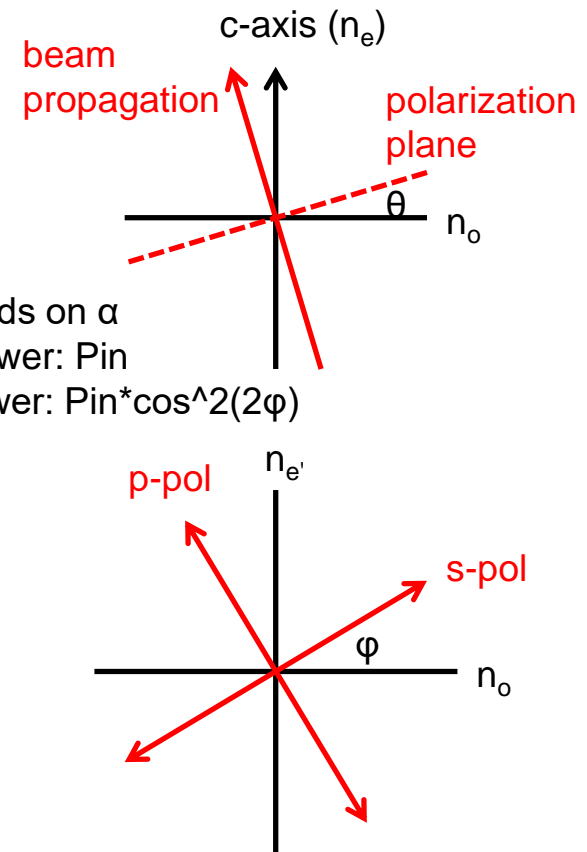
s-pol power depends on α
 Maximum s-pol power: P_{in}
 Minimum s-pol power: $P_{in} \cdot \cos^2(2\phi)$

- Transmission wavefront error

$$d(n_o - n_{e'}) = 2(\underbrace{d(n_o + n_{e'})/2}_{\text{Measured with circular polarization, and this is minimized by polishing}} - \underbrace{dn_{e'}}_{\text{Not directly measured. RMS measured with s-pol shows small dependence on mirror orientation, and this suggests } dn_{e'} \text{ map is similar to } dn_o \text{ map in RMS}})$$

Measured with circular polarization, and this is minimized by polishing

Not directly measured. RMS measured with s-pol shows small dependence on mirror orientation, and this suggests $dn_{e'}$ map is similar to dn_o map in RMS



$\theta < 0.2$ deg ([JGW-T1809173](#))
 But ϕ is totally unknown