SAMS meeting (21/02/2018)
Update on compression-fit mirror

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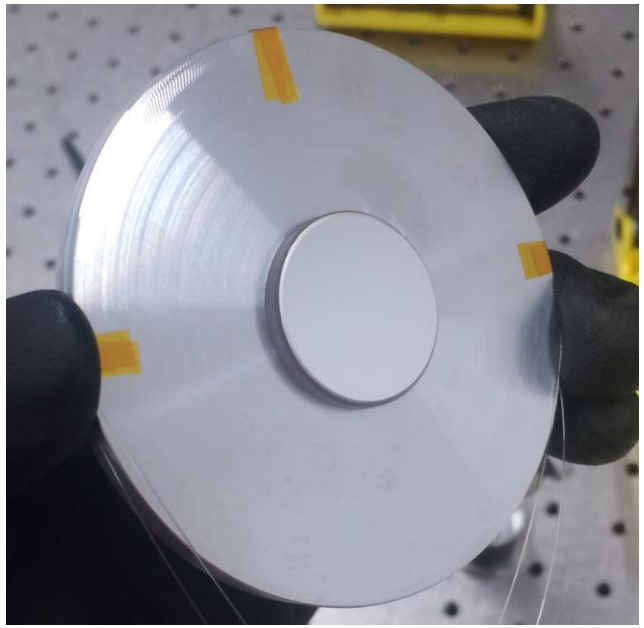
Compression fit mirror (CFM)





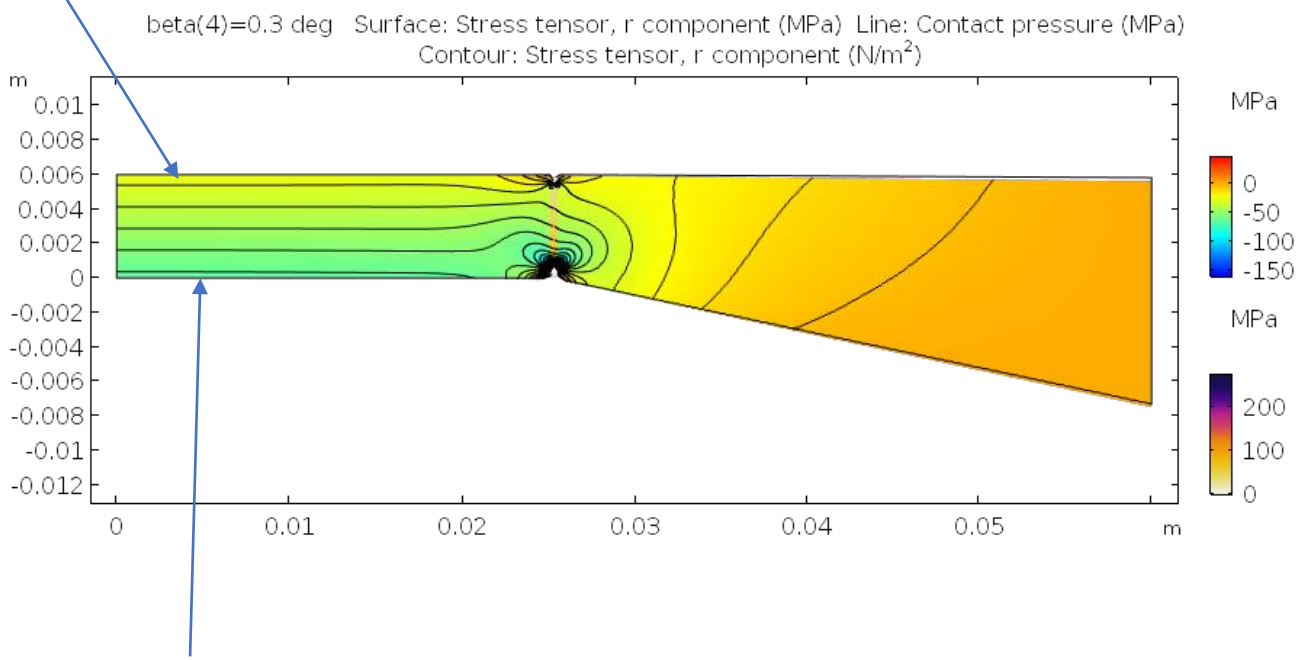
- Thermal expansion allows assembly and provides actuation
- Demonstrated low higher order aberration
- No adhesive
- Requires optimization of geometry

Stress limit of fused silica

- Tensile strength is the main limitation: c.a. 50 MPa
- From Minkyun's talk: bending + compression allows wide range of actuation
- **Figure of merit: Ratio between spherical power (S) and maximum tensile stress ($P_{T,max}$)**
- Min spherical power required: 150 mD
- With safety factor of x3, Max allowable tensile stress: 17 MPa

→ $S/P_{T,max} \geq 8.8$ mD/MPa

Tensile stress at top surface (+ve radial stress component)

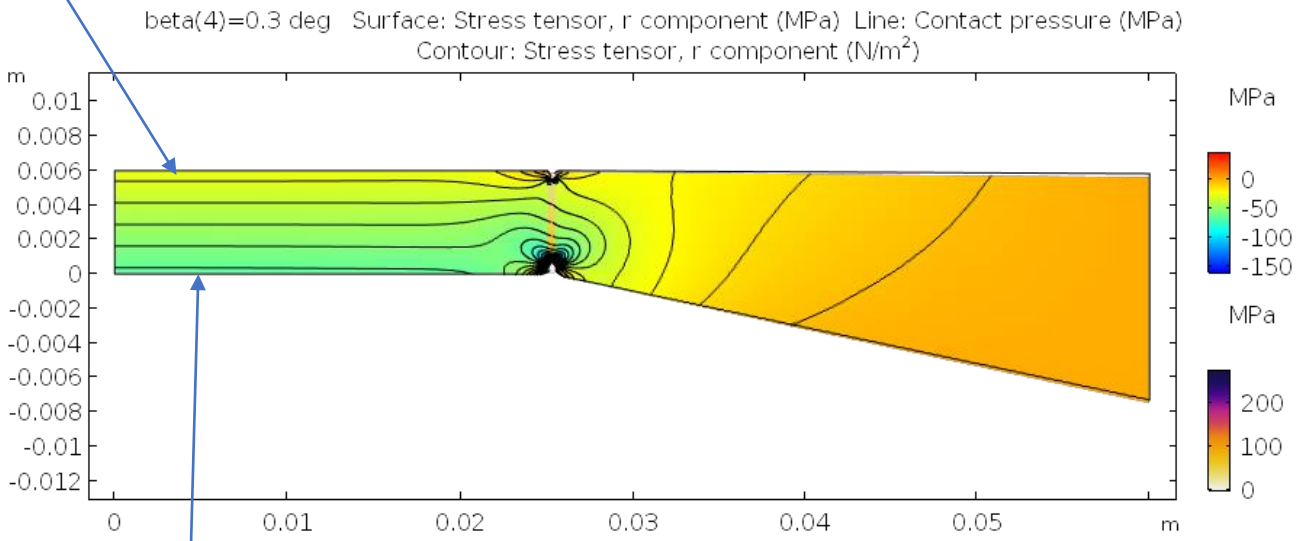


Compressive stress at bottom surface (-ve radial stress component)

Required deformation for CFM

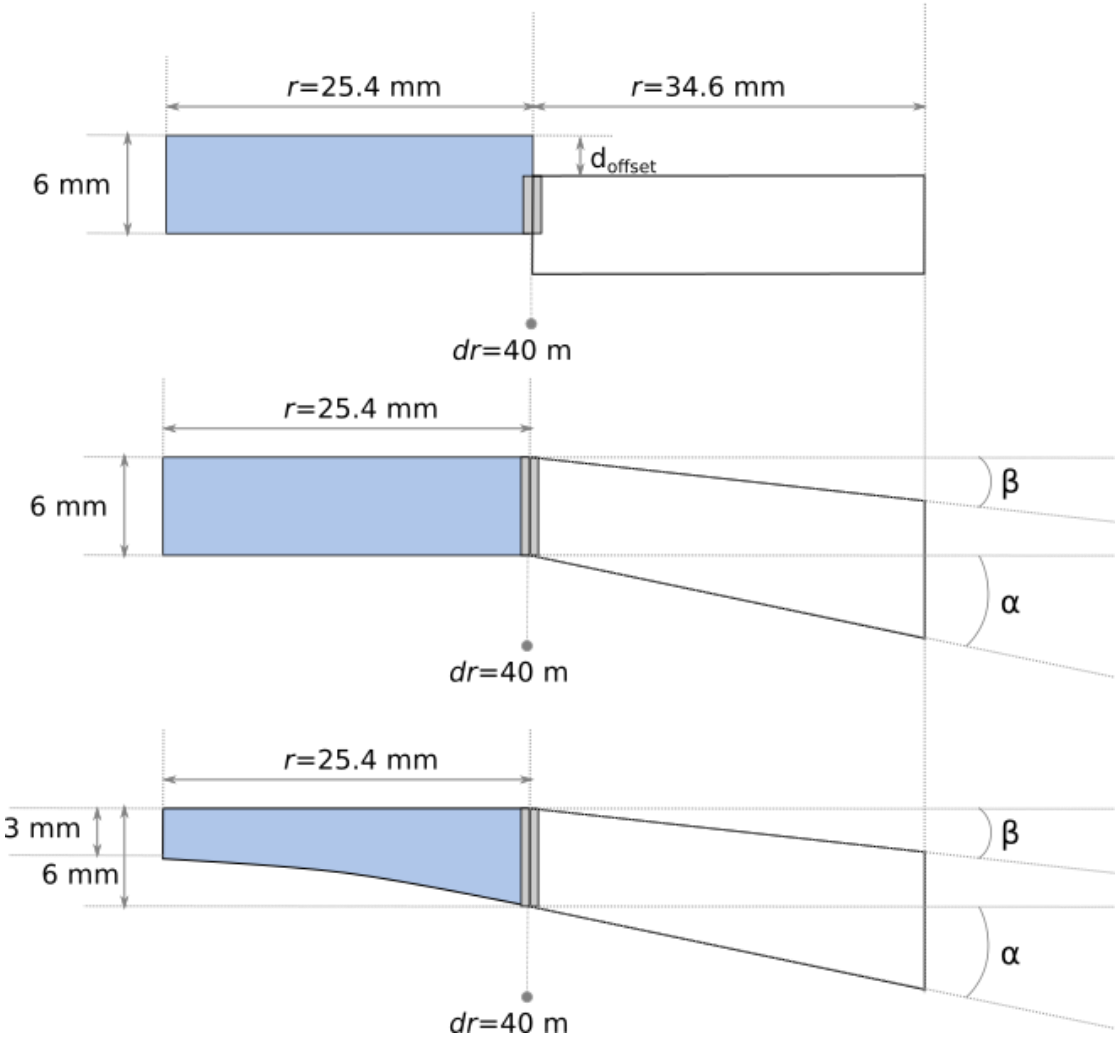
- Assuming max assembly temp of 100°C
- Interference of 40 um
- Min spherical power required: 150 mD
- **Figure of merit: Ratio between spherical power (S) and interference (dr)**
- S/dr >= 3.75 mD/um

Tensile stress at top surface (+ve radial stress component)



Compressive stress at bottom surface (-ve radial stress component)

Geometries comparison

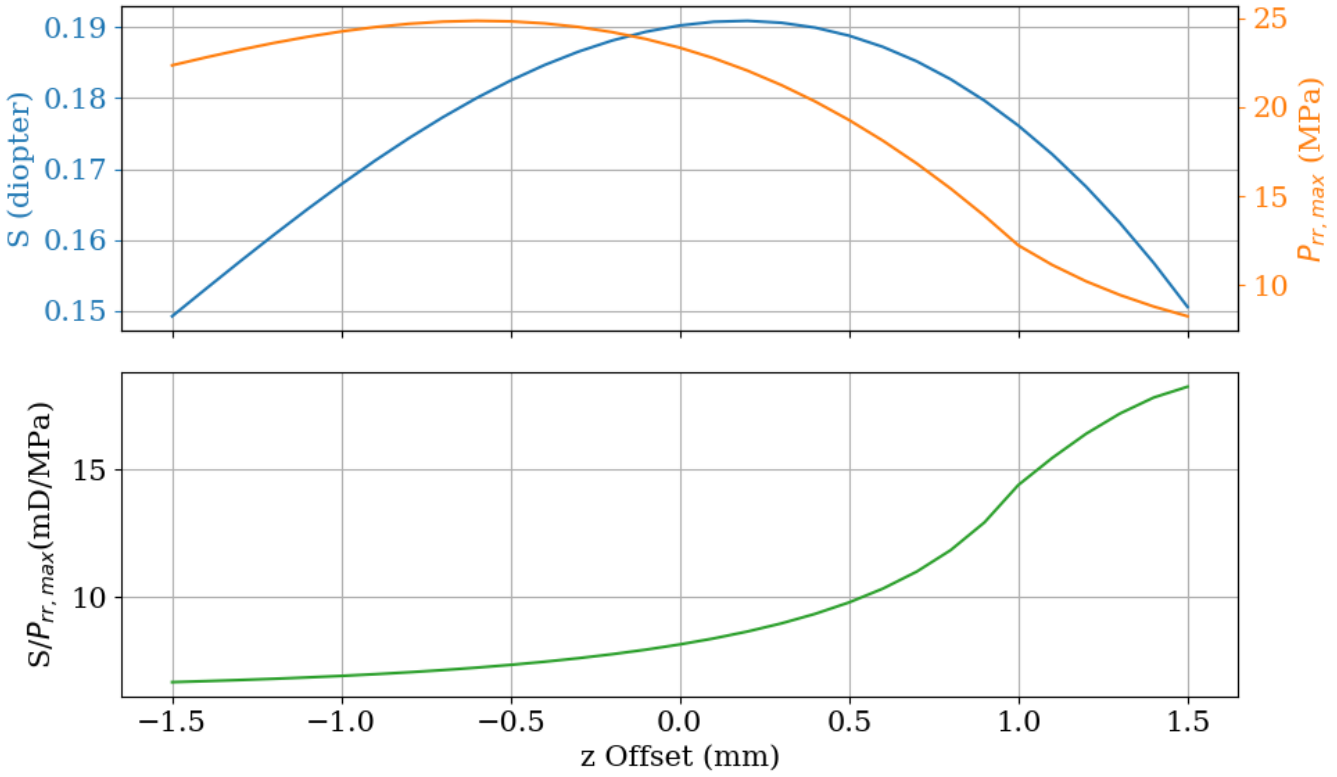


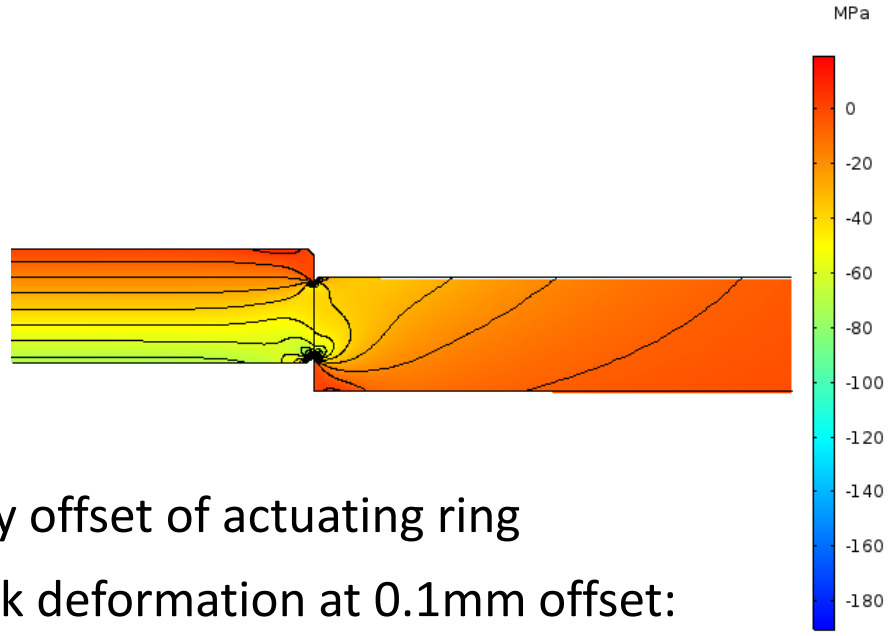
a) Offset ring	*Variable*: offset distance d_z
b) Conical ring + flat mirror	*Variable*: Upper (β) and lower angle (α)
c) Conical ring + planoconcave mirror	*Variable*: Upper (β) and lower angle (α) Edge thickness: 12 mm or 6mm Central thickness: 6 mm or 3mm

COMSOL FEA simulation

- 2D Axisymmetric model
- B.C: Rigid motion suppression
- Cold state difference in mirror radius and Al ring inner radius (interference) *dr*: 40 microns
- Adaptive meshing with finer mesh near contact surface between mirror and Al ring
- Positive radial component of stress tensor (σ_{rr}) gives tensile stress P_T
- Sweep parameters to optimize $S/P_{T,max}$ and S/dr

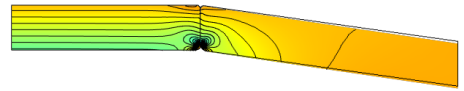
Flat mirror, flat actuator

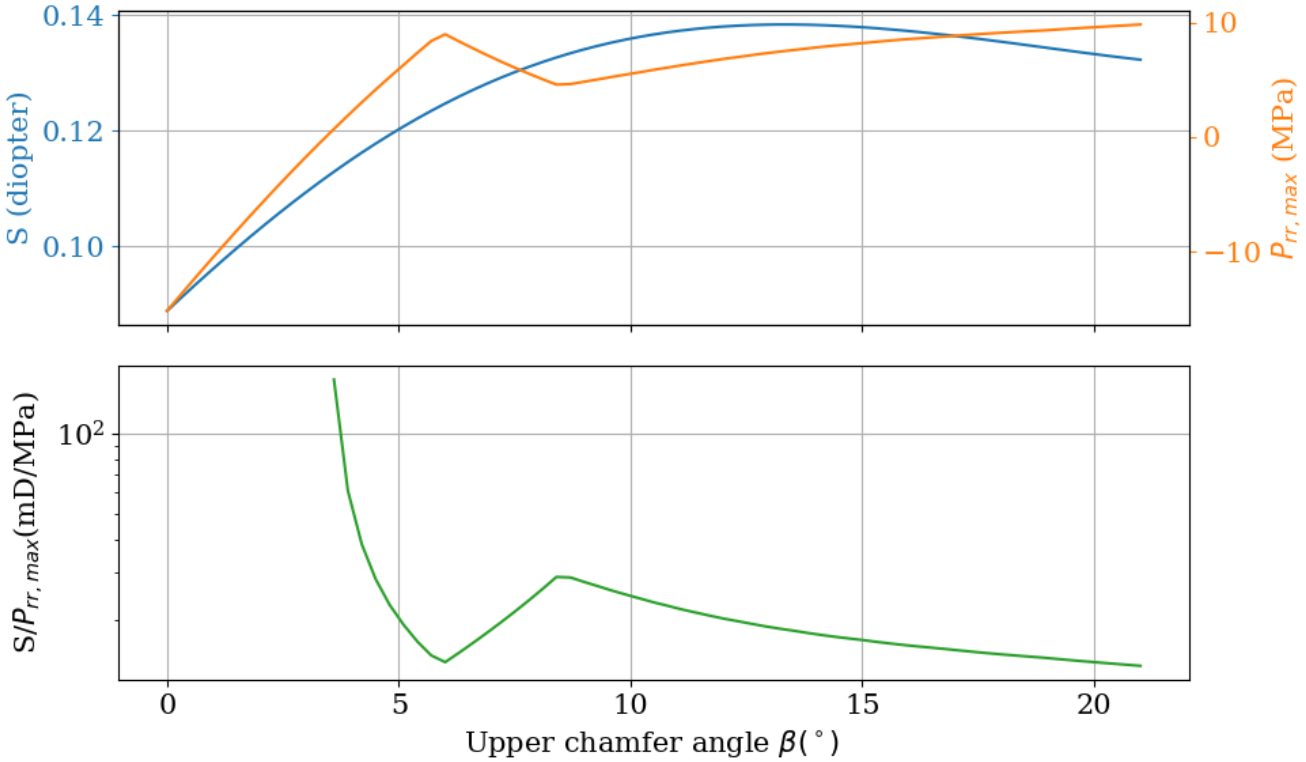




- Vary offset of actuating ring
- Peak deformation at 0.1mm offset:
  - S = 190mD ,
  - $P_{T,max}$ = 22 MPa
- Increase offset to 0.6 mm:
  - S → 165 mD
  - $P_{T,max}$ → 17 Mpa
- Optimal performance can be evaluated as:
  - **$S/P_{T,max}$ = 17 mD/Mpa**
  - **S/dr = 4.12 mD/µm**

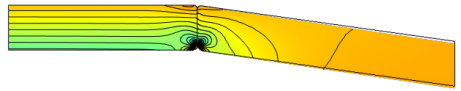
Flat mirror, Conical actuator

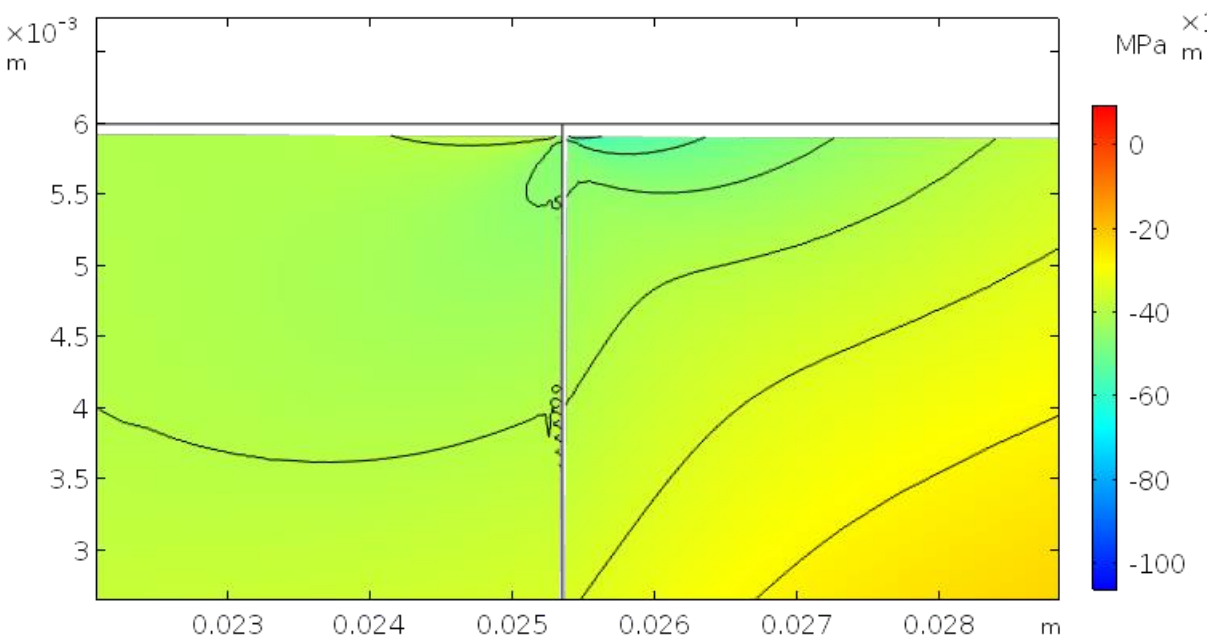


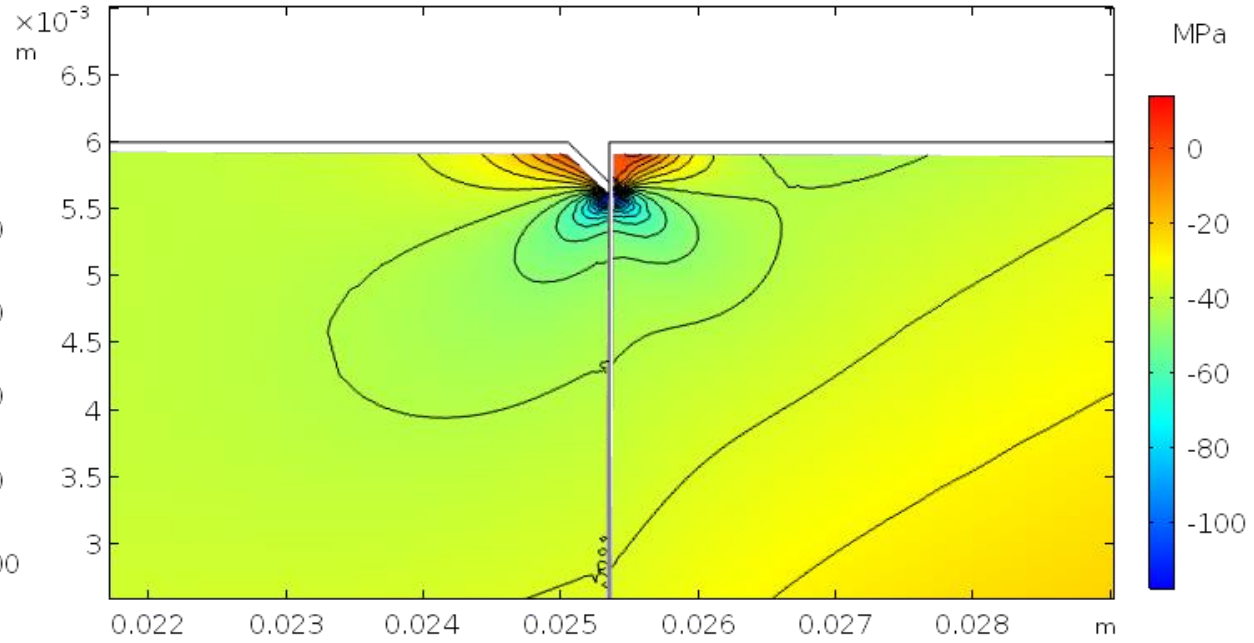


- Max S/PT,max occurs with alpha = 12 deg
- Vary upper angle (β) of actuating ring
- Pure compressive stress at small upper angle β
- **$S/P_{T,max}$** = **18.8 mD/MPa** @ β = 12 deg, α = 13 deg
- **S/dr** = **13.4 mD/µm** < requirement
- No chamfer on mirror

Mirror chamfer or no???

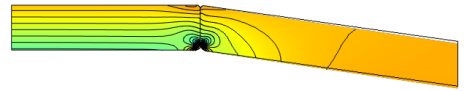


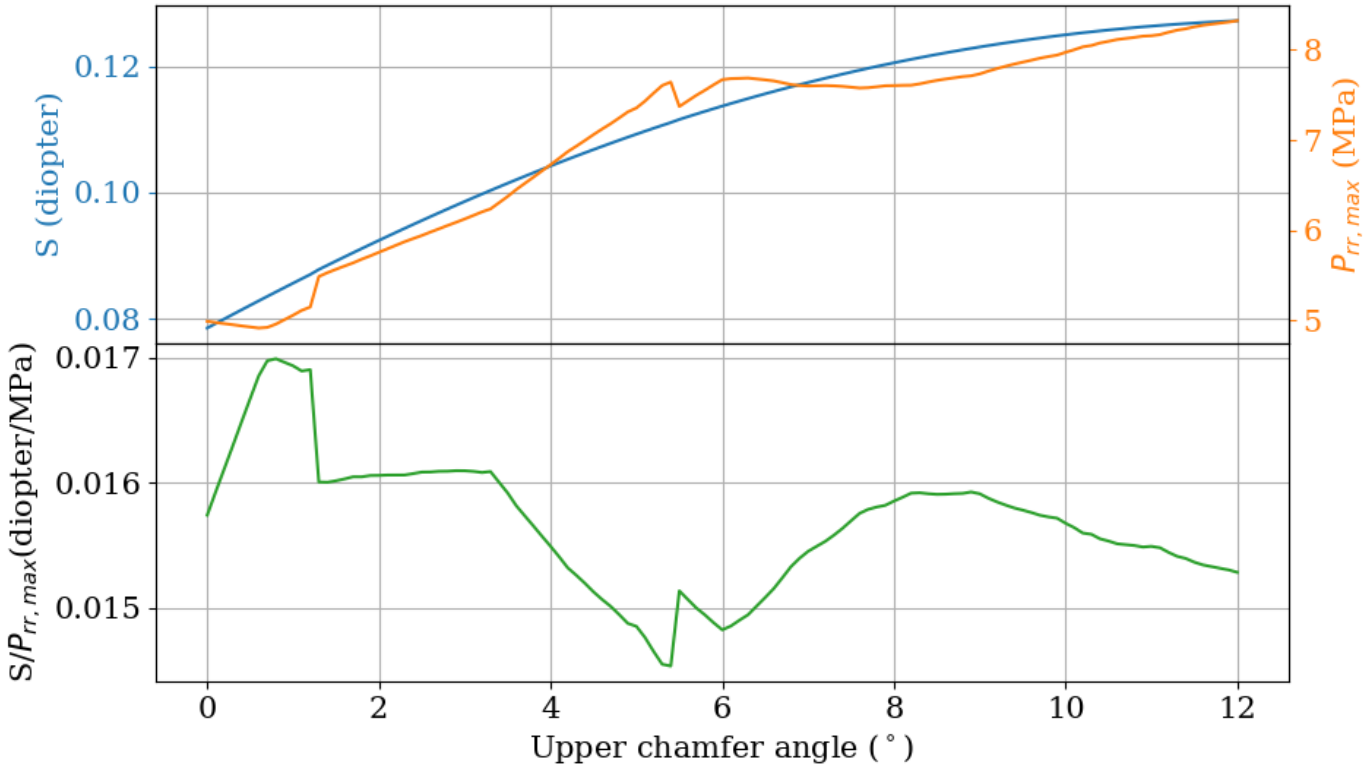




- Investigate effect of chamfering corner of mirror
- 0.3mm chamfer on mirror
- Results in increased tensile stress in unsupported region

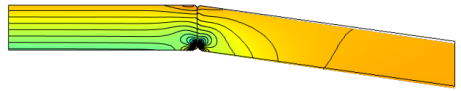
Flat mirror, conical actuator, chamfer

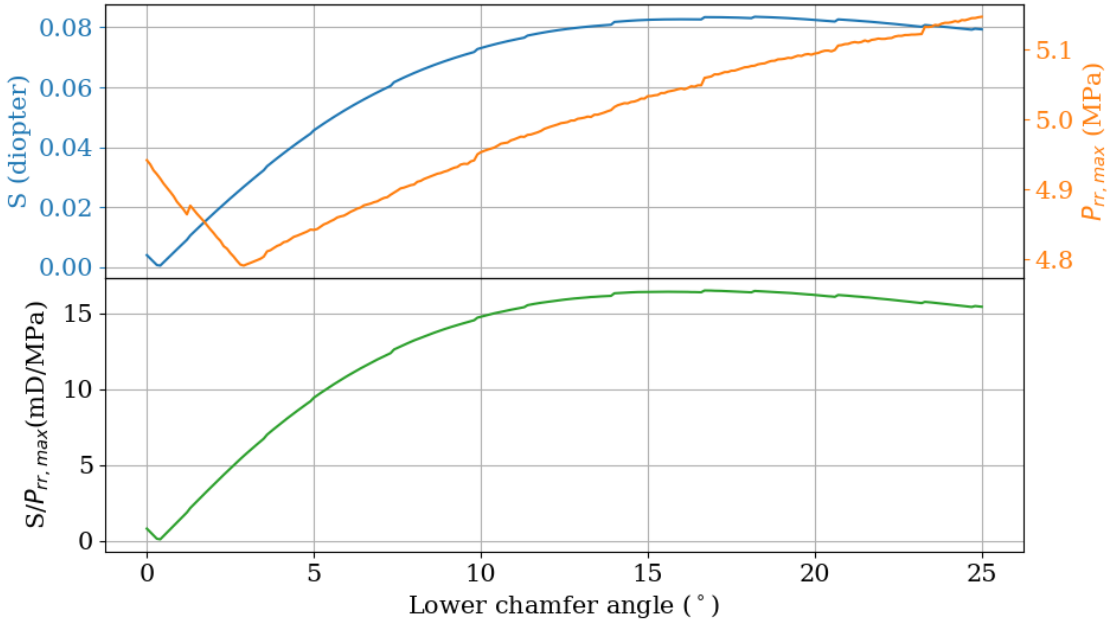


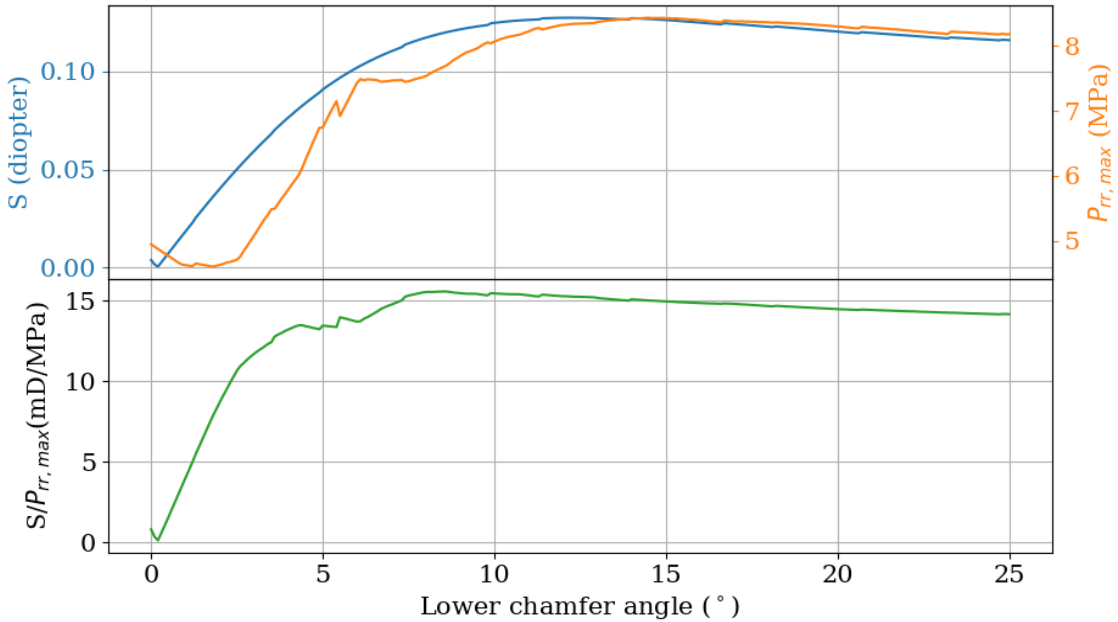


- 0.3mm chamfer on mirror
- Fixed lower angle of actuating ring (α = 12°), vary upper angle (β)
- Maximum tensile increases linearly with *θ*
- **$S/P_{T,max}$ = 15 mD/Mpa**
- **S/dr** = **3 mD/µm**
- Performance reduced below requirements with chamfer

Flat mirror, conical actuator, chamfer







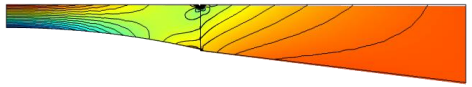
- S/P_{tmax} approximately constant with upper angle of actuating ring (β), vary lower angle alpha
- Upper angle of actuating ring (β= 0°) fixed

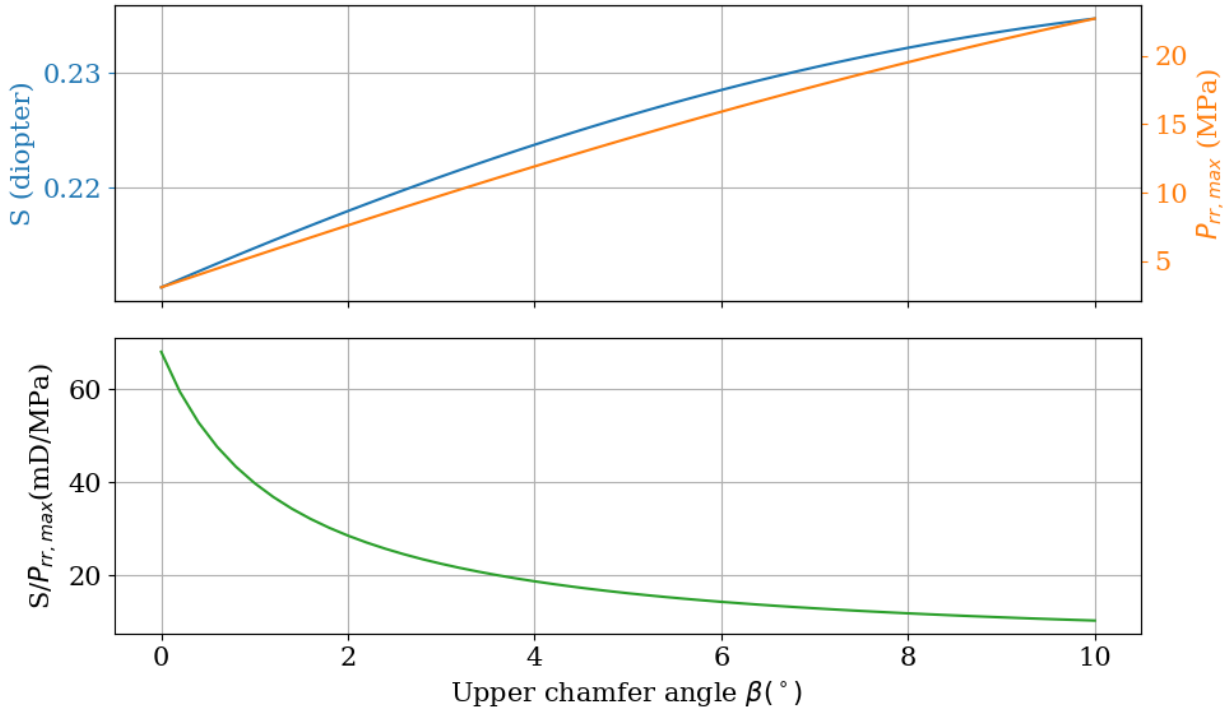
→ Optimal **$S/P_{T,max}$** = **17.4 mD/MPa** at *α= 17°*

- **S/dr** = 2 mD/µm
- S/dr < requirement for all Alpha

- Vary lower angle *α* and β (*α* = β) to increase deformation
- Deformation increases, so does stress, no improvement
- Optimal **$S/P_{T,max}$** = **15.7 mD/MPa** at *α* = β = *8°*
- **S/dr** = 3 mD/µm
- Harder to assemble

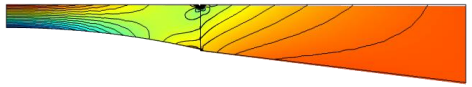
Concave mirror, Conical actuator

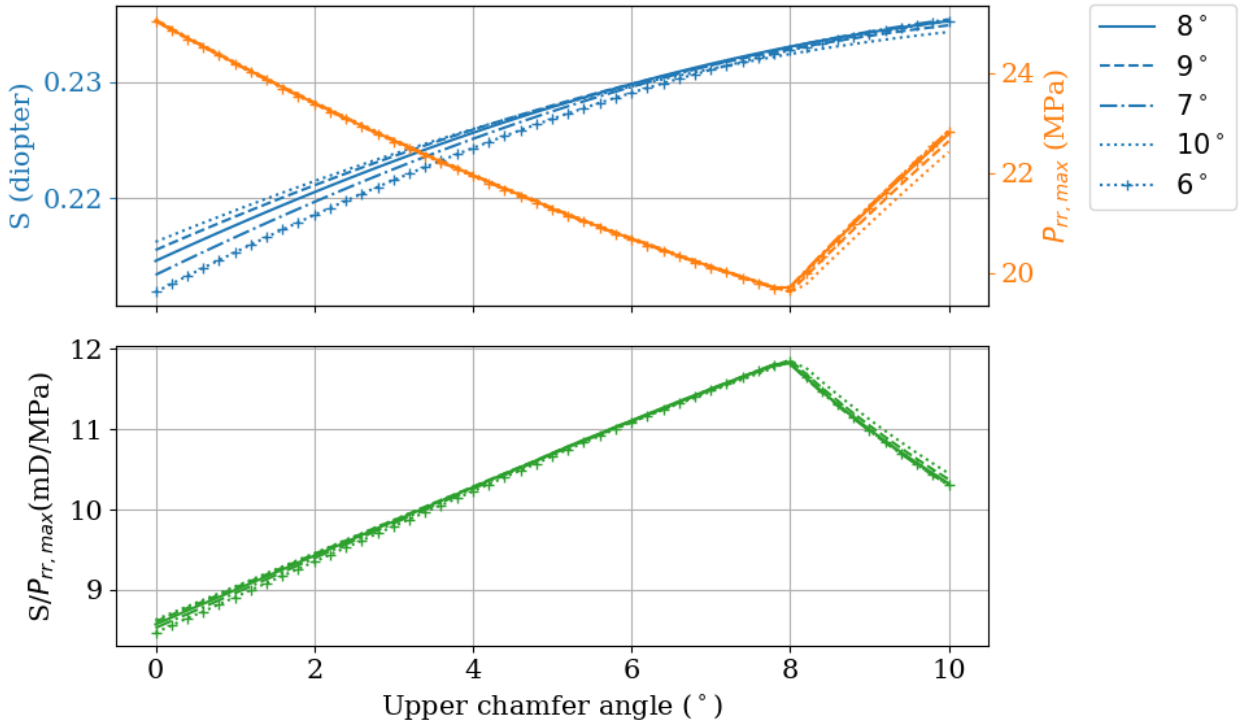




- Flat face of plano-concave substrate as mirror surface
- No chamfer
- 6mm centre, 12 mm edge, R = 56 mm
  - *$S/P_{T,max}$ linear with lower angle of actuating ring (α)*
  - *Max S/dr @ 12.5 deg, vary upper angle (β)*
  - Optimal **$S/P_{T,max}$** = **40+ mD/MPa** at *β = 0°*
  - **S/dr** > **512.2 mD/µm** for all upper angles
- 6mm edge, 3mm centre, R = 115 mm:
  - ***$S/P_{T,max}$*** **= 60+ mD/MPa**
  - ***S/dr*** *can be as large as* ***5.25*** **mD/µm**
  - Is edge or centre thickness important?

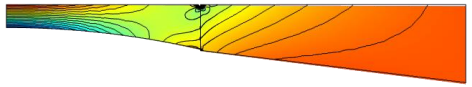
Concave mirror, Conical actuator

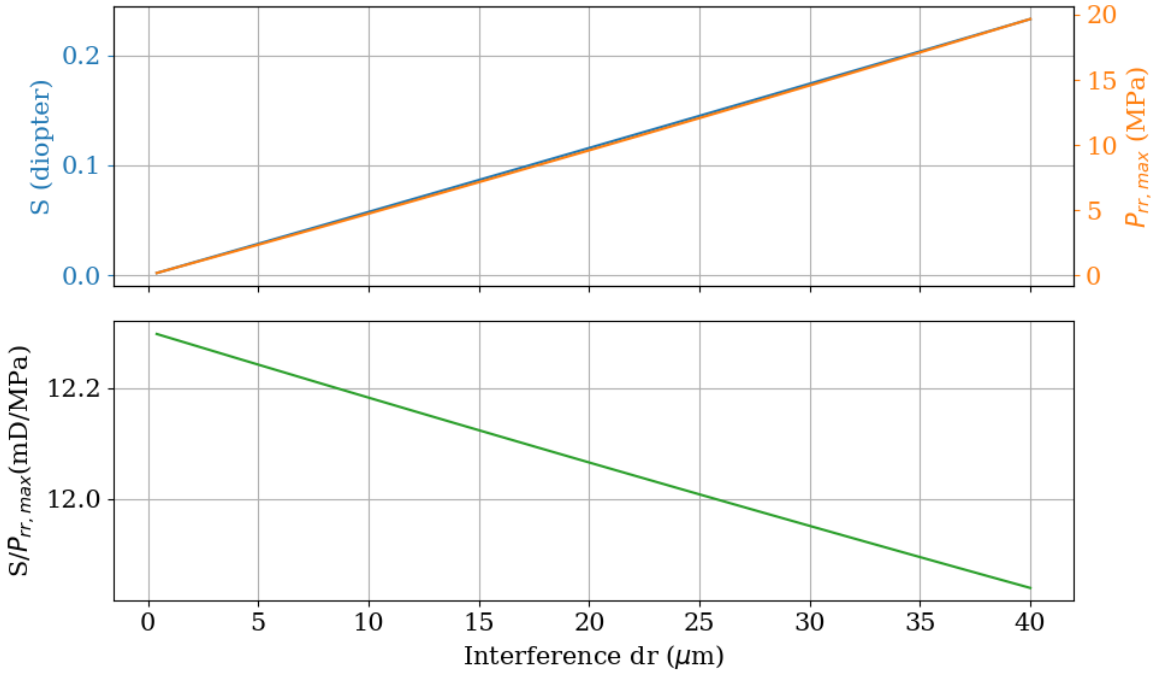




- Including 0.3mm mirror chamfer
- Edge thickness: 12 mm, central thickness: 6mm, R= 56 mm:
  - $S/PT_{,max}$ insensitive to variation in lower angle (α)
  - Optimal **$S/P_{T,max}$** = **11.8mD/MPa** at $\beta = 8^o$
  - **S/dr** = **5.8 mD/µm**
  - High tensile stress (can reduce interference)
- Edge thickness: 6 mm, central thickness: 3 mm:
  - Optimal **$S/P_{T,max}$** = **22.5 mD/MPa** at $\beta = 3^o$
  - **S/dr** = **12 mD/µm**

Concave mirror, Conical actuator





- Verify scaling of spherical power (S) with interference (dr)
- Edge thickness: 12 mm, central thickness: 6mm
- $\alpha = 8^o$, $\beta = 8^o$
- *S/dr* changes linearly with *dr*
- Drop interference to 33 um, assembly T approx. 82°C
- $P_{T,max}$ = **15 MPa**, **$S/P_{T,max}$** = **12.1 mD/MPa**
- S = **200 mD**

Summary

Recall requirements:

- **$S/P_{T,max}$ > 8.8 mD/MPa**
- **S/dr > 3.75 mD/µm**

Mirror	Actuator	Chamfer	Optimal parameter	$S/P_{T,max}$ (mD/MPa)	S/dr (mD/µm)
Flat, 6mm	Flat	Yes/No	*dz* = 1.3 mm	17	4.12
Flat, 6mm	Conical	Yes	$\alpha = 8^o, \beta = 8^o$	15.7	3.0
Flat, 6mm	Conical	No	$\alpha = 12^o, \beta = 13^o$	18.8	3.4
Plano-concave, Edge: 12 mm Center: 6mm	Conical	Yes	$\alpha = 8^o, \beta = 8^o$ *dr = 33µm*	12.1	5.0
Plano-concave, Edge: 12 mm Center: 6mm	Conical	No	$\alpha = 8^o, \beta = 0^o$	45	5.25
Plano-concave, Edge: 6 mm Center: 3mm	Conical	Yes	$\alpha = 6^o, \beta = 3^o$ *dr = 25µm*	21.5	7.5
Plano-concave, Edge: 6 mm Center: 3mm	Conical	No	$\alpha = 8^o, \beta = 0^o$	68	11.5

Summary

- With no chamfer on mirror, conical ring => **$S/P_{T,max}$ > 18 mD/MPa**
- Chamfered mirror => flat actuator ring more competitive
- May be possible to machine a lip on the actuator ring to accomodate the chamfer?
- If a plano-convex mirror is feasible, which is most relevant, edge or centre thickness?
- Most geometries can satisfy stress and actuation requirements. How should we further optimize:
  - Simplicity
  - Mass
  - Maximize actuation
  - Other considerations?