# Can we use aSi to improve coatings for A+?


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# Starting point

- We know that aSi has…
  - a high refractive index (between 3 and 4)
    → fewer and thinner layers required for high reflectivity
    = reduction in coating thermal noise (CTN)
  - low mechanical loss, in particular at low T
  - rather high absorption, which gets lower as the wavelength increases ($\alpha_{2\mu m} < \alpha_{1550nm} < \alpha_{1064nm}$ )

# Absorption of aSi at 1064nm

| | deposition | n | k @ 1064nm | k @ 1550nm | temp | loss |
|---|---|---|---|---|---|---|
| MLD | IBS | 3.35 | 1.16e-2 | 3.5e-3 | 500°C | 1.5e-4[4] |
| ATF[1] | IBS | 3.6 | 7.4e-3 | 1.8e-3 | 500°C | 1e-4[5] |
| Tafelmaier[2] | Ion plating | 3.82 | 4.32e-3 | 6.25e-4 | 500°C | 2e-5 |
| UWS / Strathcylde[3] | ERC-IBS | 3.39 (dep. @ 400°C) | 2e-4 (lowest) 5e-4 (more often) | 1.2e-5 | 450°C | 2e-5 |

(for comparison)

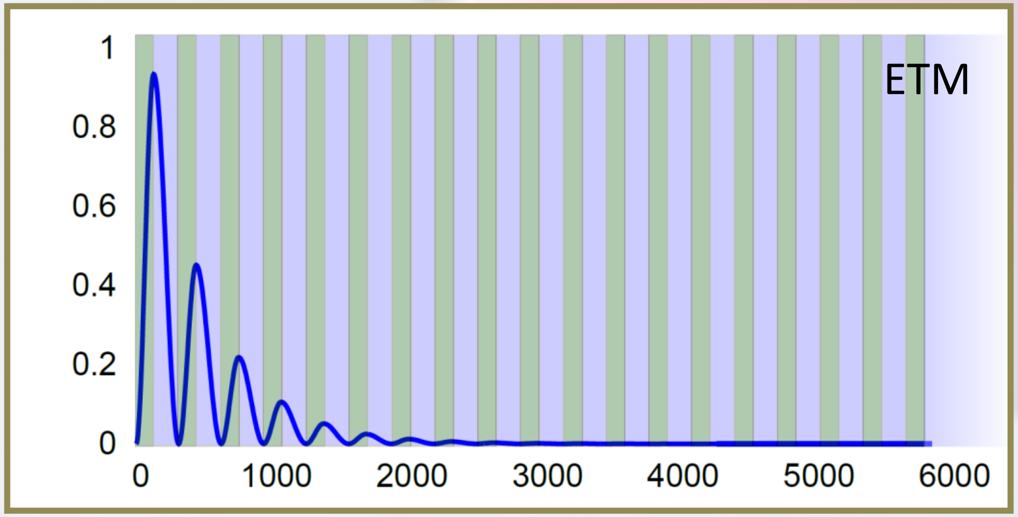
Absorption at 1064nm is not so bad compared to 1550nm - in particular as layers are thinner – less material to absorb light

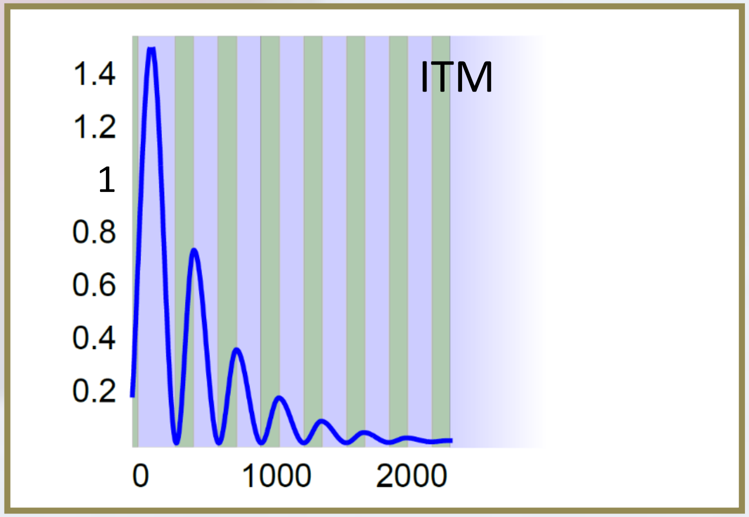
[1] Steinlechner et al PRD 93 (2016) [2] Steinlechner et al PRL 120 (2018) [3] Birney et al PRL 121 (2018)
[4] Peter Murray [5] Murray et al PRD 92 (2015)

# A standard coating for comparison

- ETM: 18 layers of $SiO_2$, 19 layers of $Ta_2O_5$ on a $SiO_2$ substrate
  - R = 99.9997% (for k=0)
  - CTN = $6.16 \times 10^{-21}$ m/√Hz
- ITM: 6 layers $SiO_2$ + 7 layers $Ta_2O_5$ + 1.55 x $SiO_2$ + 0.3 x $Ta_2O_5$
  - R=98.6 %
  - CTN: $4.23 \times 10^{-21}$ m/√Hz

total detector CTN: $10.57 \times 10^{-21}$ m/√Hz*

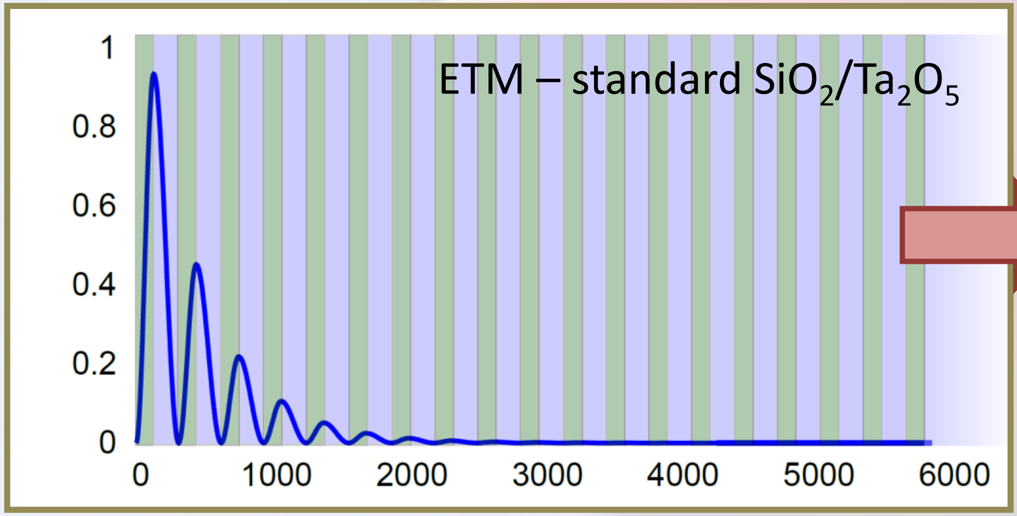


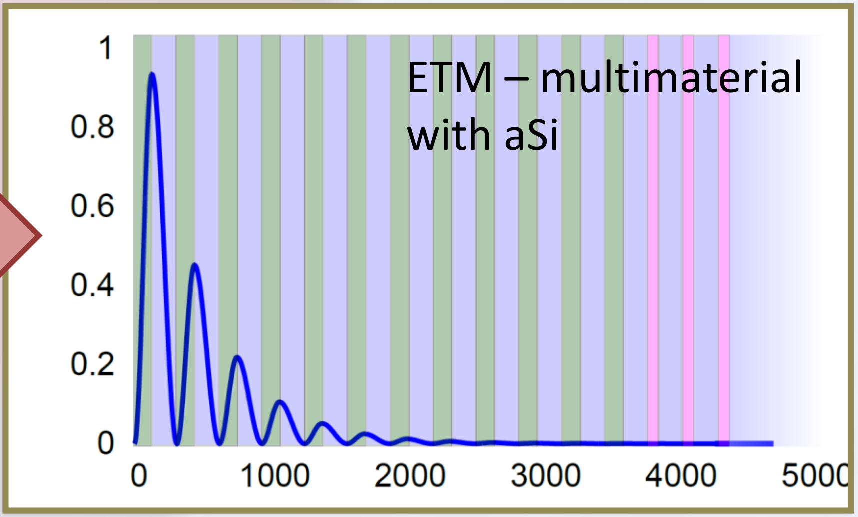




*not aLIGO coating design, but representative reference design: relative improvement from incorporation of aSi is similar
parameters used in these calculations given at end of presentation

# How much aSi can we use in a multimaterial coating?

- “worst case“: MLD aSi, k = 1.16e-2
- ETM: 11.5 x $SiO_2/Ta_2O_5$ + 3 x $aSi/SiO_2$
  - R=99.9996 %, $\alpha$ = 1.3ppm (assuming k=0 for $SiO_2/Ta_2O_5$ )
  - CTN: 5.09 x $10^{-21}$m/√Hz (-17.4%)



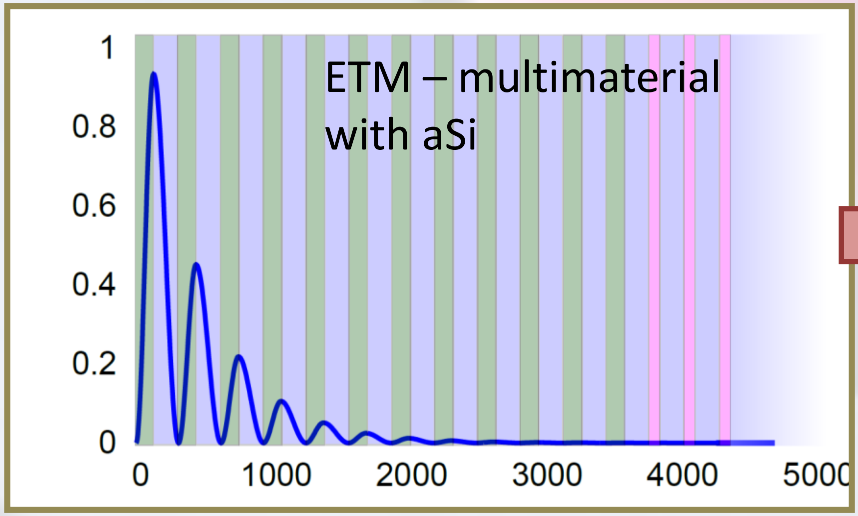



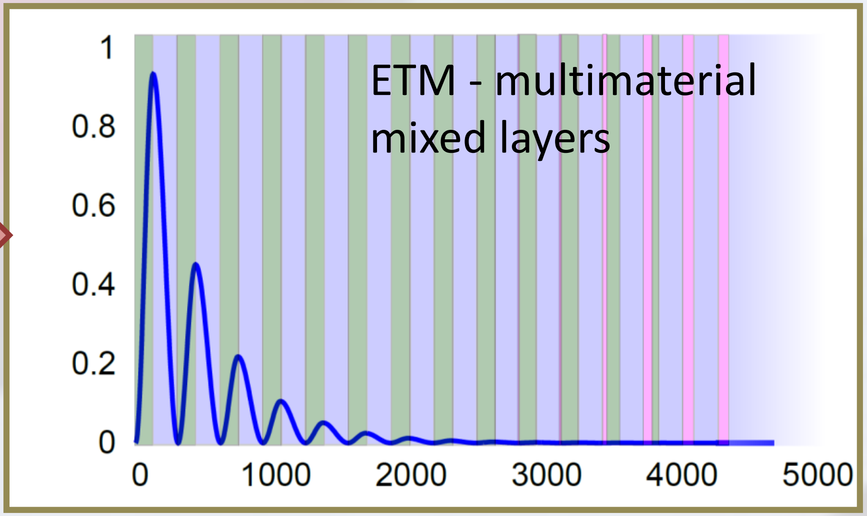

- ITM: no improvement possible due to transmitted power

total detector CTN: 9.36 x $10^{-21}$ m/√Hz **(-11.5%)**

# Reducing α by adjusting aSi layers

- Can we split high-index layers, only using aSi at points where the electric field intensity is low?
  - ETM: 2 x aSi/$SiO_2$, 1 x $SiO_2$/ 0.8 aSi + 0.36 $Ta_2O_5$, 1 x $SiO_2$/ 0.4 aSi + 0.725 $Ta_2O_5$ 1 x $SiO_2$/ 0.2 aSi + 0.875 $Ta_2O_5$, 1 x $SiO_2$/ 0.1 aSi + 0.94 $Ta_2O_5$, 8.5 x $SiO_2$/$Ta_2O_5$



# Reducing α by adjusting aSi layers

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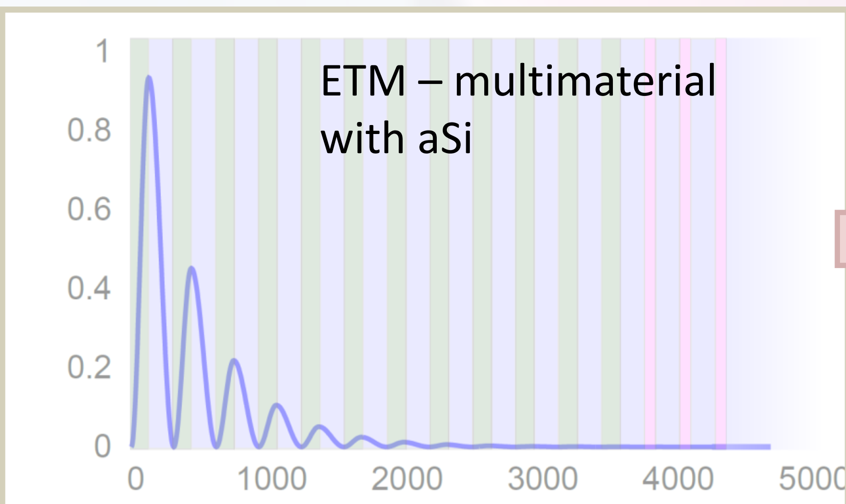
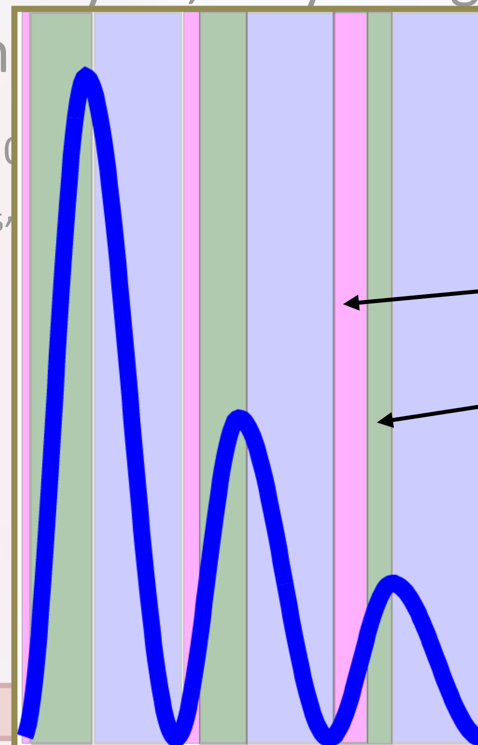
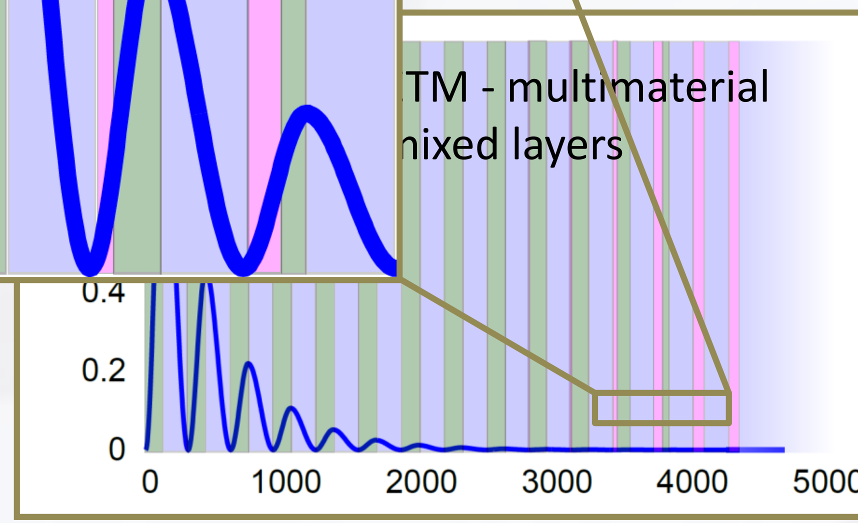
  - ETM: 2 x $Si/SiO_2$, 1 x $SiO_2$/ 0.8 aSi + 0 + 0.725 $Ta_2O_5$
    1 x $SiO_2$/ 0.2 aSi + 0.875 $Ta_2O_5$, $O_5$, 8.5 x $SiO_2/Ta_2O_5$

Use aSi in parts of the layer where the light field is low.



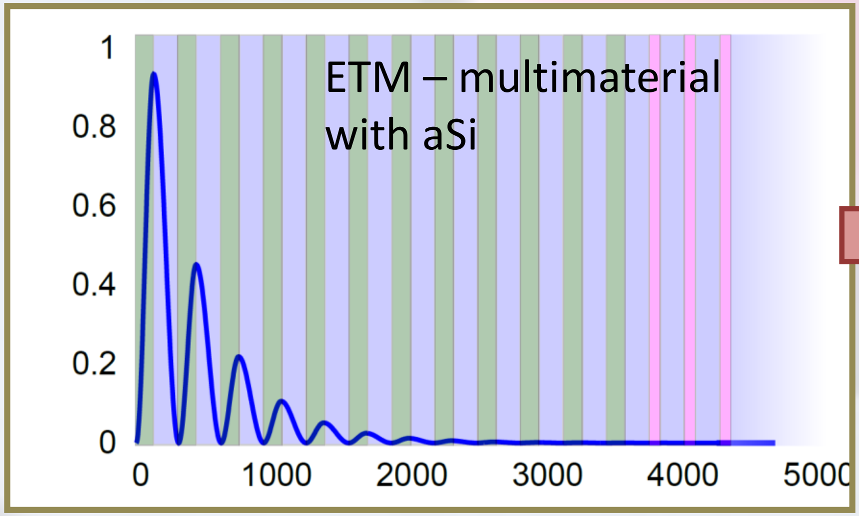



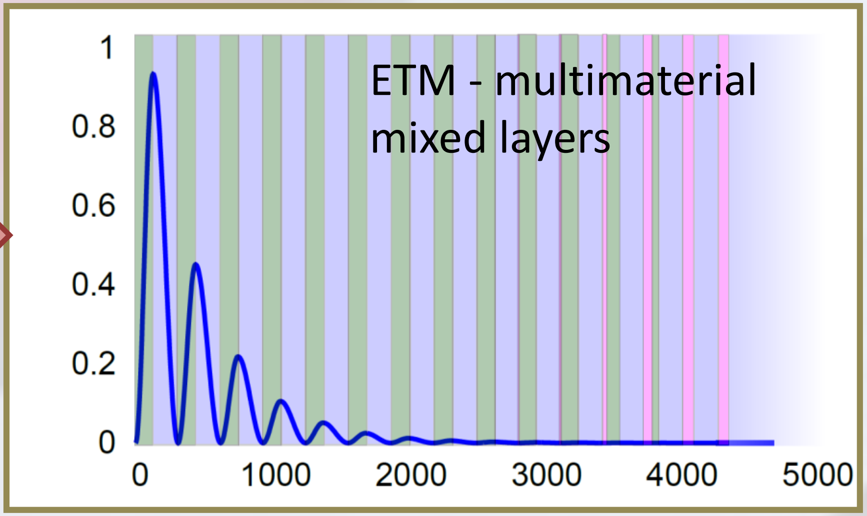



# Reducing α by adjusting aSi layers

- Can we split high-index layers, only using aSi at points where the electric field intensity is low?
  - ETM: 2 x $aSi/SiO_2$, 1 x $SiO_2$/ 0.8 aSi + 0.36 $Ta_2O_5$, 1 x $SiO_2$/ 0.4 aSi + 0.725 $Ta_2O_5$
    1 x $SiO_2$/ 0.2 aSi + 0.875 $Ta_2O_5$, 1 x $SiO_2$/ 0.1 aSi + 0.94 $Ta_2O_5$, 8.5 x $SiO_2/Ta_2O_5$

Now we have 2 $aSi/SiO_2$ layers instead of base design of 3, but use $aSi/Ta_2O_5$ combination in the next 4 layers



# Reducing α by adjusting aSi layers

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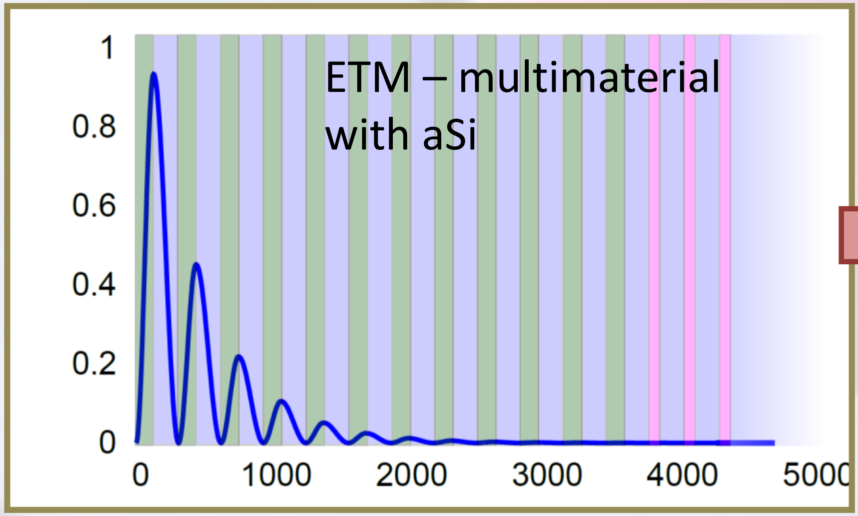
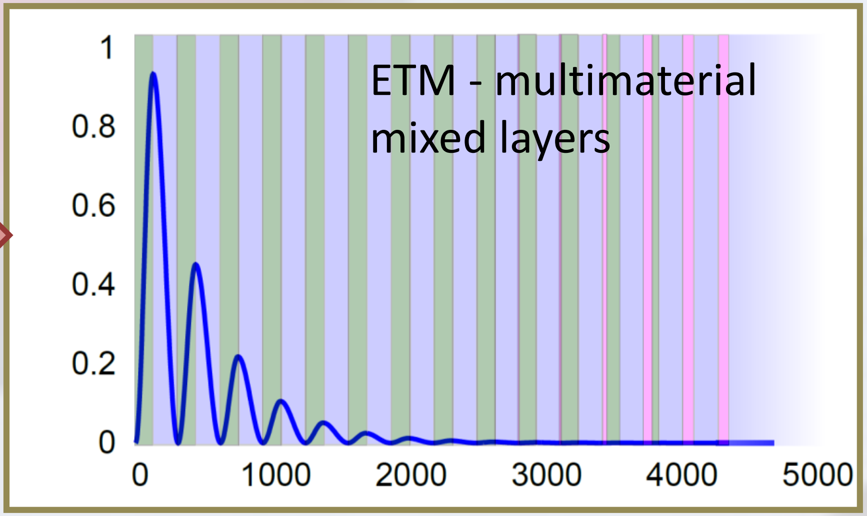
  - ETM: 2 x $Si/SiO_2$, 1 x $SiO_2$/ 0.8 aSi + 0.36 $Ta_2O_5$, 1 x $SiO_2$/ 0.4 aSi + 0.725 $Ta_2O_5$ 1 x $SiO_2$/ 0.2 aSi + 0.875 $Ta_2O_5$, 1 x $SiO_2$/ 0.1 aSi + 0.94 $Ta_2O_5$, 8.5 x $SiO_2/Ta_2O_5$
    - R=99.9996 %, $\alpha$ = 0.9 ppm (assuming k=0 for $SiO_2/Ta_2O_5$ )
    - CTN: 5.04 x $10^{-21}$m/√Hz (-18.2%)
- ITM: no improvement possible




total detector CTN: 9.31 x $10^{-21}$ m/√Hz **(-11.9%)**

# How much aSi can we use when k is lower?

- “best case“: UWS aSi, k = 2e-4
  - ETM: 5 x aSi/$SiO_2$, 1 x $SiO_2$/ 0.7 aSi + 0.5 $Ta_2O_5$, 1 x $SiO_2$/ 0.2 aSi + 0.87 $Ta_2O_5$, 1 x $SiO_2$/ 0.1 aSi + 0.925 $Ta_2O_5$, 2 x $SiO_2$/$Ta_2O_5$, 0.9 x $SiO_2$ + 0.9 x $Ta_2O_5$
    - R=99.9997 %, $\alpha$ = 1 ppm (assuming k=0 for $SiO_2$/$Ta_2O_5$ )
    - CTN: 3.70 x $10^{-21}$m/√Hz (-39.9 %)

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    - R=99.9997 %, $\alpha$ = 1 ppm (assuming k=0 for $SiO_2$/$Ta_2O_5$ )
    - CTN: 3.70 x $10^{-21}$m/√Hz (-39.9 %)
  - ITM*: 0.3 x aSi + 0.8 x $Ta_2O_5$, 6 x $SiO_2$/$Ta_2O_5$
    - R=98.6 %, $\alpha$ = 1 ppm (assuming k=0 for $SiO_2$/$Ta_2O_5$ )
    - CTN: 4.04 x $10^{-21}$m/√Hz (- 4.5 %)

# How much aSi can we use when k is lower?

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  - ETM: 5 x aSi/$SiO_2$, 1 x $SiO_2$/ 0.7 aSi + 0.5 $Ta_2O_5$, 1 x $SiO_2$/ 0.2 aSi + 0.87 $Ta_2O_5$, 1 x $SiO_2$/ 0.1 aSi + 0.925 $Ta_2O_5$, 2 x $SiO_2$/$Ta_2O_5$, 0.9 x $SiO_2$ + 0.9 x $Ta_2O_5$
    - R=99.9997 %, α = 1 ppm (assuming k=0 for $SiO_2$/$Ta_2O_5$ )
    - CTN: 3.70 x $10^{-21}$m/√Hz (-39.9 %)
  - ITM*: 0.3 x aSi + 0.8 x $Ta_2O_5$, 6 x $SiO_2$/$Ta_2O_5$
    - R=98.6 %, α = 1 ppm (assuming k=0 for $SiO_2$/$Ta_2O_5$ )
    - CTN: 4.04 x $10^{-21}$m/√Hz (- 4.5 %)

total detector CTN: 7.75 x $10^{-21}$ m/√Hz **(- 26.5 %)**

# Combination with other ways to improve CTN

- For CTN optimized layer thicknesses, slightly different (possibly less) improvement possible
- Can be fully combined with improvement from new, better materials
  - Improvement depends on the refractive indices of new materials
- Heat treatment temperature for aSi should not be above 500°C

# Summary: CTN improvement using aSi from different vendors

| aSi vendor | ETM | ITM | total |
|---|---|---|---|
| MLD | -18.2% | - 0% | -11.5% |
| ATF | -22.1% | - 0% | -14.4% |
| Tafelmaier | -26.5% | - 0% | -17.1% |
| UWS | -39.9% | -4.5% | -26.6% |
| UWS, 2ppm | -43.7% | -8.5% | -30.5% |

**$\alpha$ = 1ppm** (MLD, ATF, Tafelmaier, UWS)

**$\alpha$ = 2ppm** (UWS, 2ppm)

**with reference to standard $SiO_2$ / $Ta_2O_5$ coatings (slide 4)**

# A few things to consider

- Standard IBS aSi coatings (MLD/ATF) could probably be produced “tomorrow“, but only moderate improvement
- Tafelmaier aSi → ion plating – more improvement, but:
  - Large sizes?
  - Scattering?
- UWS aSi → ECR IBS
  - k = 2e-4: the lowest number which was ever produced
  - k = 5-6e-4: more normal
  - It is unknown why some coatings were so good*

- Absorption in multilayers possibly slightly higher than expected from single layer measurements [Steinlechner et al PRD 93 (2016)]

- A critical question for this work: what is the maximum possible tolerable absorption for A+

* More on influence of deposition parameters on absorption in next talk

# Material parameters used for standard reference coating:

$SiO_2$: n=1.44, Y=72GPa, $\phi$=0.46x$10^{-4}$, ht=500°C

$Ta_2O_5$: n=2.07, Y=140GPa, $\phi$=2.3x$10^{-4}$ ht=500°C

$w_{ETM}$=6.2cm, $w_{ITM}$=5.5cm