# Overview of possible multimaterial designs for improving current coatings

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## Introdcution

A factor of two in coating thermal noise reduction is required to achieve the design sensitivity of Advanced LIGO+. For ET-HF and the initial Cosmic Explorer design very similar coating thermal noise levels are assumed. Low optical absorption of the coatings of <1ppm is also required, but challenging to meet. Multimaterial designs [Phys. Rev. D 91, 042001 & 042002] allow for a trade-off between thermal noise and absorption, allowing for one of the parameters to be reduced while slightly increasing the other. In case of a low refractive index contrast between coating materials, a multimaterial design could also reduce the total number of layers required to achieve a certain reflectivity, potentially reducing defects during deposition, or issues from heat treatment or stress effects. This poster provides an overview and a stepwise estimate of possible improvements in coating thermal noise for materials of various refractive indices and absorptions (at 1064nm) with multimaterial designs

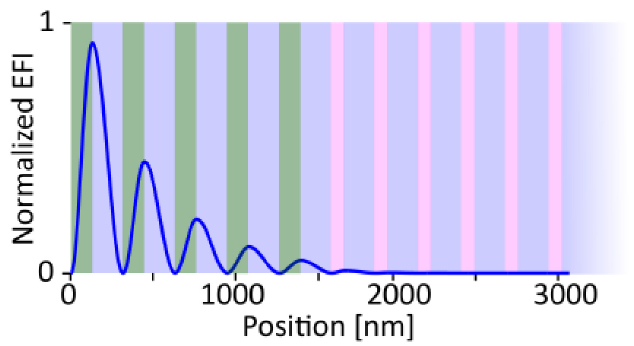
## How to use this poster

A. Convert the absorption measured on a test sample, at 1064nm, into useful units: We start from a single layer on a fused silica substrate*.
   1. Find the graph for the refractive index (or the one closest) of your coating material.
   2. Find the thickness of your layer on the x-axis and pick the data set (colour) for the absorption value you measured.
   3. Read the k from the y-axis** (left column of Fig. A). This correlation is linear and can easily be extrapolated for higher measured absorptions.
   4. Read the absorption for an HR coating, when combining your coating with $SiO_2$ as partner material, from the y-axis (right column of Fig. A, also scales linearly).
   5. Alternatively: If k is known, you can read the HR absorption from the right column.

B. Determine the thermal noise improvement possible
   1. Find the absorption determined for the HR coating on the x-axis (top of Fig. B) and read the number of $SiO_2/Ta_2O_5$ bilayers from the y-axis: This number of bilayers is required to reduce the absorption of the HR coating to < 1ppm.
   2. The middle graph of Fig. B shows how many bilayers of your material and $SiO_2$ are required to achieve ETM reflectivity - in addition to the number of $SiO_2/Ta_2O_5$ bilayers determined for absorption reduction.
   3. The bottom graph shows the coating thermal noise improvement compared to a ETM made fully of $SiO_2/Ta_2O_5$.

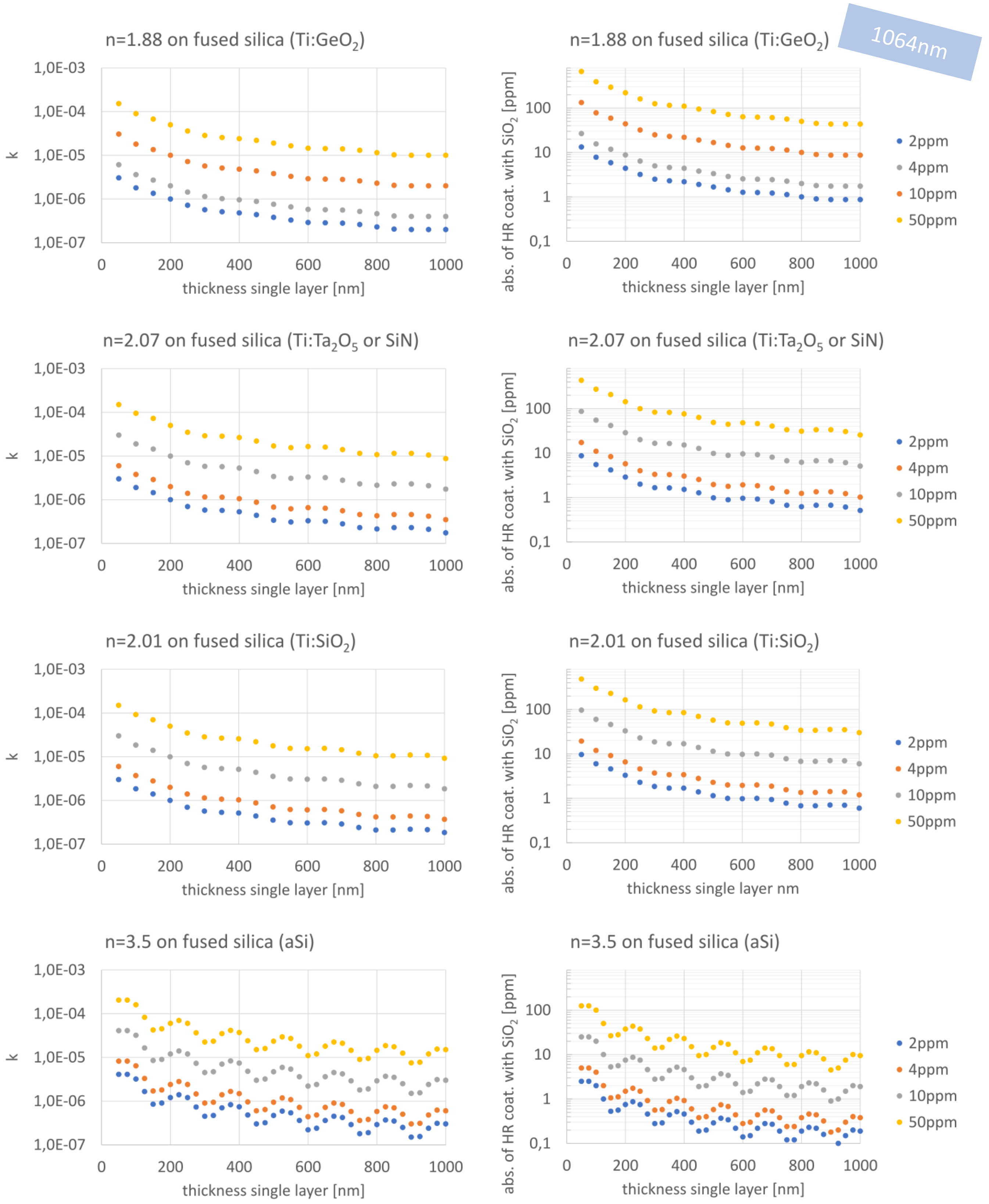
   For all HR calculations, layers of optical thickness $\lambda/4$ were used.

   Note that for an ITM, the improvement is usually smaller than for the ETM.

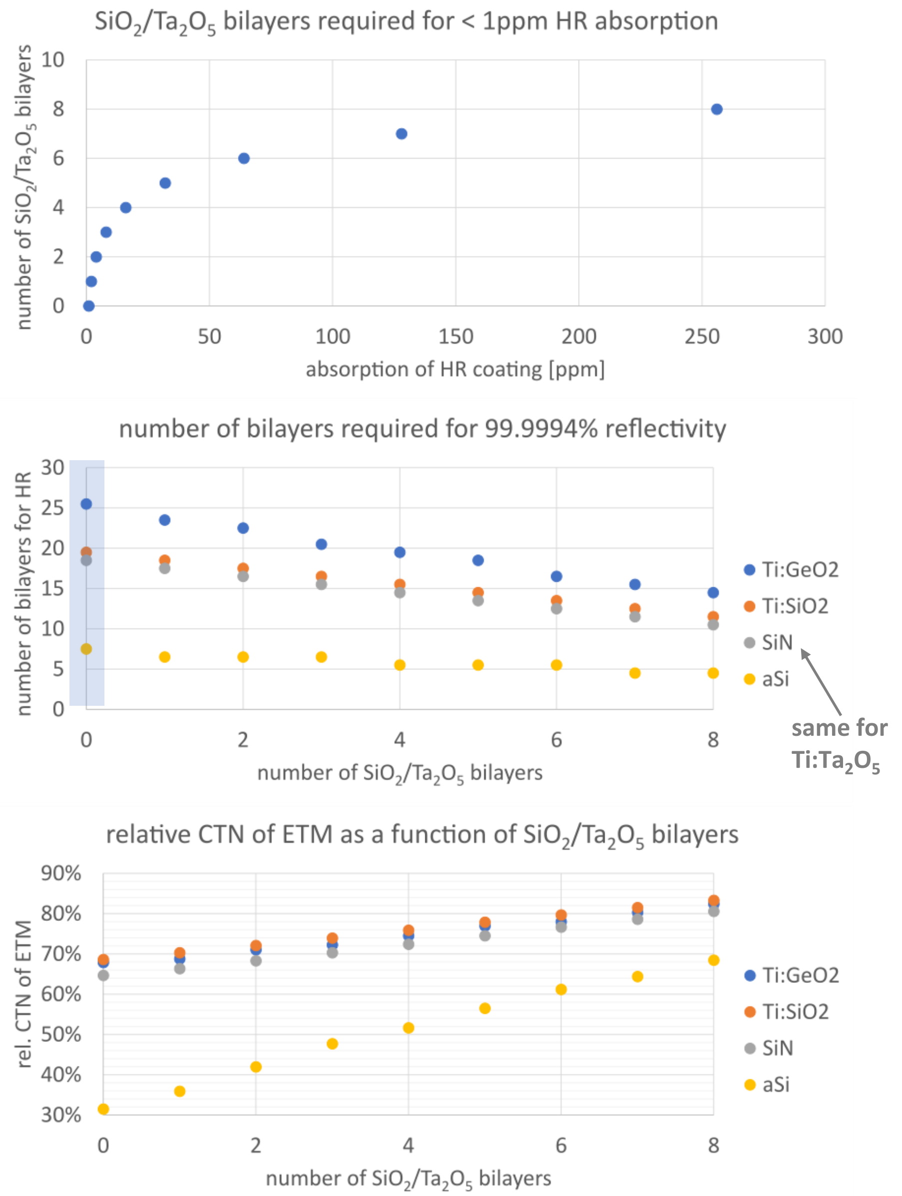



Example of a multimaterial coating:
6 bilayers of aSi (pink) and $SiO_2$ (blue) with low mechanical loss are used to achieve high reflectivity and low thermal noise.
5 bilayers of $SiO_2$ (blue) and $Ta_2O_5$ (green) with high mechanical loss are used on top to reduce the light field (blue, oscillating line – electric field intensity (EFI)) before it reaches the high-absorption aSi layers.

## Fig. A: Conversion of single layer absorption into k and HR absorption




## Fig. B: Absorption and thermal noise trade-off




## Reducing the coating thickness

To reduce the thickness of a coating, layers can be replaced by a material of higher refractive index.

The blue bar in the middle graph of Fig. B marks the number of bilayers of a material, required for an HR coating. The ratio between materials gives an approximation of the number of replaced layers.

Example: 25 bilayers of $GeO_2/SiO_2$ are required for HR, but only 8 bilayers of $aSi/SiO_2$: ratio 3 → one bilayer of $aSi/SiO_2$ can replace 3 bilayers of $GeO_2/SiO_2$.

(This is a pure thickness consideration, not taking into account absorption.)

* These calculations are for fused silica and change for substrate materials with a differen refractive index.
**k is a material parameter, while the measured absorption is system-specific.

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Material parameters used for thermal noise calculations:
$Ta_2O_5$: $\phi = 3.6\times10^{-4}$, $Y = 124$GPa; $SiO_2$: $\phi = 0.2\times10^{-4}$, $Y = 72$GPa; Ti:$GeO_2$: $\phi = 1\times10^{-4}$, $Y = 90$GPa; Ti:$SiO_2$: $\phi = 1.35\times10^{-4}$, $Y = 135$GPa; SiN: $\phi = 0.8\times10^{-4}$, $Y = 270$GPa; aSi: $\phi = 1\times10^{-4}$, $Y = 147$GPa