OIC 2025 Design Challenge

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Problem Statement

The design problems for OIC 2025 involve a Design for Production challenge (Problem A) and an Immersed, Polarizing Notch Filter challenge (Problem B).

From the very first OIC Design Challenge there have been two types of design challenges that were very different from one another. This year there will be a common theme, where each challenge will require the designer to fabricate their designs using a virtual monitoring system, and compare the results to the theoretical design.

A web-based evaluation program and tools will be provided for problems A and B. The evaluation program allows the user to calculate merit functions for these problems to ensure calculations done at home will match the calculations done by the challenge judges. In addition to providing merit functions, the website will contain links to relevant target and example design data, and provide a "Virtual Deposition Process" and a "Virtual Spectrophotometer" for problems A and B.2. Please report any problems or questions to the evaluation team with the link provided on the website.

Problem A - Design for Production

Modern multilayer design tools are quite powerful and allow to design very sophisticated coatings featuring various spectral, phase, color and other properties. Unfortunately quite often a nice theoretical design with very promising optical properties does not provide specified characteristics after production. It happens due to a number of reasons, such as thickness deposition errors, deviations of refractive indices from their nominal values, and many other perturbation factors.

In this challenge we are trying to simulate multilayer coating production by "virtual deposition" processes. These processes introduce errors to the design thicknesses (Process **A1** and **A2**) and drifts to some layer material refractive indices and extinction coefficients (Process **A2**). A "virtual spectrophotometer" can be used to obtain a feedback on the deposition of provided design samples.

The main goal of this challenge would be to try to discover ways to compensate for these perturbation factors. For the sake of the challenge induced errors are reproducible from run to run, therefore the final score of any design is not dependent on the run number, and it is very different from the reality. Thus we assume that our virtual deposition is super-stable, and introduces the same errors during the repeated productions of the coating. The levels of errors is not known, even more, they could be different for different layers.

This challenge is a simplified model of the real design-production loop, when a coating or a test sample is produced, and its spectral characteristics are measured with a spectrophotometer. The optical engineer uses these characteristics to try to compensate for discovered deposition problems by adjusting the design, or by designing a different, more robust one.

A winning design is the design demonstrating the best score after the "virtual deposition" process, i.e., the design with best compensation of these initially unknown perturbation factors.

Problem B - Immersed, Polarizing Notch Filter

For the first part of this challenge (B.1), the designer will create a three-line, polarizing notch filter at 450 nm, 550 nm, and 650 nm. The design will be immersed in a 45-degree cube with an index of 1.8. Outside of the three high-reflecting notches of s-polarized light, there should be high transmission for s-polarized light in the range of 400 nm to 700 nm. The contrast ratio (T_p/T_s) will be used for each notch, as well as the ratio of reflected s-polarized light over 99% to the transmitted s-polarized light greater than 99% over the wavelength range of 400 nm to 700 nm every 0.1 nm.

The second part of this challenge (B.2) will be the manufacture of the B.1 design using an optical monitor in reflectance at 45-degree incidence, on the actual substrate, with a choice of four bandpass filters. The monitor will only work for one of the four chosen filters for the entire virtual deposition. Unlike problem A where the virtual monitor will run without assistance, the designer will be able to *manually* manufacture their designs on the evaluation website. Each design submitted will get one practice run to get used to the system before the submitting run. The performance criteria from the first part of Problem B will be used to evaluate the fabricated design.

The evaluation website will go live on **October 16, 2024**. The submission deadline will be **April 14, 2025 by 11:59PM** Eastern Standard Time. As always, we hope designers will share their design approaches and insights.

Problem A - Design for Production, or are you able to build the Neuschwanstein castle?

For the Problem A challenge we follow the tradition of Design Challenges to propose a target function without any significant commercial interest. For OIC 2025 we selected a complicated target following the contour of the very famous Neuschwanstein castle located in Bavarian Alps [1]. In Fig. 1 the target transmittance is presented as a function of the wavelength, numerical values of wavelengths and transmittance values can be downloaded as a comma-separated file **Neuschwanstein_target.csv** from the contest website.

Figure 1: Target function for the Problem A, normal incidence transmittance (%) as a function of the wavelength (nm).

We propose to design a coating for two selections of layer materials, similar to the OIC 2016 Design Challenge, Problem B [2]. Submitted designs will be evaluated after "production" with the virtual deposition processes, described below. Similar to real production, obtained spectral characteristics could be significantly worse, than the theoretical ones. You can use "virtual spectrophotometer" provided for this challenge in order to study the properties of the virtual deposition processes, it could help to compensate some of the production errors. For simplicity the "virtual spectrophotometer" provides spectral characteristics *without the effect of the substrate back side reflection*. The winning design would be the design providing the smallest merit function (MF) value *after production by the virtual deposition process*. In Problem A the definition of MF is standard:

$$MF = 100\left[\frac{1}{N}\sum_i \left(T_i - \hat{T}_i\right)^2\right]^{1/2}, \tag{1}$$

where T_i and $\hat{T}_i$ are computed and target transmittance at the normal incidence, and the summation is performed over all target points (their number is N).

In order to use "virtual spectrophotometer" feature you need to register at the Design Challenge web site and to obtain an Access Key. This Access Key should be included to the files uploaded to the server (line 3, see the example of submission for Problem A below). Please do not share the Access Key with someone else! This measure is required to prevent unauthorized access to the Design Challenge server and possible misuse of its computational resources. We also limit time interval between two accesses with the same Access Key. It should not be smaller than 2 minutes.

Problem A.1 - The deposition process **A1** can only use the dielectric materials shown in the Table 1. It is known that the refractive indices of materials deposited by **A1** process are perfectly accurate, but the deposited thicknesses can be different from the thicknesses provided in the submitted file.

Problem A.2 - The deposition process **A2** can also use metal-like materials with potentially unstable dispersion properties. The deposited refractive index and extinction coefficient may be

Table 1: Index of refraction for the substrate and each material.

Substrate	H	L	A	F	M	T
1.52	2.25	1.45	1.65	2.00	1.38	2.15

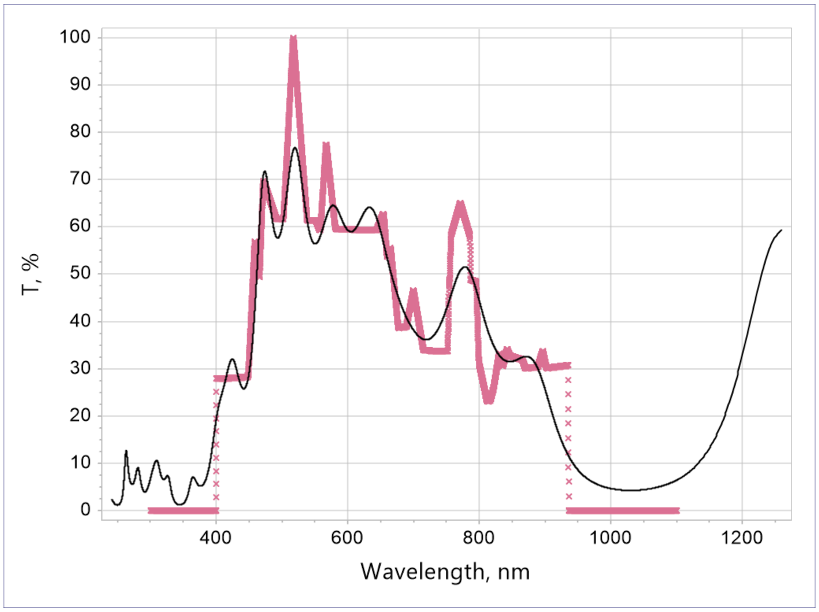

Figure 2: The transmittance of a sample design for the Problem A (the file TrubetA21.txt).

dependent on the deposited layer thickness. Metal-island films have similar behaviour, and in the second part of the challenge we propose to adapt your design or to create a different design for this case. Therefore, the process **A2** can use all materials listed in Tables 1-2. Wider choice of the layer materials can allow achieving a better theoretical fit of the target function. Nevertheless one should take into account, that in the process **A2** refractive indices of some layer materials can also be unstable. It is especially true in relation to the "metal" materials (Table 2).

Table 2: Refractive index and extinction coefficient (n, k) for the "metal" materials. Note that in Process 2 actual deposited refractive index and extinction coefficient may differ from these values.

Ag	Au	Ni
(0.12, 3.45)	(0.306, 2.88)	(1.8, 3.33)

The maximum number of layers for both processes is 100, the limit for the thinnest dielectric layer (materials H, L, A, F, M, T) is 5 nm, while for metal layers (Ag, Au, Ni) this limit is smaller and equal to 2 nm.

The theoretical MF = 7.006763 for the example design (File **TrubetA21.txt** at the contest website), the transmittance is shown in Fig. 2.

Problem B - Immersed, Polarizing, Notch Beam-Splitter

This problem will challenge the designer to create an immersed polarizing, notch beam-splitter at 45° incidence, where the incoming light is white light, and the reflected light are three wavelengths (450 nm, 550 nm, and 650 nm) for s-polarization (see Figure 3). The transmitted light will be all remaining polarized light that is not reflected. The incoming and exiting faces of the prism are uncoated and their reflectance/transmittance will not be included in the final merit function calculation. There will be two parts to this problem, B.1 and B.2, where the designer will develop the design, and then use a given optical monitoring strategy to virtually manufacture it.

B.1 - Design: Immersed three-line polarizing beam-splitter

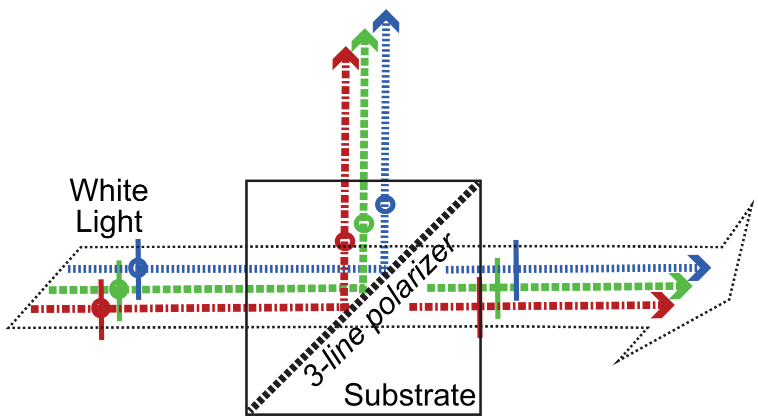

Figure 3: The design will be immersed along the 45° line dividing the prisms of the cube. White light (400 nm - 700 nm) will enter the cube, and only s-polarized light of the three wavelengths (450 nm, 550 nm, and 650 nm) will reflect out.

Table 3: Index of refraction for the substrate and each material.

Substrate	H	L	A	F	M	T
1.80	2.25	1.45	1.65	2.00	1.38	2.15

Accepted designs must meet the following:

- The design must work at 45° incidence immersed in the cube. Therefore, the incoming and exiting light will be at normal incidence to the prism outer surfaces.
- The design shall work for an immersed medium that has the index of the substrate, with layer indices listed in Table 3.
- The total number of layers cannot exceed **100**.
- There is no limit for the minimum thickness of any layer.
- There is no limit for the maximum thickness of any layer.

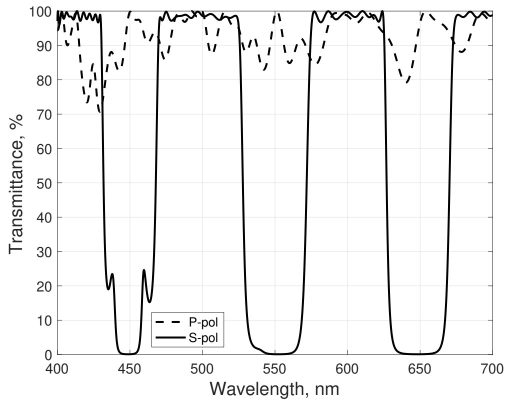

Figure 4: Example 68-layer design.

The evaluation of the three-line, immersed, polarizing notch beam-splitter will be to weight the average of the reciprocal contrast ratio (T_p/T_s). In addition, the number of the wavelengths that have R_s that is $\geq$ 99% will be divided by the number of wavelengths where T_s is $\geq$ 99% across the wavelength range of 400 nm to 700 nm, every 0.1 nm. The Merit Function (MF) will be the contrast ratio value added to the wavelength point numbers ratio (see Equation 2).

$$MF = \frac{500}{3}\left\{\left[\frac{T_s}{T_p}\right]_{450nm} + \left[\frac{T_s}{T_p}\right]_{550nm} + \left[\frac{T_s}{T_p}\right]_{650nm}\right\} + \frac{\sum_{i=4000}^{7000} H(R_s(\lambda_i) - 99\%)}{\sum_{i=4000}^{7000} H(T_s(\lambda_i) - 99\%)} \tag{2}$$

where the wavelength step size is $\Delta\lambda = 0.1$ nm, thus $\lambda_i = i \cdot 0.1$ nm, and $H(x)$ is the Heaviside step function:

$$H(x) = \begin{cases} 1, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

The 1.8540762059025715 for the example design. The ultimate goal is to have a very high contrast ratio, and narrow-band notch filters. In the event of a tie, the design with the smallest physical thickness will be declared the winner.

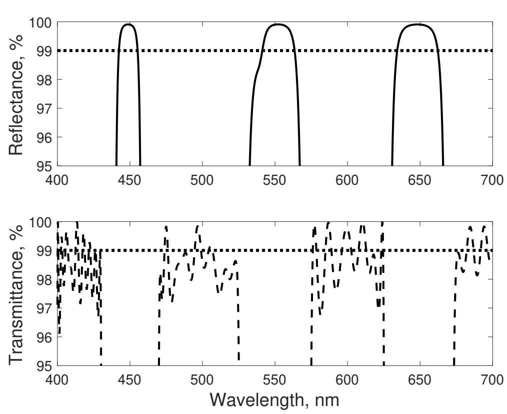

Figure 5: Example 68-layer design S-pol reflectance and transmittance values over 99%.

B.2 - Manufacture: Design from B.1

Optical Monitor Construction

Every designer will have the option to manufacture their designs from Problem B.1 using an online, digital optical monitor. This monitor is very basic and only uses four bandpass filters: 440 nm, 515 nm, 580 nm, and 620 nm. The spectral bandwidths are shown in Figure 6 and given in Table 4. The layout of the optical monitor is shown in Figure 7, where the incoming white light (which is randomly polarized) comes into the vacuum chamber, is reflected from the surface of the actual part [in air] at 45°. The reflected light exits the vacuum chamber, and transmits through one of the four bandpass filters [at normal incidence] and into the detector. This monitor can only use *one* bandpass filter for the entire run.

Optical Monitor Online Directions

In order to complete Problem B.2, you will have to upload the desired design using the submission format given on page 9, where line 3 indicates the bandpass wavelength you wish to use. As of 8/8/24 the directions are the following:

1. The START button will begin deposition.
2. The END LAYER button is used to stop deposition of the current layer and begin deposition of the next layer.
3. The START OVER button can be used at any time during the deposition run to begin again.
4. The SUBMIT button will be active at the end of the run, if you are satisfied with the overall spectral reflectance of the run.

NOTE: The material deposition rate may be between 40Å/s and 50Å/s, and will be specifically given on the Design Challenge website. Please refer to all directions given on the website because they are the most current.

Table 4: Bandpass filter peak wavelengths and FWHM (see Figure 6)

Peak Wavelength	**FWHM**
440 nm	10 nm
515 nm	10 nm
580 nm	10 nm
620 nm	10 nm

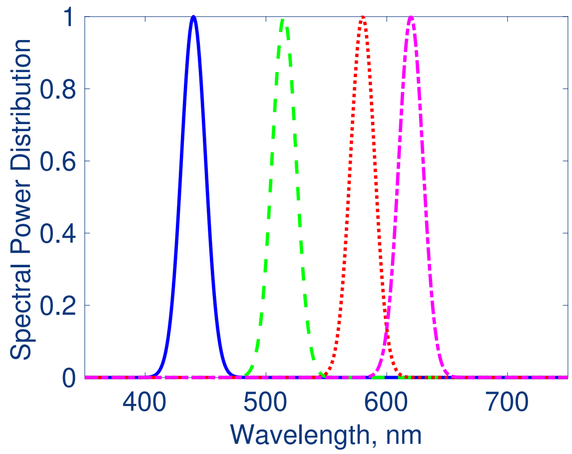

Figure 6: Bandpass filters for optical monitoring system. Peak wavelengths are 440 nm, 515 nm, 580 nm, and 620 nm.

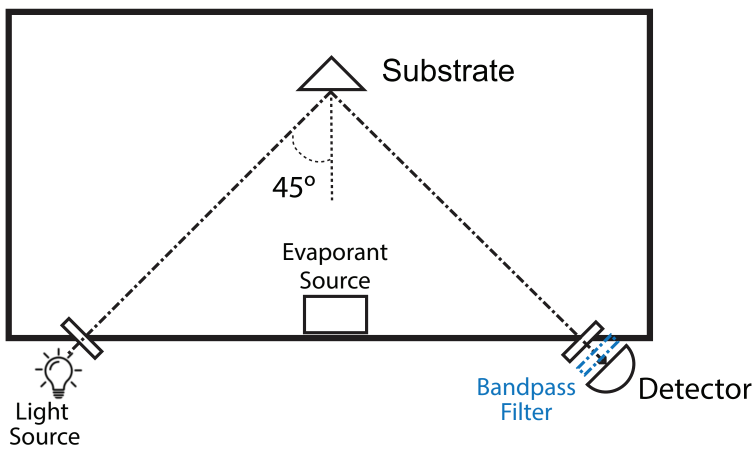

Figure 7: The part will be monitored in reflectance, at 45-degree angle of incidence, average polarization, using one of the bandpass filters before the detector.

Submission

Participants are welcome to submit up to two designs for Problem A.1 and/or Problem A.2 (totaling a maximum of four designs per designer.) Participants are also welcome to submit up to two designs for Problems B.1. For Problem B.2 each submitted design from B.1 can be deposited with a choice of two monitoring wavelengths (totaling a maximum of six designs per designer.) Depending on merit, a submitted design may be published as part of a paper presented at OIC 2025, and later in a special OIC 2025 issue of Applied Optics. Until then, any submitted design will be known (and kept confidential) only by the OIC Design Challenge team, the OIC 2025 General and Program Chair persons, and some Optica staff members.

The evaluation webpage can be found at URL: www.clearapertures.com and will go live on **October 16, 2024** until **April 14, 2025 by 11:59PM** Eastern Standard Time, when the submitted designs are due.

Submit your final designs to design.challenge@clearapertures.com with the email subject line: OIC Submission.

The only requirement for participation in the challenge is the submission of a design in the correct text format prior to the submission deadline. However, design authors are encouraged to accompany their designs with an explanation of how they arrived at their solutions. Questions regarding the evaluation program should be directed to Jason Keck at jkeck@clearapertures.com. With questions regarding the design problems and explanations of design submissions please contact Jennifer Kruschwitz and Michael Trubetskov at design.challenge@clearapertures.com.

The submission should be in the form of a text file (ANSI or UTF-8 encoding) (i.e., a file with '.txt' extension) that should be either tab or space delimited. The filename should be the last name of the author shortened to six letters followed by three identifying characters for Problem A or two identifying characters for Problem B. (If the author name is less than six characters, underscore characters should fill the extra spaces, e.g., Smith_A11.) Examples of files for Problem A and Problem B are shown below.

Submission for Problem A

Three identifying characters for the problem A should be as follows. The first symbol is **A**, the second should be either **1** or **2** for the sub-problems A1 and A2, respectively (i.e., for the deposition process **1** or **2**). The third symbol is the number of submission. We limit the number of submissions for each sub-problem by two, therefore the third symbol can be also either **1** or **2**.

For the Problem A the layers should be listed from substrate to incident medium, each line should consist of the layer material specification and physical layer thickness in nanometer.

In order to obtain the Access Key you need to register at the Design Challenge web site.

Filename: TrubetA21.txt [six characters for name, problem A, the second deposition process, 1st submission]

line 1	Name, Affiliation
line 2	Email address
line 3	Access Key value obtaining from the Challenge Evaluation server. Without correct access key the Challenge server will reject the submitted file.
line 4	Process **number** (the **number** can be 1 or 2 only)
line 5	- *blank* - [delimits start of design]
line 6	M 163.35 [material **M** and layer thickness in nm for layer 1]
line 7	A 139.73 [material **A** and layer thickness in nm for layer 2]
...	
line 13	AG 12.005 [material **Ag** and layer thickness in nm for layer 12]
...	
last line	H 115.23 [material **H** and layer thickness in nm for the last layer]

Submission for Problem B

For Problem B submissions, line 1 should give the designer name and affiliation, and line 2 the designer's email. Line 3 should designate the wavelength chosen for part B.2's optical monitor. Skip a line below the monitor wavelength to delimit line 1 of the design. Each of the submitted designs can have up to 100 layers. In this case line numbers are changed accordingly. The example design has 68 layers. *In order to obtain the Access Key you need to register at the Design Challenge web site.*

Filename: KruschB1.txt [six characters for name, problem B, 1st submission]

line 1	Name, Affiliation
line 2	Email address
line 3	440 [Indicates the optical monitor wavelength in nanometers used for B.2]
line 4	- *blank* - [delimits start of design]
line 5	F 226.142 [material **F** and layer thickness in nm for layer 1]
line 6	A 44.805 [material **A** and layer thickness in nm for layer 2]
line 6	F 39.818 [material **F** and layer thickness in nm for layer 3]
line 8	A 282.671 [material **A** and layer thickness in nm for layer 4]
. . .	
line 72	F 167.252 [material **F** and layer thickness in nm for layer 67]
line 73	A 222.953 [material **A** and layer thickness in nm for layer 68 of Example Design]

References

[1] "Neuschwanstein Castle", https://en.wikipedia.org/wiki/Neuschwanstein_Castle

[2] J. Kruschwitz, V. Pervak, J. Keck, I. Bolshakov, Z. Gerig, F. Lemarchand, K. Sato, W. Southwell, M. Sugiura, M. Trubetskov, and W. Yuan, "Optical interference coating design challenge 2016: a dispersive mirror and coating uniformity challenge," Appl. Opt. **56**, C151-C162 (2017).

Appendix

The link to access the data, example files, instructions for optical monitor and any other necessary evaluation tools can be found at www.clearapertures.com.