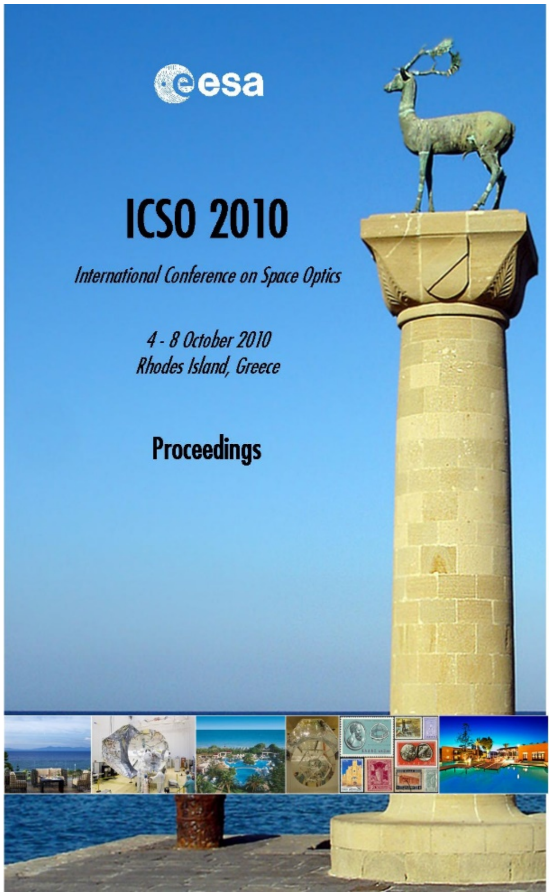
International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010

Edited by Errico Armandillo, Bruno Cugny, and Nikos Karafolas



High performance UV anti-reflection coating for backthinned CCD and CMOS image sensors

J. Vaillant, G. Grand, Y. Lee, J. Raby, et al.

esa icso proceedings cnes

International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny,
Nikos Karafolas, Proc. of SPIE Vol. 10565, 105655R · © 2010 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2552634

HIGH PERFORMANCE UV ANTI-REFLECTION COATING FOR BACKTHINNED CCD AND CMOS IMAGE SENSORS

Joël Vaillant[1], Gilles Grand[2], Yann Lee[2], Jacques Raby[2], Yvon Cazaux[2], Yann Henrion[1], Vincent Hibon[1]
[1] *e2V semiconductors, avenue de Rochepleine, BP123, 38521 Saint-Egrève Cedex, France*
[2] *LETI MINATEC, DOPT department, CEA-Grenoble, 17 rue des Martyrs, 38054 GRENOBLE Cedex 9, France*

I. INTRODUCTION

Backthinning of image sensors is a very well established process for achieving high Quantum Efficiency for high-specification space and science applications. To optimize the QE performance in various spectral bands, the AR coating need to be adjusted. A new multilayer low thickness UV AR coating has been developed by e2v and CEA-Leti with very high transmission at 266 nm and 355 nm laser wavelengths. It is compatible with CCD and CMOS backthinned image sensor process. We describe hereafter the first results obtained on glass and silicon substrates for this AR coating. The manufacturing of backthinned CCD and CMOS image sensors samples is ongoing. This development is supported by Minalogic project (financed by French FUI-DGCIS).

II. MATERIAL CHOICE AND FILTER STACK MODELING

A. Modeling a high transmittance filter

The best way to achieve efficient anti-reflecting filters is to optimize a multilayer stack made with 2 transparent materials: a high index H and a low index L. The target is to optimize the multilayer stack around 266 nm and 355 nm over a bandwidth of +/- 10 nm in order to take into account the variation or performance due to optical aperture.

To select the materials, at these UV wavelengths, care must be taken about transparency, in addition to usual care about material stresses, stability, adhesion. Other special requests in the case of imaging applications are:

- the materials must be resistant to UV irradiation and ageing,
- during process, care must be taken to avoid silicon backside damage, which could affect the dark current and UV response of the pixel.

There are several potential available materials and all that follows can be used with any of them. We have selected one of the possible couples for this study, and named the materials H and L.

Modeling and optimizing the stack are performed with the powerful optical software for thin films named OPTILAYER®. For each central wavelength λ_c (266 and 355 nm), the targeted transmittance T is more than 90% in the range [λ_c – 10 nm, λ_c + 10 nm]. Using data from literature [1,2], the optimization converges to some stacks of 4 layers, and examples of the corresponding transmittances in silicon are showed at both wavelengths in Figure 1. The thickness of each layer is between 20 and 80 nm, all of them are quite easily achievable with various deposition process. The influence of optical aperture on peak transmittance is acceptable as it is in the range of 5 nm shift with a 20 degree angle.

Although the optical results are always better when the first layer is H, the selection of the first layer may also be driven by silicon backside damaging considerations already mentioned. However, it is very difficult to predict final performances because k at 266 and 355 nm are extracted from literature ; the actual figures will mainly depend on achievable material quality.

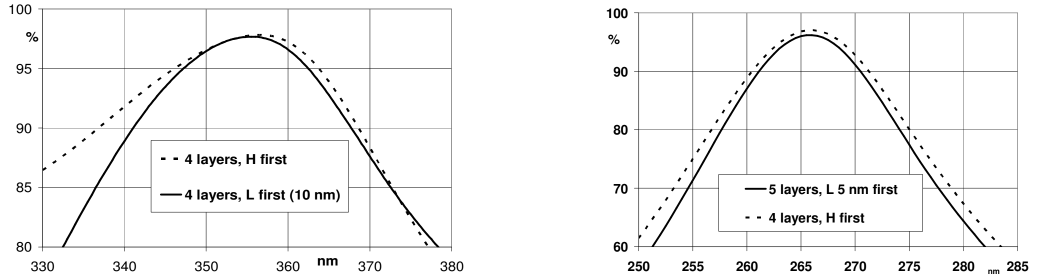


Figure 1 : Calculated transmittances with optimized stacks, at 355 and 266 nm, for one of the usable (L,H) couples of materials

B. Uncertainty and sensitivity

With industrial deposition techniques, it is difficult to obtain 20 nm thicknesses with excellent accuracy, and then modeling must include dimensional uncertainties. OPTILAYER® includes various tools to quantify them: random errors for a defined Gaussian uncertainty, systematic errors, level of sensitivity for each layer, etc.

We studied this question, and concluded that the most critical and sensitive data are the thicknesses of the first layers (starting from substrate): For example, in both cases, +2 nm on the bottom H layer translates the spectral response of +5.5 nm. Thus, our filters are quite sensitive, which is not surprising for so thin stacks (total thickness is roughly 140 nm for λ =355 nm and 100 nm for λ= 266 nm).

III. DEPOSITION PROCESS

Another request is specific to imaging applications : the deposition process must not degrade the CMOS or CCD imager which is underneath. Only low temperature and low X radiation process can then be chosen, that discard CVD and evaporation techniques for these materials. Cathode sputtering seems to be the best compromise and was adopted for deposition process. We used the flexible configuration of a multiple chamber equipment, which allows, more particularly, to coat a thin layer on 200 mm diameter wafers.

IV. OPTICAL CHARACTERIZATION TECHNIQUES, TEST VEHICLES, AND MEASUREMENT METHODOLOGY

UV-visible spectrophotometry is the key technique to obtain transmission T(λ), reflection R(λ) and absorption A(λ) for final stack filters as well as spectral optical properties (n and k) of basic materials. We used Varian Cary 5 UV-Vis-IR facility.

To measure optical properties of materials, we need totally transparent substrates, typically alumina or silica depending on material to be measured (it must be distinct enough from the substrate to obtain interference fringes). The accuracy on n(λ) and k(λ) deduced by regression from these measurements is about 2.10^{-3}.

In addition to this technique, ellipsometry has also been investigated, but finally the accuracy on the refractive index n was not significantly better than 2.10^{-3}, and accuracy on k index is never better than 10^{-2} which is not enough for this application. Ellipsometry is therefore only used as a verification technique.

The filter stacks are tested on silicon substrate, but it is not possible to measure the transmittance T(λ) into an absorbing substrate, unless achieving a photo-detector inside. From silicon substrates, we can only obtain the reflectance R(λ), and then deduce the complementary sum T(λ)+A(λ), where A(λ) is the absorption of the multilayer stack. Thus, accurate prediction of the transmittance T(λ) mainly requires measurements of the refraction indices n(λ) and overall the extinction indices k(λ) of both materials. The absorbance A(λ) of the stack on silicon can be deduced from respective extinctions k of L and H , and then T(λ) =1- R(λ)- A(λ) is finally predicted.

In fact, we need also a regression on thicknesses (Figure 2): the difference between simulation and experiment is not only due to k(λ), but also to slight thickness differences which translate responses on wavelength axis (cf section II.B).

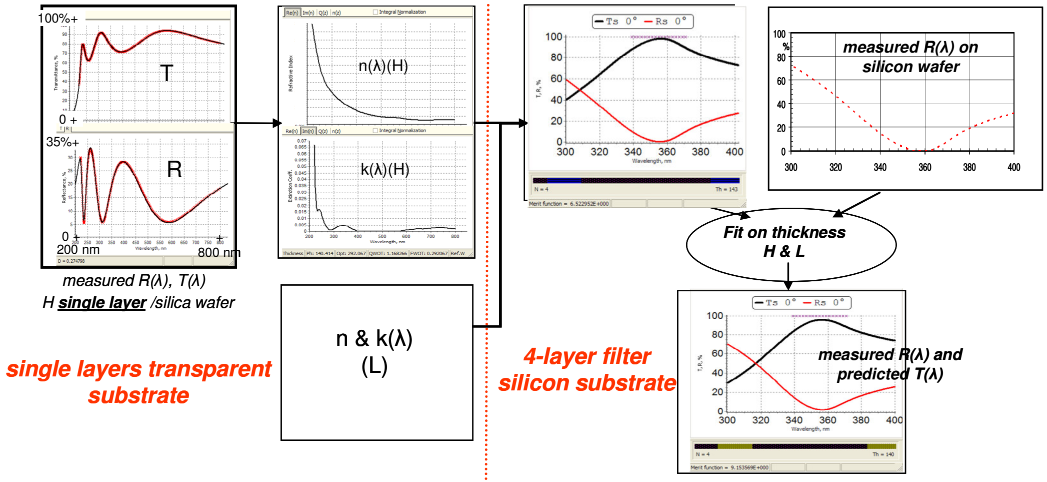


Figure 2 : Measurement methodology based on spectrophotometry, using both transparent and silicon substrates

V. OPTICAL RESULTS ON BLANK WAFERS

A. Material indices obtained from single layers on transparent substrate

We used alumina and UV-silica as substrates for thin film optical properties measurements. These substrates were specially selected for their high UV transparency. Typical thicknesses of 100 to 150 nm were deposited on them. We also made ellipsometry measurements on identical films deposited on silicon substrate.

The extinctions of the L and H layers are showed on Figure 3: $k_H(\lambda)$ is very low (< 0.005) above 250 nm, and for L material this low limit is around 230 nm. These excellent results let us expect high performances for filters.

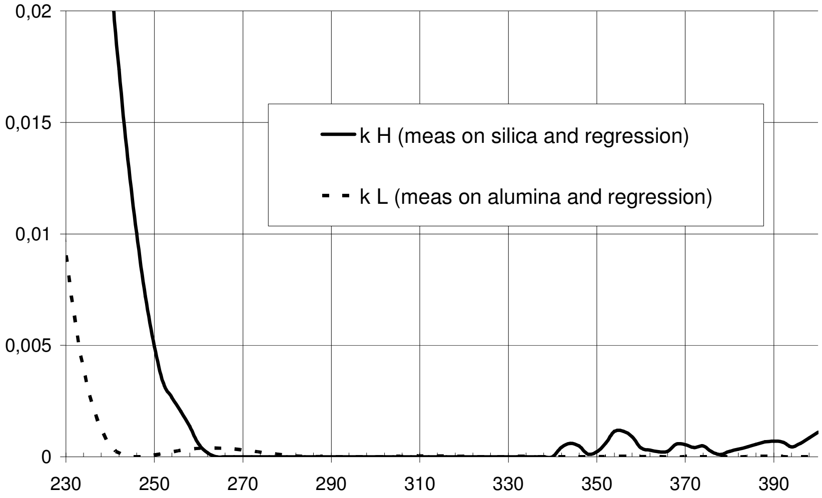


Figure 3 : Extinction k(λ) for L and H materials

B. Final filters on silicon substrate

We followed the method described in Figure 2. The results for transmission, reflection, and absorption are showed in Figure 4, for both wavelengths 355 and 266 nm. We measured numerous samples, and Figure 4 shows 3 of them to illustrate the process variations.

There is obviously dispersion among the wafers. However the results are very good because this dispersion does not exceed a critical figure, and then does not much penalize maximal transmission. Anyway, predicted Tmax is very high (typically 98%).

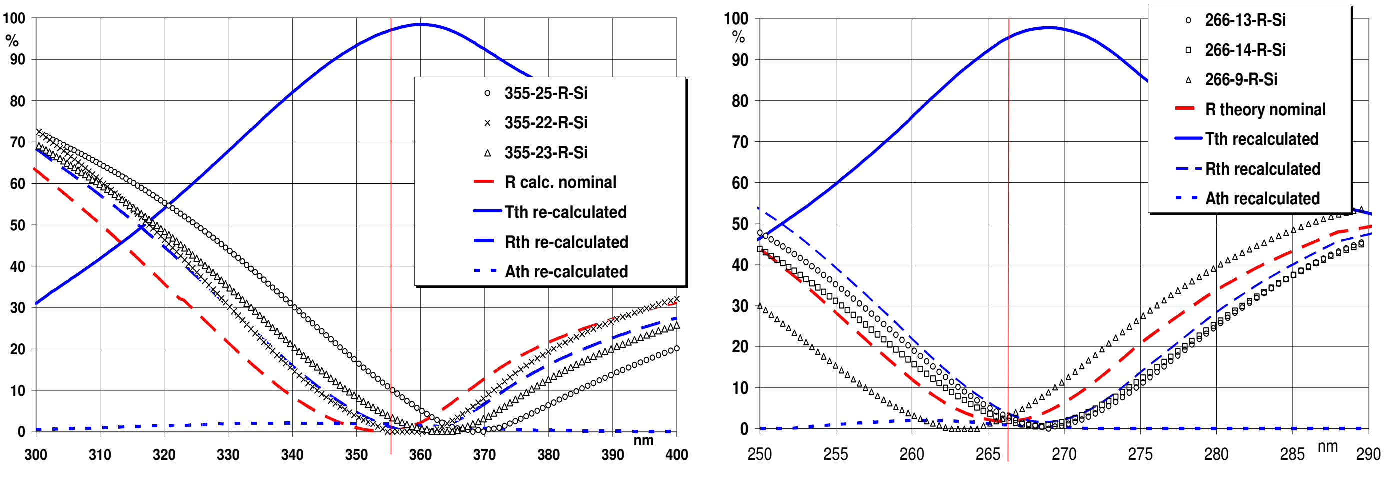


Figure 4 : R(λ) measured on silicon substrate filter and predicted A(λ) and T(λ) , for 355 nm and 266 nm

C. Ageing tests

One constraint for this kind of UV layer is the ageing under UV light. First results of ageing are now available : they have been done on UV-silica substrates for the 355 nm optimized filter. Using a 350 nm laser, we have cumulated up to 3000 J/cm² with no degradation of the AR filter transmission performance.

VI. CONCLUSION

We have developed a new high performance UV AR coating compatible with CCD and CMOS backthinned image sensors. The optical properties which have been measured on glass and silicon substrates are in accordance with the modeling results : a peak transmission close to 98% is reached for 355 nm and 266 nm AR coatings. The manufacturing of CCD and CMOS image sensors samples using this process is ongoing.

REFERENCES

[1] Philipp (1985) in Palik E. (ed) Handbook of Optical Constants of Solids. Acad. Press
[2] Rochester Institute of Technology, Center for nanolithography research,
http://www.rit.edu/kgcoe/microsystems/lithography/thinfilms/thinfilms/thinfilms_mobile.html