“SPESS” a tool for the thickness measurement of thin ice films

C. Scirè (*)[1], R. G. Urso[1,2], G. A. Baratta[1], M. E. Palumbo[1]

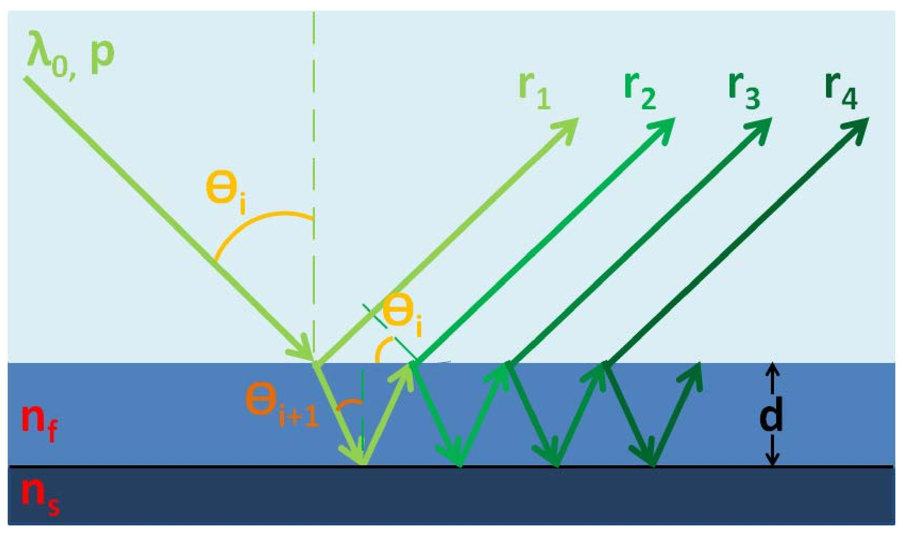
[1] *INAF-Osservatorio Astrofisico di Catania, Via Santa Sofia 78, 95123 Catania (Italy)*
[2] *Dipartimento di Scienze Chimiche, Università degli Studi di Catania, Viale Andrea Doria 6, 95125 Catania (Italy)*
(*) cscire@oact.inaf.it

Abstract

We have developed a tool, written in FORTRAN language, to estimate the refractive index and the thickness of a thin ice film from the experimental interference curve obtained during deposition of the ice. The “SPESS ice thickness calculator” is accessible from users worldwide.

It is provided with a user friendly interface and it is possible to consult an explicative guideline for the requested input parameter values and for the correct choice of the laser wavelength according to the substrate.

A laser beam directed towards a system composed by a thin film of ice deposited on a substrate, gives reflections at the interfaces vacuum-film and film-substrate. For thin optical film interference is observed and constructive and destructive superposition of the reflected beams form a characteristic interference pattern during the deposition of the ice that can provide film thickness information.



In general the reflectance (R) is a function of: the laser wavelength (λ_0), the refractive index of the film (n_f), the refractive index of the substrate (n_s), the film thickness (d), the incident angle (Θ_i with respect to the normal) and the polarization of the laser light (p):

$$R=f(\lambda_0, n_f, n_s, d, \Theta_i, p) \qquad (1)$$

If we assume that there is no absorption in the film at the laser wavelength, R is a periodic function of the thickness and the period, that is the distance between two maxima or two minima in the interference curve (reflectance R versus the film thickness), is given by the equation:

$$\Delta d = \frac{\lambda_0}{2n_f\sqrt{1-\sin^2\Theta_i/n_f^2}} \qquad (2)$$

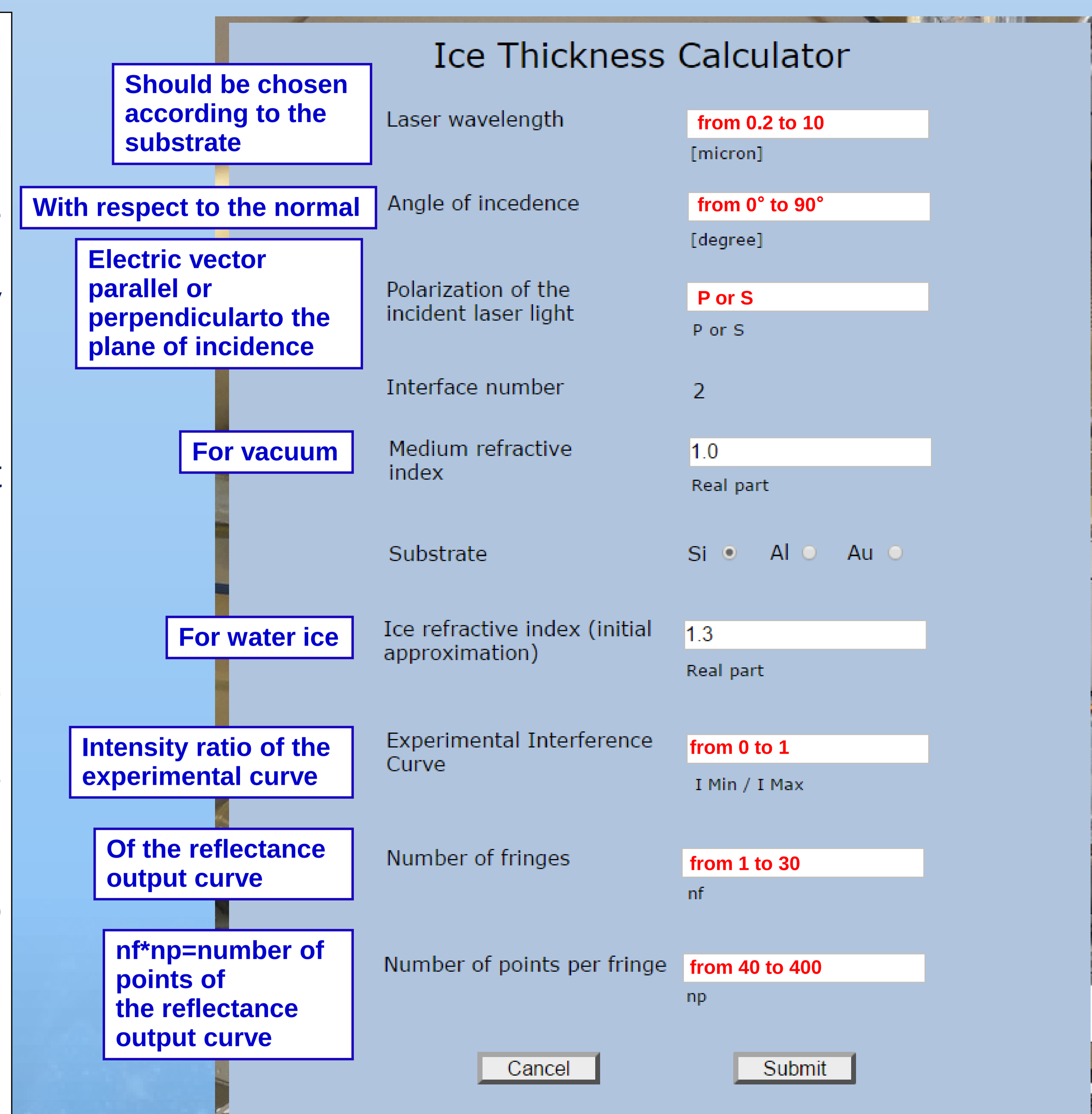
From eq. (2) it is evident that n_f, the refractive index of the film, must be known in order to measure the thickness. From the known parameters (λ_0, n_s, Θ_i, p) and the measured amplitude of the interference curve provided by the user, the program evaluates the best fit refractive index of the film and the theoretical interference curve.

Indeed the amplitude of the interference curve depends on the refractive index of the film, it is then possible to derive this parameter from the intensity ratio between maxima and minima in the experimental interference curve.
From the comparison between the theoretical interference curve and the experimental one it is then possible to accurately measure the thickness.
Further details can be found in [1].

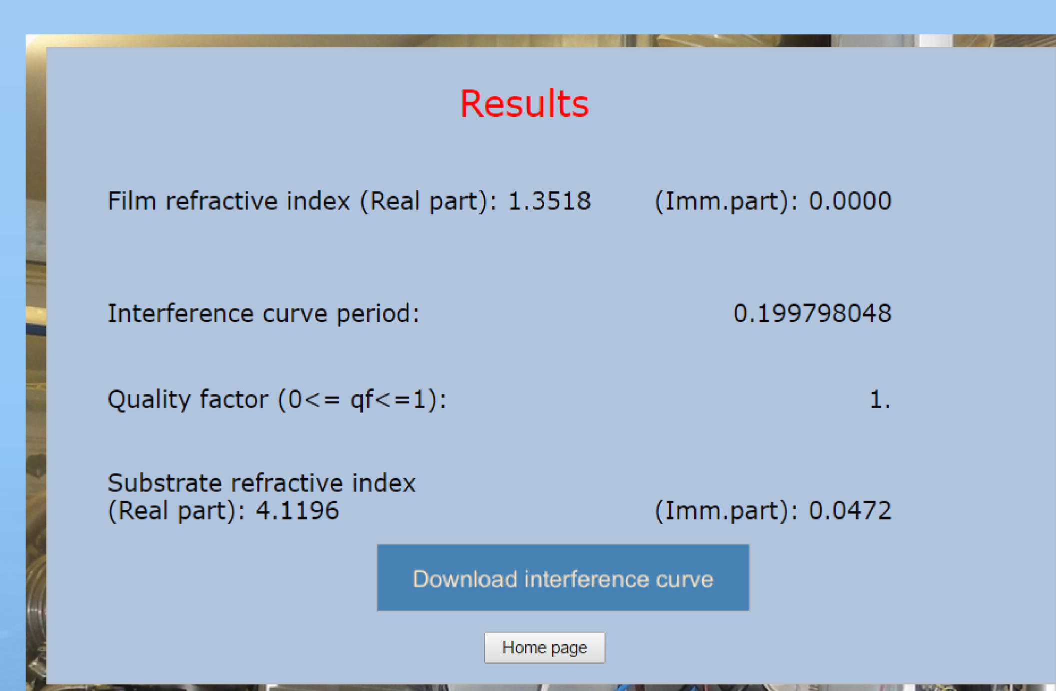
It was developed a tool that uses a program called SPESS, written in FORTRAN language, to measure the thickness of thin films under specific conditions:
- The number of interfaces are two, medium-film and film-substrate
- The substrates considered are completely opaque, the reflected light at the second substrate interface can be neglected

Some defaults values are preset:
- The medium is vacuum or, in first approximation, air
- The ice refractive index is, at first, approximated to the value of 1.3.

This procedure is incorporated in a web interface called **“Ice Thickness Calculator”.**
In the main interface it is possible to insert the requested values for the calculation of the thickness.
Comments are provided to help the users to fill in correctly the form fields.
The tool is available for all the interested users at the web address:
http://oact.inaf.it/thickness/



From the values inserted on the user interface, the SPESS program calculates the refractive index of the film and the theoretical interference curve, giving also the period of the theoretical interference curve, the substrate refractive index corresponding at the inserted laser wavelength and a quote of the quality of the measurement (quality factor).
The theoretical interference curve (reflectance versus thickness) is downloadable in ascii format.



Output file
Theoretical interf. curve
- Not Normalized -

Thickness(micron)	Reflectance
0.00000000E+00	0.371570
0.19979805E-02	0.371364
0.39959610E-02	0.370834
0.59939418E-02	0.369979
0.79919221E-02	0.368801
0.99899024E-02	0.367300
0.11987884E-01	0.365478
0.13985864E-01	0.363338
0.15983844E-01	0.360880
0.17981825E-01	0.358107
0.19979805E-01	0.355024
0.21977786E-01	0.351633
0.23975767E-01	0.347938
0.25973747E-01	0.343945
0.27971728E-01	0.3396[illegible]
0.29969707E-01	0.3350
0.31967688E-01	0.3302
0.33965670E-01	0.3251
0.35963651E-01	0.3197
0.37961628E-01	0.3141
0.39959610E-01	0.3082
0.41957591E-01	0.3021
0.43955572E-01	0.2958
0.45953553E-01	0.2894
0.47951534E-01	0.2827
0.49949512E-01	0.2759
0.51947493E-01	0.2690
0.53945474E-01	0.2620
0.55943456E-01	0.2549
0.57941437E-01	0.2477
0.59939414E-01	0.2406
0.61937395E-01	0.2334
0.63935377E-01	0.2263
0.65933354E-01	0.2193
0.67931339E-01	0.2124
0.69929317E-01	0.2057
0.71927302E-01	0.1992
0.73925279E-01	0.1929
0.75923257E-01	0.1868
0.77921242E-01	0.1811
0.79919219E-01	0.1758
0.81917204E-01	0.1708
0.83915181E-01	0.1663
0.85913159E-01	0.1622
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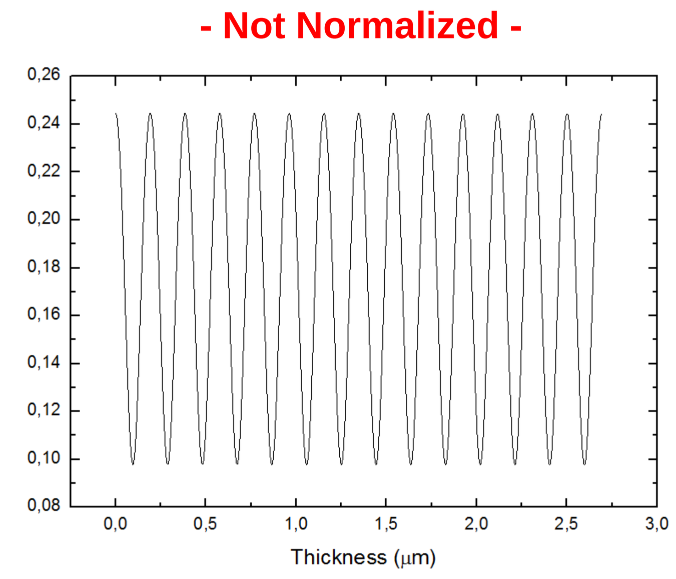
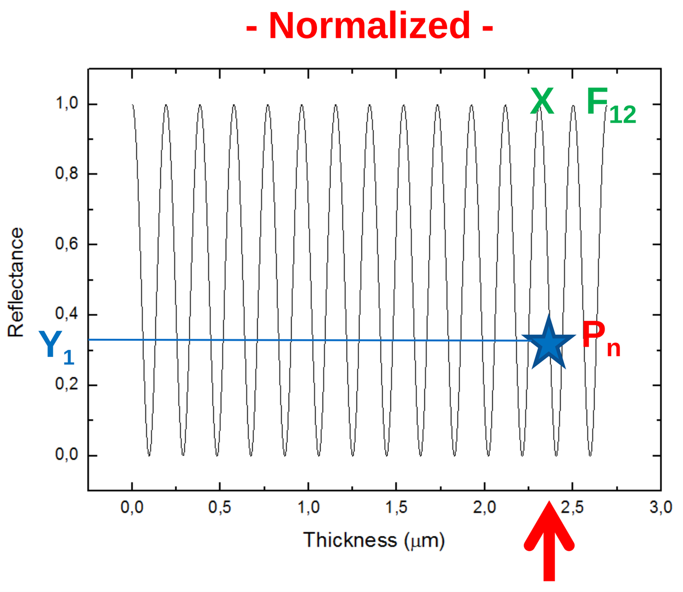
The comparison for the measurement of the thickness is made between the theoretical interference curve and the experimental one:
- Both the interference curves are normalized (by setting all the minima at 0 and maxima at 1) before comparing them
- A given point (**P_n**) in the experimental normalized interference curve is identified on the theoretical interference curve at the given normalized ordinate (**Y_1**) and at the given fringe number (**F_{12}**).
- The corresponding abscissa found represents the thickness.

Instead of normalize the full experimental interference curve it is possible to obtain the normalized intensity of the **P** point by using the formula:
$Y_1 = (Y_0 - Y_{MIN1})/(Y_{MAX1} - Y_{MIN1})$ where **MIN1** and **MAX1** are the closest minimum and maximum to the point.

Theoretical interference curve
- Not Normalized -

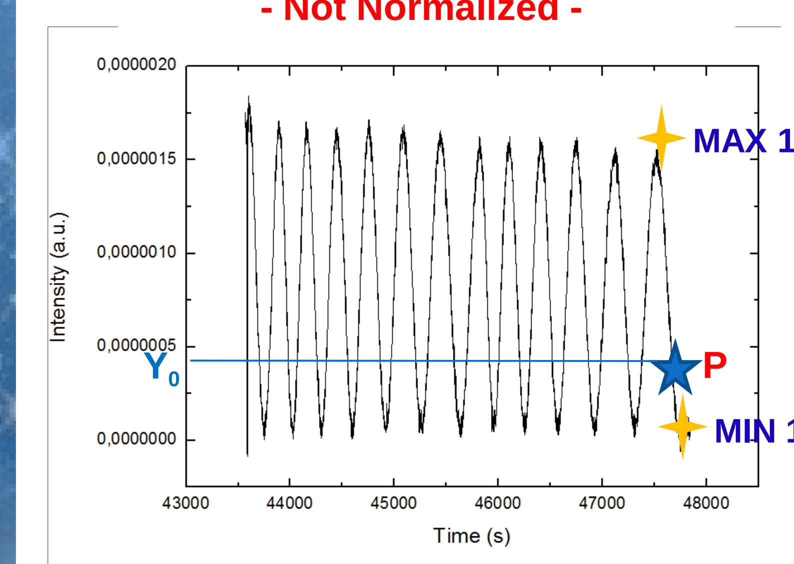


Theoretical interference curve
- Normalized -

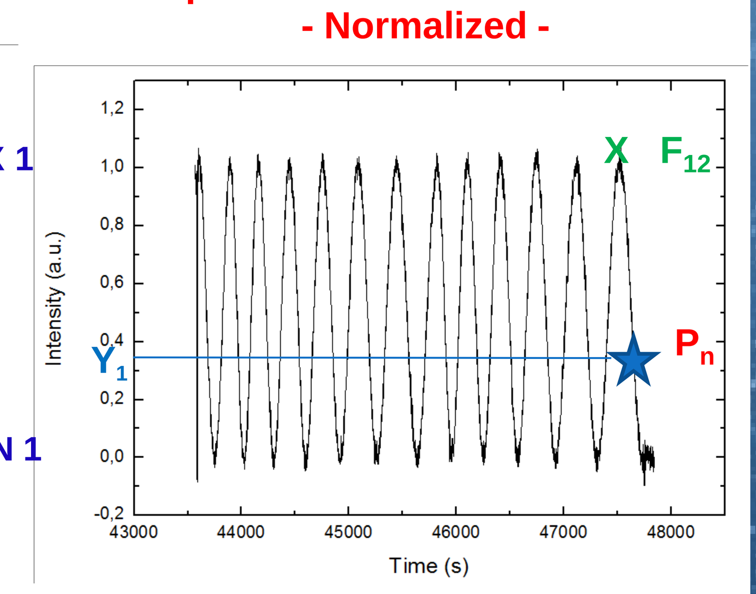


Thickness Value

Experimental interference curve
- Not Normalized -



Experimental interference curve
- Normalized -



The absolute accuracy of this measuring method is approximately equal to 5%.
The precision of the calculation is affected by the uncertainty of the optical constants knowledge for the substrate at low temperature and the measuring error of the laser incidence angle.

Conclusion:
It is described a numerical method that allows to measure with a good accuracy the thickness of thin film of ices deposited on a substrate.
It could be usefull for those who need to know the thickness of a film by using the laser interference technique.

References
[1] Urso, R. G.; Scirè, C.; Baratta, G. A.; Compagnini, G. and Palumbo, M. E., 2016, *Astronomy & Astrophysics, 594, A80*.