# SiON Taguchi method Exp2

This experiment used varied 4 factors, 1 four level and three two level. The resultant films had a n range of 1.54 to 2.15. Clearly the N2O flow is an effective control variable. In this case four samples were generated per experiment for optics, over two consecutive deposition runs. (Passivation samples were fabricated which were destroyed prior to annealing, their initial as deposited lifetime was low < 10 us).

# Experimental table

Table 1 outlines the eight experiments, each experiment was performed twice with two samples. 32 samples were measured with the JA Wollum ellipsometer.

Table 1: Taguchi table, experimental factors in green, N2 was varied with N2O.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| N2O/N2 | Pressure | SiH | NH3 | N\_2 | Power | Time (s) |
| 90 | 500 | 7 | 3 | 890 | 20 | 120 |
| 90 | 1000 | 13 | 12 | 890 | 20 | 120 |
| 60 | 500 | 7 | 12 | 920 | 20 | 120 |
| 60 | 1000 | 13 | 3 | 920 | 20 | 120 |
| 30 | 500 | 13 | 3 | 950 | 20 | 120 |
| 30 | 1000 | 7 | 12 | 950 | 20 | 120 |
| 0 | 500 | 13 | 12 | 980 | 20 | 120 |
| 0 | 1000 | 7 | 3 | 980 | 20 | 120 |

# Data modelling

In all cases the TL oscillator was fitted. Fits become poor (MSE > 5) for high refractive index samples. The TL model is described in refs. [[1](#_ENREF_1), [2](#_ENREF_2)]. This model needs to be improved for high-RI materials.

Figure 1: MSE for all measurements lplotted versus the RI. There is a trend for increasing RI with n.

The TL model has 5 parameters

|  |  |  |
| --- | --- | --- |
| Einf |  | The dielectric constant at high infinite energy |
| Eg |  | The band gap energy |
| A |  |  |
| Eo |  | The optical band gap energy |
| C |  |  |

From two experiments combined I have found it is possible to achieve reasonable fit to measured data by constraining the fitting process. Here Einf is set to 1. When performing the unconstrained fitting, the 4 free fit parameters (Einf set to 1), show the following dependence with *n*.

Figure 2: fitting using the J. A. Woollum optmizer.

Similar fits can be achieved by constraining the A and B parameter and altering the energy parameters. This does not aid in the physical interpretation overly, but allows for simple interpolation of the optical properties.

With A set to 100 and B set to 11 we have

Figure 3: refitting of TL model with constant A and B parameters.

From this fit we can optically model all films that can be created by similar deposition conditions. This interpolation results in the following RI surface



I am certainty that for this experiment this interpolation is valid. I am not sure how it extends more generally.

# Interpolation functions

I have made an n,k generator for this system, appended. Simply input the n at 633 between 1.45 and 2.2, then enter the nm range. If you get funny results your units should be in nm not m. As requested I have included the min and max nn,n and k from my experiments for your own interpolation. (I have worked extensively on using effective medium approximations to interpolate). Plotted in the following figure are all the n,k data measured.

Figure 4: All measured n and k data.

# On Taguchi DOE

The Taguchi DOE allows for rapid evaluation of parameter combination that increase the repeatability of production techniques, by selecting parameter settings that minimise variation, whilst achieving acceptable results.

I now plot the sensitivity plots for the parameter settings outlined in Table 1. From the means of means it is clear that altering the N2O flow is a reasonable control variable. The deposition rate with N2O does change significantly so this will need to be accounted for. The pressure and other gas flows can be chosen such that the signal to noise is maximised. We see in both the thickness and the n that the SN ratio is not strong for low N2O. This likely relates to the modelling of these films, having a larger RI.



Figure 5: Main effect plots from the Taguchi DOE.

We see that increasing the pressure and ammonia, in all cases increases the predictability, where as there is opposing SN trend for the silane flow, although the change is small. For future tests, I shall alter the silane flow while maintaining the pressure and ammonia flow.

To give a better feel of what is occurring we plot all the measured data for the change in N2O, including the average parameter for each setting in a similar manner to the main effect for the plot of means.



Figure 6: Plot for the mean of each depostion.

Contour plots can also be extracted with surface DOE analysis. I see that for predicting the RI the matrix is un realistic, hence suggest to this is the natural extension to move to higher RI by implementing Taguchi 3 on SiN only. That is N2O set at 0. Change the SiH, NH3 and pressure over a broader range.

# References

1. Jellison, G.E., Jr., and F.A. Modine, *Parameterization of the optical functions of amorphous materials in the interband region.* Applied Physics Letters, 1996. **69**(3): p. 371-373.

2. Jellison, G.E. and F.A. Modine, *Erratum: ‘‘Parameterization of the optical functions of amorphous materials in the interband region’’ [Appl. Phys. Lett. 69, 371 (1996)].* Applied Physics Letters, 1996. **69**(14): p. 2137-2137.

# Appended n,k generator

function [n, k] = sion\_opt (n633, nm)

%nm in units of nm

% input the 633nm ri for sion from e2 and generate the spectroscoic

% refractive index.

amp1 = 100;

br1 = 11;

% y = 5.9616x4 + 113.06x3 - 751.62x2 + 1450.9x - 888.73

eo1 = 5.9616\*n633^4 + 113.06\*n633^3 - 751.62\*n633^2 + 1450.9\*n633^1 - 888.73

% y = -120.47x4 + 913.2x3 - 2579.4x2 + 3211.7x - 1481.3

eg1 = -120.47\*n633^4 + 913.2\*n633^3 - 2579.4\*n633^2 + 3211.7\*n633 - 1481.3;

eV = 1240./nm

e = TL\_plott (1,amp1, br1, eo1, eg1, eV);

n = real(e.^0.5);

k = imag(e.^0.5);

# n, k min and max (measured and fitted ie. not interpolated with the function)

Table of n and k, inserted as an excel object, you can easily copy paste.

