

Composition measurements using a multi-wavelength laser interferometer

Stuart J C Irvine, School of Chemistry, University of Wales, Bangor

Introduction

This paper outlines an approach to determine alloy composition robustly using a laser interferometer. In principle, it is possible to determine composition by fitting n , k to a single wavelength interferometer signal as both are a function of alloy composition. However, this would not be robust over a wide range of alloys, for a single-wavelength interferometer, as an absorbing wavelength is needed to fix the value of k as a function of alloy composition. The laser wavelength for continuous monitoring through the full thickness of the layer needs to be longer than the band gap cut-off. This wavelength would be insensitive to composition as k would be 0. In general, the changes in n across an alloy system are not huge and would not, alone, give good sensitivity to small changes in composition. A dual-wavelength laser interferometer offers the opportunity to have an absorbing and a non-absorbing wavelength at the same time, where the absorbing wavelength is a more sensitive measure of composition changes. Further robustness can be achieved by using a third wavelength in the blue part of the spectrum that addresses the much stronger E_1 transition. This paper presents these arguments and shows how a three-wavelength interferometer can be used to measure alloy composition in addition to the usual parameters of thickness, growth rate, roughening, n and k .

Wavelength dependence of n , k

The spectral dependence of n , k for a compound semiconductor is shown in Figure 1. The band gap transition is around 1.6 eV and can be seen as a relatively small change in the n , k values. The much larger transition, at the blue end of the spectrum, is the E_1 transition and gives a good opportunity for composition measurement. In this example, we have taken the $\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}$ composition. A comparison with $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ is shown in Figure 2.

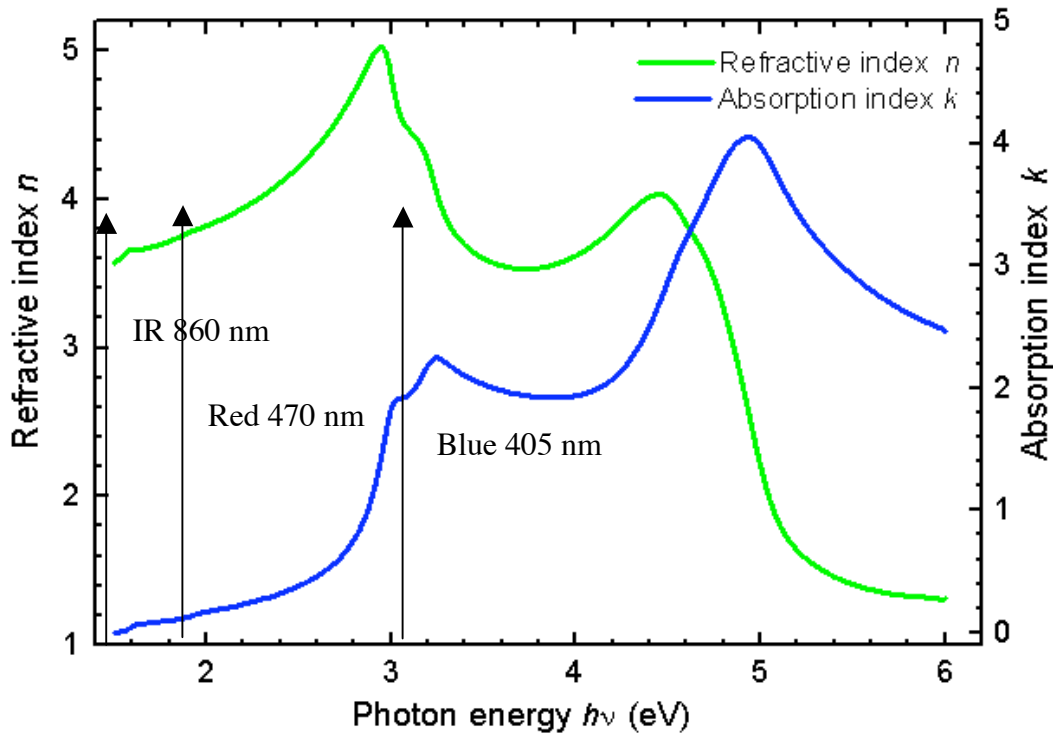


Fig. 1: The function of n and k versus photon energy for $\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}$ (data from Ioffe)

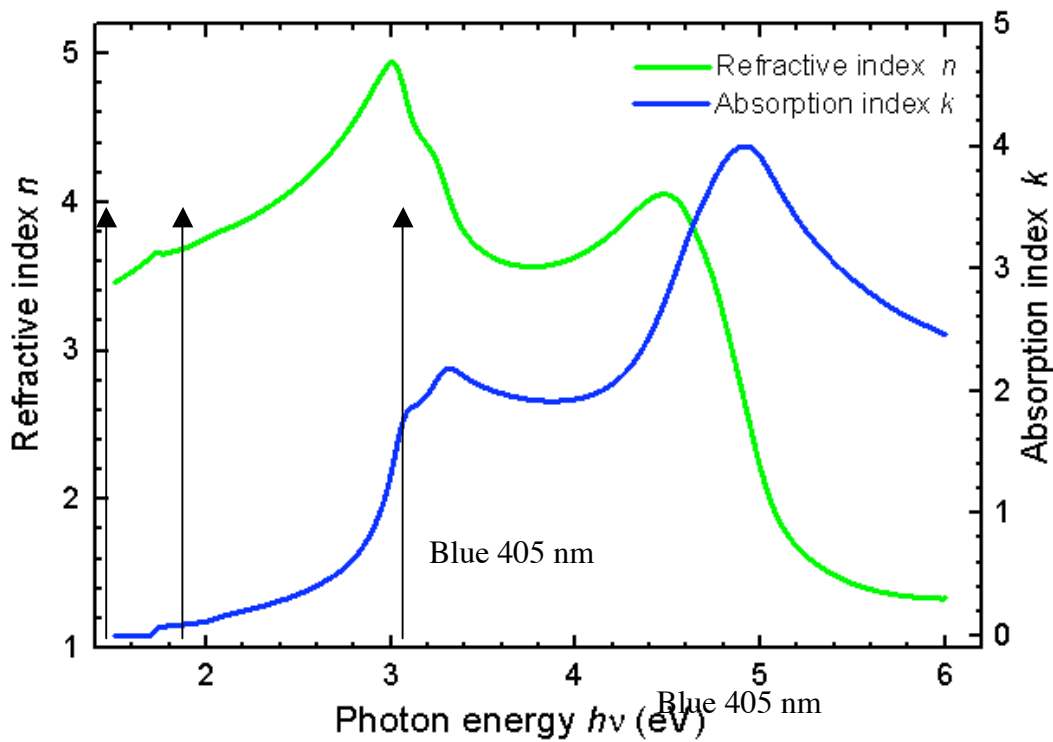


Fig. 2: The function of n and k versus photon energy for $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ (data from Ioffe)

The shift in band gap to higher energy can be seen at around 1.8 eV, but the larger change in k occurs at the much higher photon energy for the blue laser. It can also be seen that the value of n is changing more rapidly at the higher energy and will again be a more sensitive measure of changes in the alloy composition. The following table shows the values of n , k at 3 eV as a function of the AlGaAs alloy composition.

x(Al)	n	k
0	4.54	1.94
0.1	4.87	1.74
0.2	4.92	0.95
0.3	4.76	0.97
0.4	4.58	0.8
0.5	4.48	0.5

Table 1: variation in n , k as a function of alloy composition at 3 eV photon energy

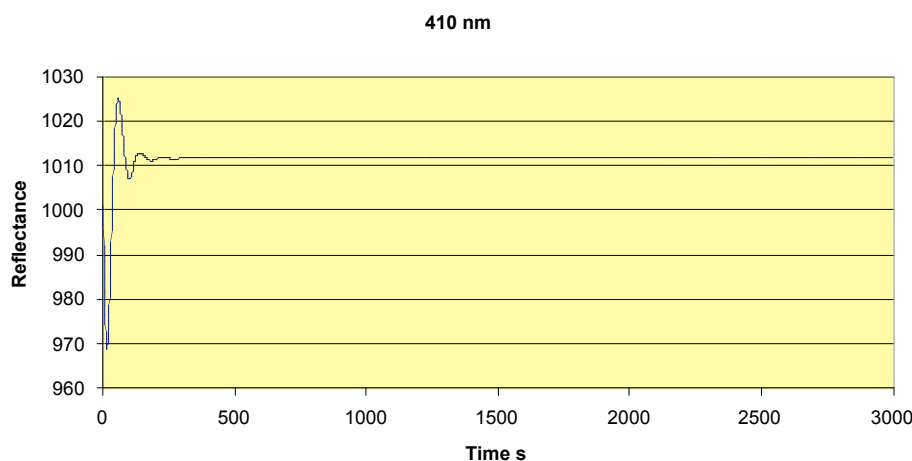
This table shows that the change in values of n and k are not uniform across the alloy but in regions such as 0.0–0.2 and 0.4–0.5, a reasonable fit of n , k will give at least 1% accuracy in alloy composition. In the region of low sensitivity, the second absorbing wavelength for the red laser would be used to give a fix on the alloy composition. This will track more uniformly with band gap but will be less sensitive, overall, compared with the shorter wavelength. A compromise of using the green part of the spectrum could also be considered. In general, for AlGaAs composition measurement, it will be possible to get an accurate measure of the alloy composition for a sub-micron thick layer for low and high Al content alloys.

Time-resolved reflectance

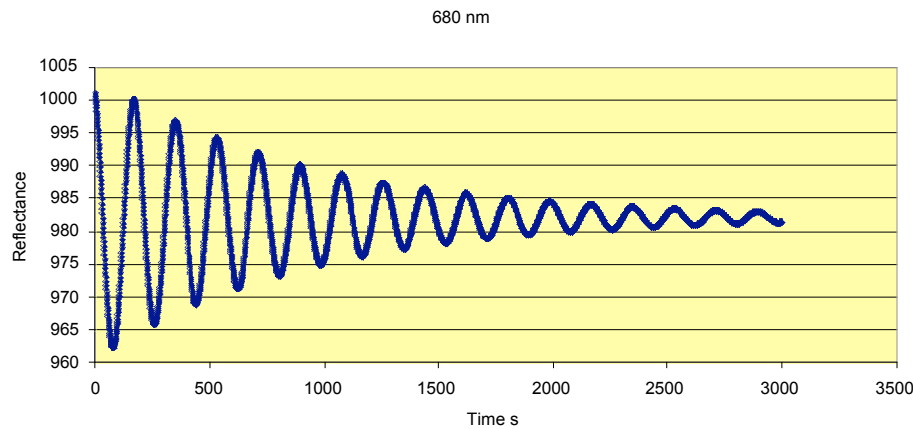
The time-resolved interferometer signal will show rapid attenuation at the shorter wavelength but will manage three turning points before the oscillations are lost altogether. This has a two-fold advantage.

1. It will be easy to get an accurate fit of k and therefore of the composition x .
2. The composition determination will be made rapidly and will be indicative of the near surface region rather than averaged over a larger depth.

The following time-resolved interferometer traces for $Al_{0.1}Ga_{0.9}As$ illustrate these features.



(a)



(b)

Fig. 3: Theoretical interference traces for $Al_{0.1}Ga_{0.9}As$, comparing the different rates of attenuation at (a) 410 nm and (b) 680 nm.

Argument for three wavelengths

For semiconductor materials in the band gap range 1.4 to 2.9 eV, the blue laser wavelength remains absorbing and will enable a determination of composition through the fit-to-extinction coefficient. However, continuous monitoring of the layer thickness will require a non-absorbing wavelength and this would be achieved using an infrared laser. Using the 980 nm infrared laser, the minimum band gap that could be monitored is 1.27 eV. This range of band gaps would be appropriate for monitoring growth of laser structures and detectors in the red and near-infrared region. This band gap range also corresponds very well with thin-film solar-cell structures such as CdTe/CdS and CIGS (copper indium gallium diselenide). The absorber layers (CdTe and CIGS) have band gaps around 1.5 eV, which is the optimum value for an efficient single-junction solar cell. The window layers are in the range of 2.4 eV to 3.0 eV, although higher band gaps are required for the transparent conducting oxide layer. It is clear that the triple-wavelength laser interferometer would be applicable to the deposition and control of the absorber and window layers. It may be particularly critical for the CIGS growth where the most efficient cells require a grading of the alloy composition.

Conclusions

The TriDENT laser reflectance system offers a number of advantages for *in situ* monitoring structures in the near-infrared and red regions of the spectrum and for thin-film photovoltaic devices. The advantages can be summarised as follows:

1. Measuring the extinction coefficient near to the E1 transition will give excellent sensitivity to alloy composition in minimal grown layer thickness.
2. The composition measurement can be supplemented with the less-sensitive, longer wavelength extinction coefficient.
3. The infrared laser will maintain continuous monitoring of thickness for thicker films.