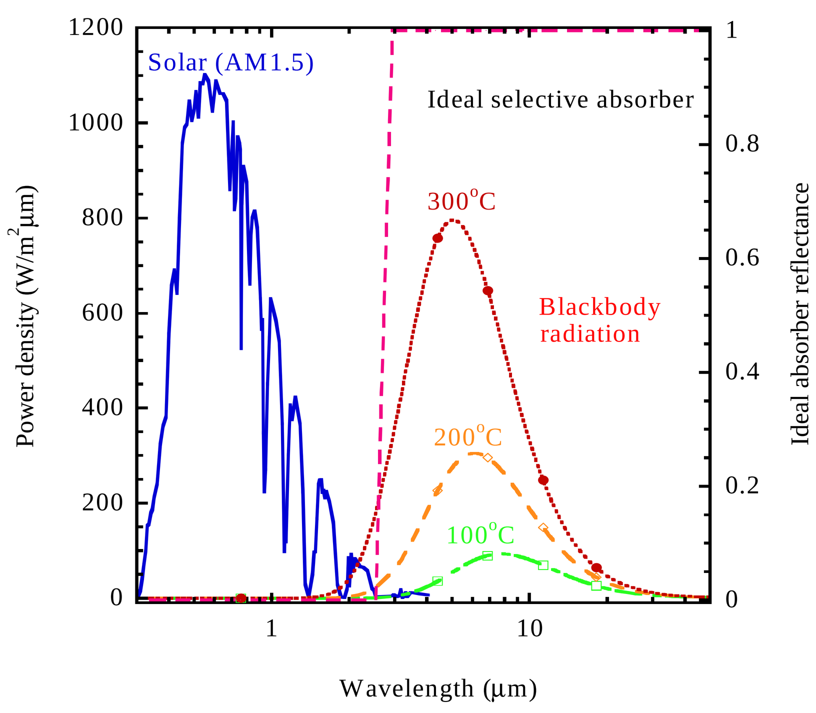
our future through science

Fabrication of selective solar absorbers using pulsed laser deposition

B. Yalisi[1, 2], G. Katumba[1], A. Forbes[1, 2] and S. R. Pillay[2]
[1]Council for Scientific and Industrial Research, National Laser Centre, P.O. Box 395, Pretoria 0001, South Africa
[2]School of Physics, University of KwaZulu Natal, Private Bag X54001, Durban 4000, South Africa
Email: byalisi@csir.co.za

Introduction

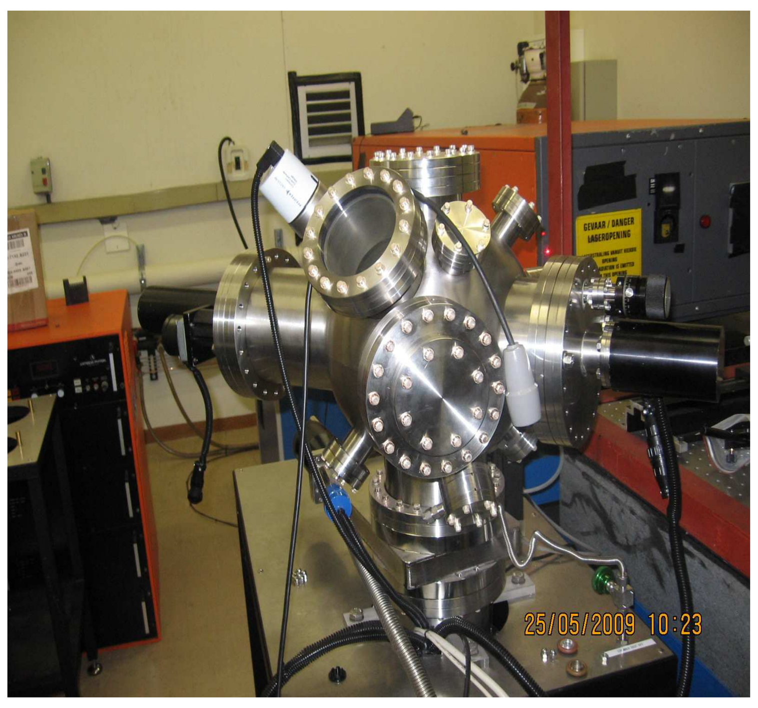
Selective solar absorbers are devices that have been designed to absorb as much as possible of the solar radiation which is in the wavelength range of 0.3 to 2.5 µm and to minimise thermal emittance in the wavelength range from 2.5µm to the far infrared region. Minimising thermal emittance implies that the device retains all the solar energy that it absorbs from the sun without releasing it in the form of heat, until it has been collected and delivered to where it is to be utilised. Selective solar absorbers have been fabricated before using different techniques, among them the sol gel technique, sputtering, painting and the chemical vapour deposition (CVD) technique.



The ideal selective solar absorber, the solar spectrum and blackbodies radiating at 100, 200 and 300 °C

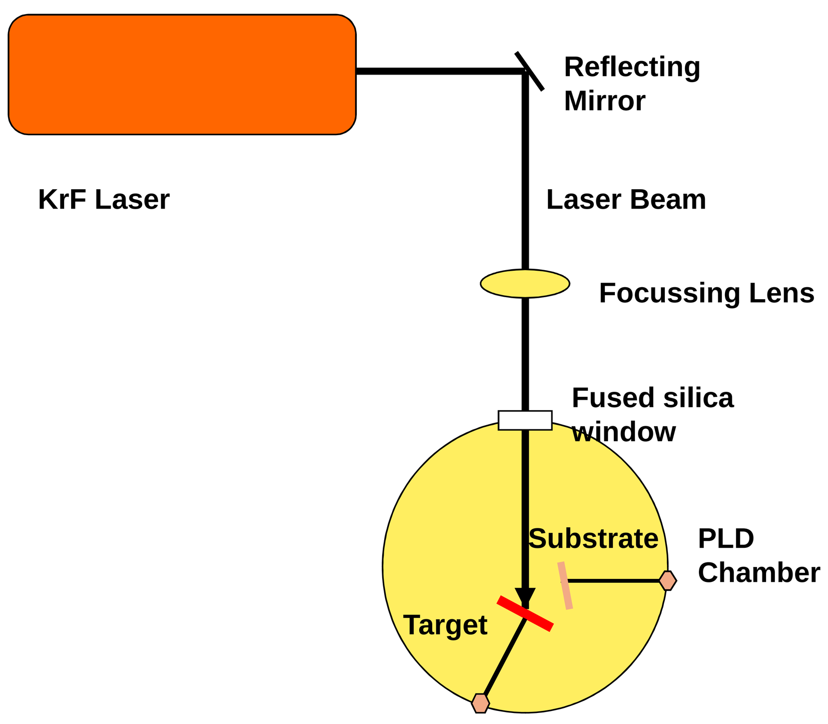
Pulsed laser deposition

Pulsed laser deposition (PLD) is a thin film deposition technique, which uses a high powered laser beam which has been tightly focussed into a high vacuum chamber to strike a hard pressed target of the desired composition. The material will then be vaporised from the target and deposited as a thin film on the substrate which can be anything from aluminium, stainless steel to silicon wafers.



The Pulsed laser deposition system showing the deposition chamber and the observation window

The KrF Lambda Physik LPX200 Laser with its remote control



The Pulsed laser deposition setup

The KrF excimer laser

Excimer lasers are a group of pulsed lasers that make use of electronic transitions within short-lived molecules. These lasers are composed of the combination of a rare gas atom, for example Argon, Krypton or Xenon and a halogen atom (Fl, Cl or I). The KrF laser uses Krypton and Fluorine as the excitation gases. The principal laser transition in KrF is at 248nm. The pulsed output of the laser has duration of about 30ns and pulse energy of around 300mJ maximum.

The laser beam propagation equation

$$w(z) = w_o\left[1+\left(\frac{z-z_o}{z_R}\right)^2\right]^{\frac{1}{2}} \qquad (1)$$

Where $z_R = \frac{\pi w_o^2}{M^2\lambda}$ and is called the Rayleigh range, the distance at which the laser beam has increased to twice the beam waist diameter W_o and M^2 is the beam quality. λ is the wavelength of the KrF laser.

Equation 1 can be reduced to the following quadratic form:

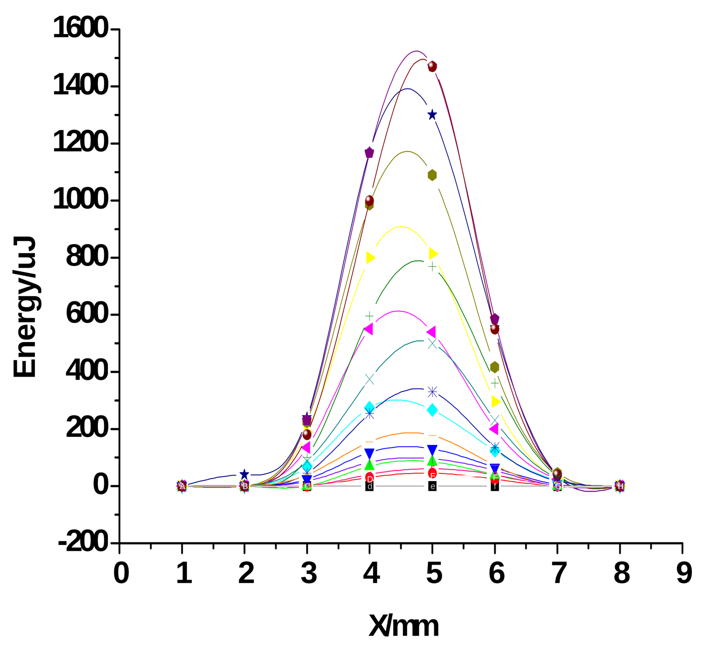
$$w_o^2(z) = \left(\frac{M^2\lambda}{\pi w_o}\right)^2 z^2 - 2z_o\left(\frac{M^2\lambda}{\pi w_o}\right)^2 z + \left(\frac{M^2\lambda}{\pi w_o}\right)^2 z_o^2 + w_o^2 \qquad (2)$$

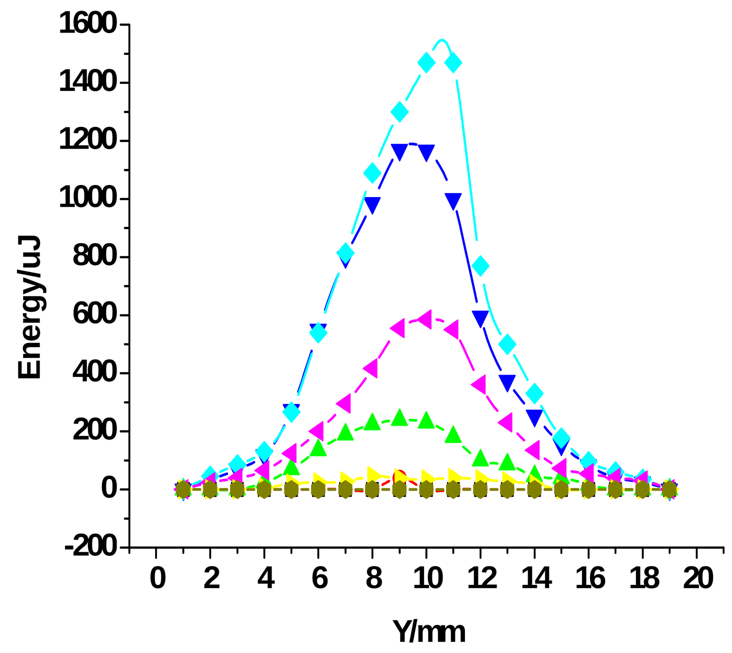
The method for second moments for calculating beam widths

This method starts by evaluating the beam intensity profile, $I(x,y)$ across the rectangular co-ordinate, x (and also across the y co-ordinate) in the form:

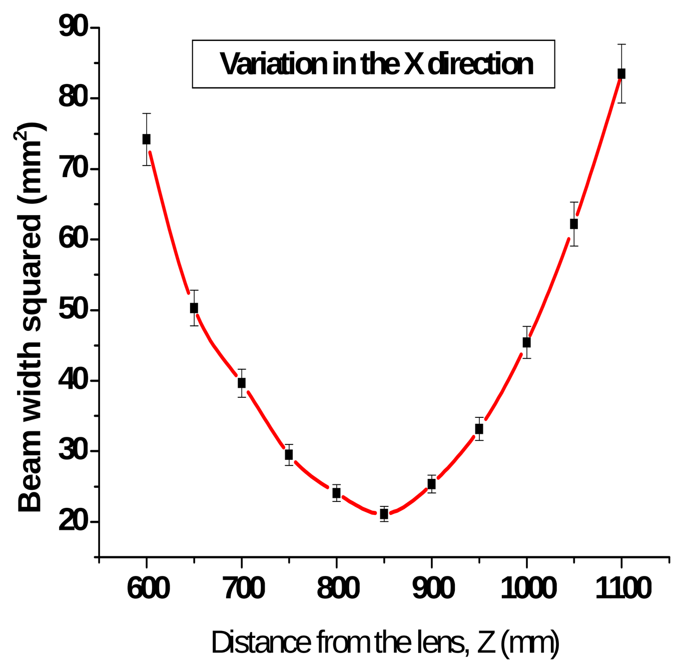
$$\sigma_x^2 = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}(x-x_o)^2 I(x,y)\,dydx}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(x,y)\,dxdy} \qquad (3)$$

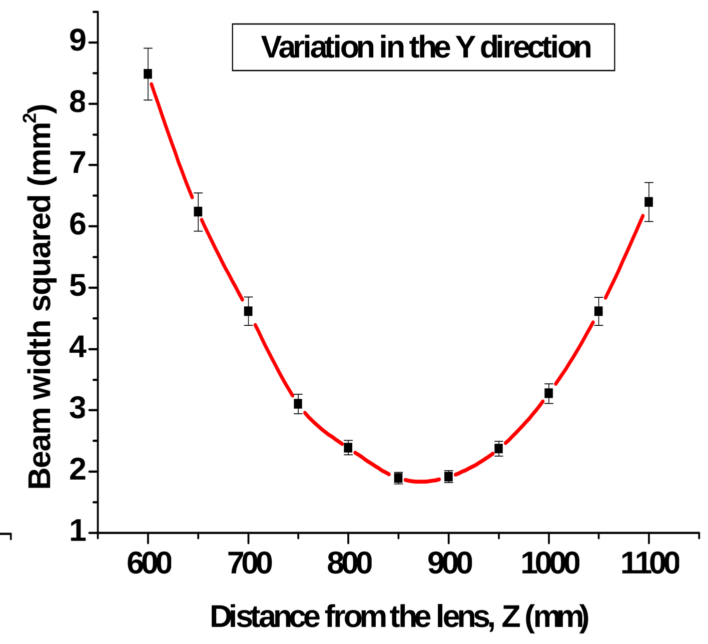
Where x_o is the centroid of the beam and σ_x^2 is the second moment in the X-direction. It can be shown that for a laser beam, the beam diameter at any point is given by $w_x = 2\sigma_x$ and $w_y = 2\sigma_y$ for the X and the Y directions respectively. After calculating the beam widths and plotting their square against the distance from the lens and fitting a quadratic polynomial, the beam parameters were determined.





Variation in energy as a function of position on the beam spot at a distance of 750mm from the lens

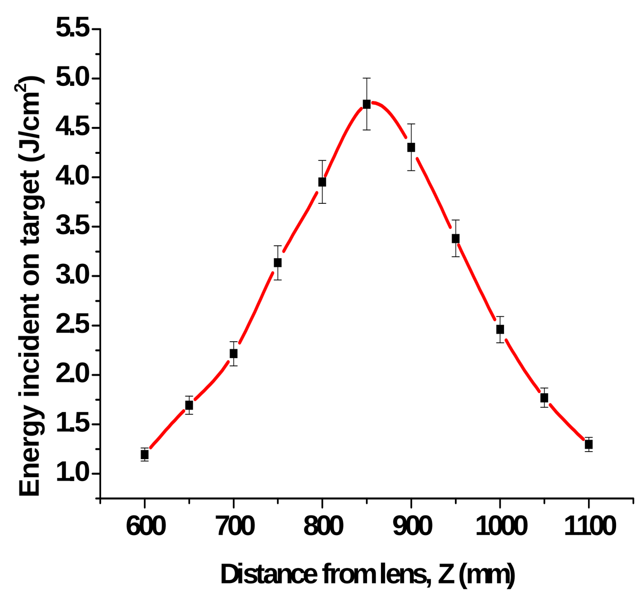




Variation in beam width as a function of distance from the lens, for the X and the Y directions respectively

Beam parameter	X direction	Y direction
w_o	4.68±0.33mm	0.83±0.074mm
z_o	840±70mm	910±100 mm
M^2	1800±200	100±11

The energy reaching a square centimetre of the target is calculated by first finding the area of the beam spot size. Using the maximum energy of 300mJ, the intensity is then calculated.



Graph showing the variation of the beam intensity with the distance of the target from the lens. The intensity is highest at a distance of about 850mm, and decreases as the target as brought closer or taken further from that distance.

References

1. Katumba, G., PhD thesis, University of Zimbabwe 2006;
2. Lasers and related equipment – Test methods for laser beam parameters, beam widths, divergence angle and beam propagation factor, International standard, ISO 11146;
3. John C. Miller (ed), Laser Ablation: Principles and applications, Springer-Verlag, 1994.