INTRODUCTION

Concerted RND is underway for the development of novel materials, especially in the nano scale. Techniques that are non-destructive in nature attract special attention in characterization of such materials. Thermal diffusivity is an important thermal parameter for any material. IR thermographic techniques are gaining wide popularity for measurement of this parameter, because of the non-contact nature and easy to handle approach. Welch et al. [1] first presented an infrared imaging method to determine the thermal diffusivities of metal and graphite-epoxy plates, where a focused pulsed laser beam was used as an excitation and an infrared camera was used to record the temperature distribution on the surface of the sample. By calculating the successive temperature profiles, the thermal diffusivities of the plates were obtained. Later, Milner et al. [2] and Telenkov et al. [3] implemented similar techniques to measure the thermal diffusivities of biomaterials (tissues). The thermal diffusivities of the materials can also be obtained by theoretical simulations of the successive images of the diffusing temperature distributions. Recently, Laskar et al. [4] have reported that the thermal diffusivity of solids could be obtained, using a continuous heat source on the front surface of a solid and an infrared thermal camera detecting the time-dependent temperature variations at the rear surface; a technique similar to the Flash Method by Parker et al. [5]

In the present paper, we demonstrate application of a non-contact IR imaging technique developed for measurement of thermal diffusivity in nanopore membranes. These nanopore membranes are used for fabricating nanowires for desired applications. The membranes show anisotropic thermal diffusivity in directions both parallel and perpendicular to the nano channels as shown in fig.1. We confine ourselves to the study of thermal diffusivity in the direction perpendicular to the nano channels in this work.

THEORY

The well known Angstrom ‘temperature-wave’ method [6] forms the basis of this development and is extended for the determination of thermal diffusivity of µm thin nanopore membranes.

A periodic heating is applied at the centre of the membrane. The diffusivity is given either by the attenuation of the temperature wave or the phase lag between the periodic temperatures at the two measurement points. The equations employed are those of the thermal wave equation in cylindrical co-ordinate system

\[
\frac{\partial T}{\partial t} = D \left( \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) \right)
\]  

(1)

where D is the thermal diffusivity in direction perpendicular to nano channels, T the temperature, t the Time, r the radius of membrane.
The boundary conditions are,

\[ T = T_0 \exp(i\omega t) \quad \text{at} \quad r = 0 \]
\[ \frac{\partial T}{\partial r} = 0 \quad \text{at} \quad r = \infty \]

We further relate the thermal diffusivity value with the phase lag \( \phi \) between two considered points as,

\[ \phi = L \sqrt{\frac{\omega}{2D}} \]

where \( L \) is the distance of separation between considered points, \( \omega \) the angular frequency of modulated laser beam.

The thermal diffusivity value can be obtained from equation (2).

**EXPERIMENT**

The experimental setup used to measure the thermal diffusivity of the membrane is shown in Fig.3. Thermal (temperature) waves are generated by a chopped laser beam of wavelength 532nm, operating at different angular frequencies each with 50% duty cycles. The sample is mounted on a thermally insulated holder. The sample is mounted such that it is fully suspended in air without any physical contact anywhere inside the sample.

No heat sink is attached to the sample, but the angular frequency is chosen such that our sample behaves as a semi infinite body.

An uncooled type IR camera VarioCAM hr with spectral range 7.5-14\( \mu \)m was used. The camera operation was controlled through IRBIS professional software, supplied with the camera, and IR image video files were captured at 50 Hz frame rate.

The time sequenced IR images are stored in a computer and are used for further processing. The laser is placed at an angle of 5\( ^\circ \) with the camera axis.

**RESULTS**

Experiments were performed for a wide range of \( \omega \) values: 15.7 rad/s to 2.09 rad/s. Fig.4 shows the plot of temperature as a function of time for points separated by 1mm. The modulation frequency corresponds to \( \omega = 6.28 \) rad/s. The temperature attenuation and change in phase values for points away from the source, is clearly visible.
The phase data is used for estimating the thermal diffusivity values. From the IR video files at different ‘\( \omega \)’, the phase images were extracted using the IRBIS software. From the individual phase image, \( \Omega/L \) ratio was estimated. Finally the diffusivity value was calculated from the slope of \( \omega \) vs. \( (\Omega/L)^2 \) plot as in Fig.5. For our sample of 20nm pores the measured value of thermal diffusivity was \( D = 8.5 \times 10^{-7} \).

CONCLUSION

IR thermography can be suitably used for determining the perpendicular channel thermal diffusivity of extremely delicate nanopore membranes. The technique may be extended to nanowires filled membranes for estimating the thermal diffusivity of the nanowires solely.

REFERENCES