largely deviates from initial to final observation. The glucose level has responded to treated diet ranging from 1.16 to 9464.08 points.

Testing of data was not significant at 5% level but reversing the site of analysis was negative which is important because it indicated progressively lower values than the initial values. The lowest value of total observations was considered as mean to check each interval of observation (Table 4).

The study involved different experiences of people taking medicine and multigrain flour. The multigrain flour on consumption energized and maintained the glucose level, whereas medicines did not give such feeling because the blood sugar level went down and required energy could not be obtained from it; medicine has not provided any nutrition.

The higher level of fibre present in finger millet made the chapati tasty and binding capacity of wheat made chapati consist form. Although the colour of multigrain chapati was darker than wheat chapati, it was a healthier option. The proportion of finger millet grain could be varied according to age of persons. More finger millet proportion made the chapati hard. People of all age groups participated enthusiastically in this study[5,6].

Health is an important issue for all of us. Diabetes can be managed by slight modification in diet and low dosage of medicine.

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ADIKANT PRADHAN*
S. K. NAG
S. K. PATIL

S.G. College of Agriculture and Research Station,
Jagdalpur 494 005, India
**For correspondence.*
e-mail: adi_197753@rediffmail.com

Laser ablation of semiconductor thin films – dependence of deposition rate on bandgap

The availability of high power pulsed and continuous wave (CW) lasers has made laser materials processing (LMP) industrially important. In semiconductor technology, lasers are being used for wafer marking, ohmic contact formation, ion implantation annealing and thin film deposition[1]. Due to the extremely fast nature of laser heating, direct conversion from solid to vapour phase may occur instead of melting, which is the process of ablation. A number of different types of semiconductor films have been deposited by laser ablation but a direct comparison between these is absent in the literature. This report compares the dependence of the deposition rate of thin films of wide-band gap such as BN and narrow gap semiconductors such as GaSb by ruby laser ablation.

Considerable work has been done in India since the 1980s on the deposition of a range of semiconductors in the Materials Science Centre at IIT Kharagpur[2–7]. Laser ablation was carried out using a pulsed ruby laser $\lambda = 694$ nm (1.786 eV) in a system consisting of a cylindrical stainless steel chamber provided with quartz windows. The chamber was pumped down to 10^{-6} mmHg using rotary and diffusion pumps. The Q-switched ruby laser emitted pulses of 30 ns duration with a repetition rate of 4 per minute. The energy could be controlled and varied between 0.5 and 3.0 J/pulse and measured with a power meter. The target was held at an angle to the incident beam in the centre of the chamber facing the substrate held directly opposite, a typical target–substrate distance being 3–4 cm found to be optimum for avoiding particulate deposition (splattering). The target could be rotated slowly at a few rpm to prevent erosion of the target at a given spot. The number of pulses was varied to give films of thickness 50–100 nm measurable by a Talystep and the deposition rate found accordingly. This can be estimated by analytical and numerical techniques to compare with the experiment. For identical deposition conditions, the rate has been found to depend strongly on the bandgap, showing a maximum for CdTe ($E_g = 1.54$ eV) and to decrease rapidly for semi-metals such as TiN and wide bandgap materials such as BN ($E_g = 6.4$ eV). These results can be explained on the basis of the optical properties and thermal conductivities of semiconductors, except for the anomalous behaviour of SiC.

The physical phenomena that occur when a high power laser beam is incident on a material's surface depends on the laser wavelength, power density, the absorptivity of the material at the laser wavelength and its thermal properties such as thermal conductivity κ, diffusivity D_p and heat capacity c. In the case of pulsed laser processing, the heating and cooling cycles are short with a small volume of the target quickly being brought to boiling temperature. After the cessation of the pulse, the volume cools off rapidly due to thermal conduction into the bulk. The short times involved are insufficient for substantial loss of energy due to atomic diffusion. Thus for a given length of time, the surface is heated to a depth determined by the thermal diffusivity of the target.

There are two distinct conditions depending on the given factors.

(a) Strongly absorbing materials: $1/\alpha << L_p$, where α is the absorption coefficient of target at laser wavelength and L_p the thermal diffusion distance = $(2D_p\tau_p)^{1/2}$, D_p the thermal diffusivity = $\kappa/\rho c$ and τ_p the laser pulse duration. In this case, the laser power is distributed within a characteristic volume defined by beam size and diffusion distance D_p and the temperature rise is given by

$$\Delta T = (1-R)I\tau_p/(2D_p\tau_p)^{1/2}\rho c.$$

Heating and cooling rate

$$\Delta T/\tau_p = (1-R)I/(2D_p\tau_p)^{1/2}$$
$$\rho c = (1-R)I/L_p\rho c = T_M/\tau_p,$$

where T_M is the melting point.

(b) Weakly absorbing materials: $1/\alpha >> L_p$. In this case, the laser energy is confined within a depth determined by the absorption coefficient α. Then

$$\Delta T(z) = (1-R)\alpha I\tau_p e^{-\alpha z}/\rho c.$$

Heating rate = $\Delta T(z)/\tau_p$, cooling time = $\alpha^{-2}/2D_p$ and $dT/dt = (1-R)\alpha^3(2D_p I\tau_p)/\rho c$.

To calculate the thickness of deposited films the following techniques may be used. The differential equation for heat conduction may be written in terms of the temperature distribution $T(x, t)$.

$$\delta T/\delta t = \delta/\delta x[(k/\rho c)\delta T/\delta x] + Q/\rho c$$

Energy absorbed $Q = I_0(t)\,(1-R)\exp(-\alpha x)$,

where R is the reflectivity, α the absorption coefficient and $I_0(t)$ the intensity of laser beam.

Since the thermal and optical constants are all temperature dependent, the equation is nonlinear. Numerical techniques such as the finite difference method or finite element method are thus used, the former by Bell *et al.*[8] and Jain *et al.*[9]. Bhattacharyya *et al.*[4] have also used this technique for estimating the variation of temperature (T) with time (t) and depth (x) for ruby laser heating of CdTe and BN using the known thermal and optical properties of these materials. Figure 1 shows a comparison between analytical and numerical techniques[4] for the estimation of temperature versus depth for CdTe. Experiments[2,3] showed that the rate of deposition of BN thin films for a laser energy of 2.5 J/cm^2 was 7 Å/pulse compared with the finite difference method which gave a value of 10 Å/pulse. The agreement is reasonably good, showing that theoretical estimates are possible in spite of simplifying assumptions being made.

In the present studies, laser deposition was carried out on semiconductors ranging from wide bandgap III–V semiconductors such as BN and AlN[2,3], II–VI compounds such as CdTe[4], ZnSe[5] and ZnTe[7] to semi-metals such as TiN[6]. Films were deposited on glass substrates

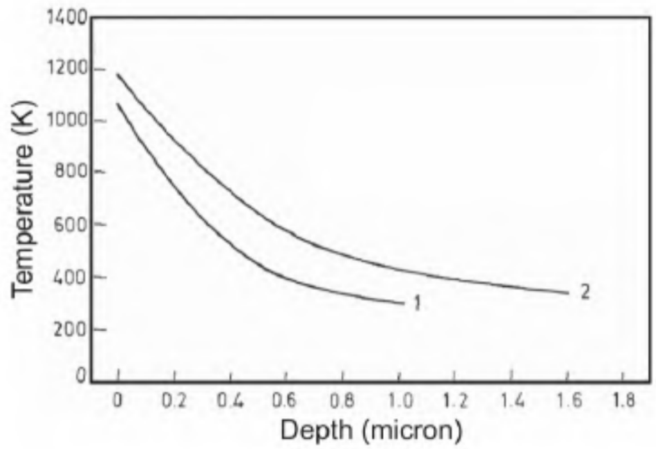

Figure 1. Estimation of temperature versus depth for CdTe by (1) analytical and (2) numerical techniques[4].

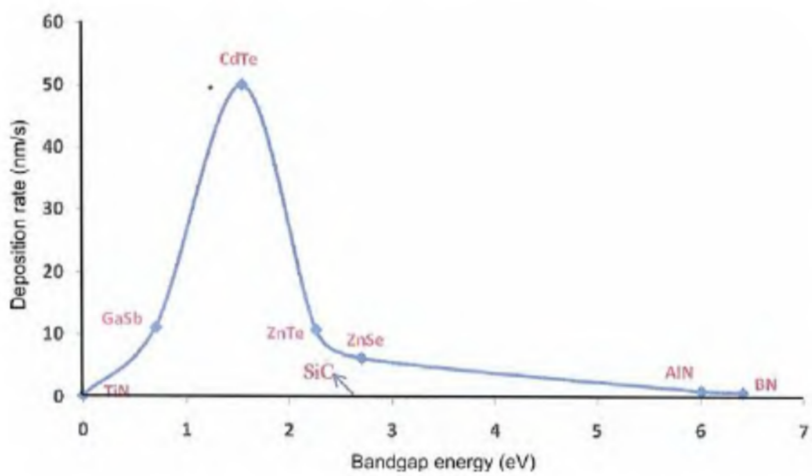

Figure 2. Comparison of deposition rates versus bandgap for different semiconductors.

Table 1. Laser ablation results on semiconductors. Ruby laser λ = 694 nm (1.786 eV)

Material	Bandgap (eV)	Deposition rate (nm/s)	Melting point (°C)
BN	6.4	0. 8	3000
AlN	6.0	1.1	2500
ZnSe	2.7	6.3	1520
SiC	2.6	0.4	2500
ZnTe	2.26	10.8	1295
CdTe	1.54	50	1092
GaSb	0.70	11.2	707
TiN	~0	0.3	2930

for electrical and optical measurements. The targets were pressed pellets in the case of AlN and BN and small crystals in the case of others. The results are given in Table 1 and the deposition rate versus band gap plotted in Figure 2.

The comparison of deposition rates for different materials, being presented for the first time, shows that as expected the deposition rates for BN and AlN are very small since direct band–band absorption is not possible because the photon energy is much less than the band gaps. These are weakly absorbing materials with low value of α in which absorption takes place after multiple scattering through impurity/defect levels. The deposition rate is a maximum for CdTe for which the bandgap 1.54 eV is slightly smaller than the photon energy of 1.786 eV, the absorption constant $\alpha \sim 10^3\ cm^{-1}$ is large and the absorption depth ~0.1 μm small, thus representing a strongly absorbing material. α is very small for TiN which is metallic, has very high reflectivity R in the red region and is thus a weak absorber. The only anomaly appears to be for SiC[6] for which the deposition rate was very small even at very high incident energies although its band gap is almost similar to that of ZnSe. SiC is known to have very high thermal diffusivity D_p, a high melting point and an indirect band-gap giving a low α and hence a higher absorption depth which may be the reason for this behaviour.

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DWARKA N. BOSE

University Science Instrumentation Centre,
University of Calcutta,
Kolkata 700 009, India
e-mail: dwarkabose322@gmail.com