L.1: Study of nano-ripple formation on different band-gap semiconductor surfaces using femtosecond pulses

Surface structuring of metal and semiconductor materials is topic of considerable interest in various areas like improvement of photovoltaic devices by increasing effective surface area, bio-medical applications like directional cell growth etc. Surface structuring with lasers is highly competitive due to its capability of making fast and easy to implement changes in the structure design. Mid-IR femtosecond laser radiation is generally used for the generation of surface ripples, also known as laser-induced periodic surface structures (LIPSS). Various mechanisms have been proposed to explain the nano-ripple formation like interference between the laser radiation, the plasmon - polariton waves created during initial random surface heterogeneities, self-organization, Coulomb explosion, influence of second harmonic generation, local field enhancement etc.

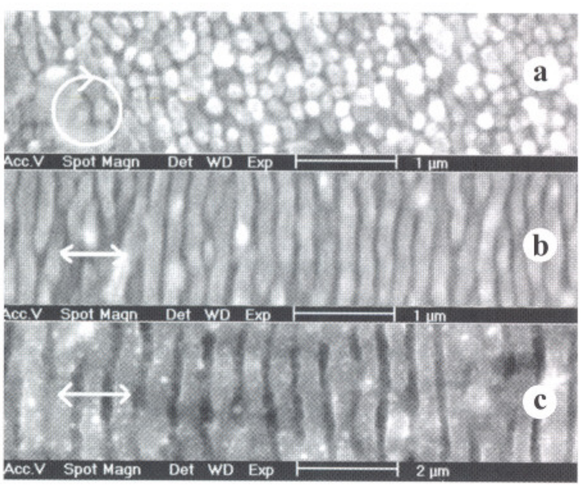

Fig. L.1.1 : GaP irradiated by 800 nm ultrashort laser pulses. a) with circularly polarised beam, b) and c) linearly polarised beam.

At the Laser Plasma Laboratory of RRCAT, we have studied the nano-ripple formation from ultrashort laser pulse irradiation of various semiconductor materials of different band gaps. The following semiconductor materials of low band gap were used in the experiments : InAs (0.36 eV), GaAs (1.42 eV), InP (1.35eV) and high band gap materials like GaP (2.3 eV), GaN (3.4 eV), SiC (2.86 eV), ZnSe (2.82 eV). Multiple laser shots from a Ti-sapphire laser with 8 mJ energy, 45 fs pulse duration and 800 nm wavelength (1.5 eV) were focussed in air on the semiconductor wafers at a fluence of ~ 100 mJ/cm^2. The second harmonic (400 nm) of the 800 nm laser beam was also used to study the influence of the wavelength on the ripple formation. The effect of the number of laser shots, the angle of incidence, polarisation of the laser, fluence, band gap and ambient medium was studied. Some of the results of this investigation are given below.

Fig. L.1.1 shows the various surface morphologies resulting from the irradiation of a GaP wafer by femtosecond pulses in two different conditions. Fig. L.1.1a shows the formation of spherical nanoparticles (~100 nm) with circularly polarized laser light. Fig. L.1.1b shows narrow nano-ripples with 200 nm spacing (1/4 of laser wavelength) at mild focussing conditions of linearly polarised laser pulses. Fig. L.1.1c shows wider nano-ripples with 600 nm spacing (3/4 of laser wavelength) near the central hot region of the laser irradiated spot. It is also noted that for linearly polarized light, the nano-ripple orientation was always orthogonal to the laser polarisation.

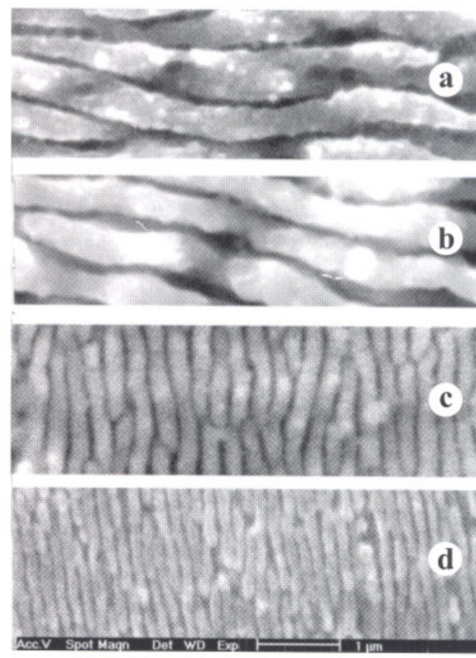

Fig. L.1.2 : Nano ripple formation using 800 nm pulses in low band gap semiconductors : a) GaAs and b) InP; and high band gap semiconductors : c) GaN d) SiC

Figure L.1.2 shows the nano-ripple formation using linearly polarised laser pulses. In the low band gap semiconductors like : a) GaAs and b) InP, the SEM picture of the irradiated spot shows the spacing to be of the order of wavelength (i.e. 800 nm). On the contrary, in high band gap material like : c) GaN and d) SiC, the spacing is of the order of 135-200 nm. Thus, the above studies have shown that, in general, the narrow nano-ripples are formed from material with a high band gap. The width of the nano-ripples also decreases with the laser wavelength and the laser fluence.

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