are closer to the Nevada test site curve; thus the use of Shagan River ($m_b$ vs $Y$) relation for Pokhran site is not appropriate. For a given $M_s$, the $m_b$ for SRTS event is ~ 0.4 magnitude units more than the $m_b$ for Pokhran event. Although there are only two observations from the Pokhran site, the trend is easily seen.

It may also be pointed out that Sikka *et al.*[21] had earlier determined the value of $C_1 = 4.04$ for Pokhran and $C_2 = 0.77$, which is close to the $C_2$ value of eq. (1). This, together with the present analysis confirms that $m_b$-bias between SRTS and Pokhran sites is about 0.4 magnitude units.


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# High-temperature studies on Mo–Si multilayers using transmission electron microscope

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**In the present investigation we have carried out studies on thermally-induced phase transformations in Mo–Si multilayer. The microstructural characterizations were carried out on samples deposited on copper grids and heated *in situ*, using a transmission electron microscope. We have found that at temperatures above 400°C, the sample starts transforming to crystalline phase. Almost complete transformation of Mo–Si multilayer takes place at around 750°C to the $Mo_5Si_3$ phase.**

SYNTHETICALLY produced multilayer structures made it possible to reflect energies in soft X-ray regions. The mirrors are fabricated using a high atomic number material and a low atomic number material alternately in a stack[1]. Molybdenum (Mo) and silicon (Si) are the most widely used materials for fabrication of mirrors for soft X-rays in the wavelength range of 13 to 30 nm, due to their high reflection efficiencies. The normal incidence reflectivity of a Mo–Si multilayer mirror is around 60% (refs 2–4). High brilliance soft X-rays incident on the multilayer produce high heat load, if not cooled, and may deteriorate the performance of these mirrors[5–8]. The rise in temperature sometimes may be as high as 900°C (ref. 7), so the multilayer structure must be highly heat-resistant in order to have good X-ray reflectance over the whole temperature range. The loss of reflectivity is related to the structural change in the multilayer structure. In the present investigation we have studied the effect of temperature (up to 750°C) on the structural changes in the multilayer fabricated using electron beam evaporation technique. The microstructural characterization was carried out using a transmission electron microscope (TEM). We have found that the formation of crystalline phase ($Mo_5Si_3$) starts at around 450°C and nearly complete transformation of phase takes place at 750°C, where $Mo_5Si_3$ and $MoSi_2$ phases form. The formation of $Mo_5Si_3$ phase was confirmed by high-resolution electron microscopy coupled with selected area diffraction pattern.

Mo–Si multilayer was deposited using an electron beam evaporation system[9] in ultra high vacuum environment at a base pressure of $2 \times 10^{-9}$ mbar. The vacuum chamber was pumped using a turbomolecular pump and sputter ion pump combination, which contained three

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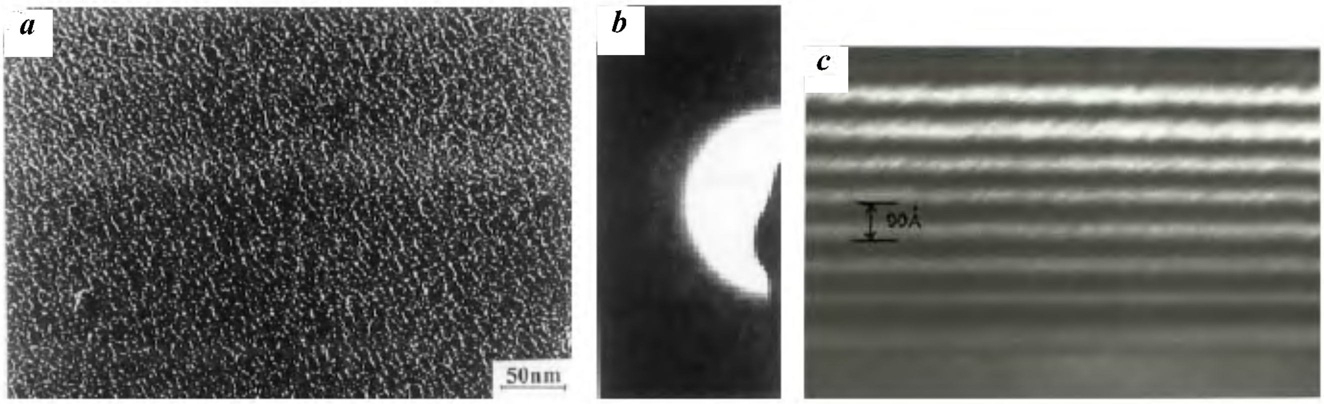


**Figure 1.** ***a***, Bright field micrograph of as-deposited sample; ***b***, Corresponding diffraction pattern and ***c***, Cross-sectional micrograph of Mo–Si multilayer.

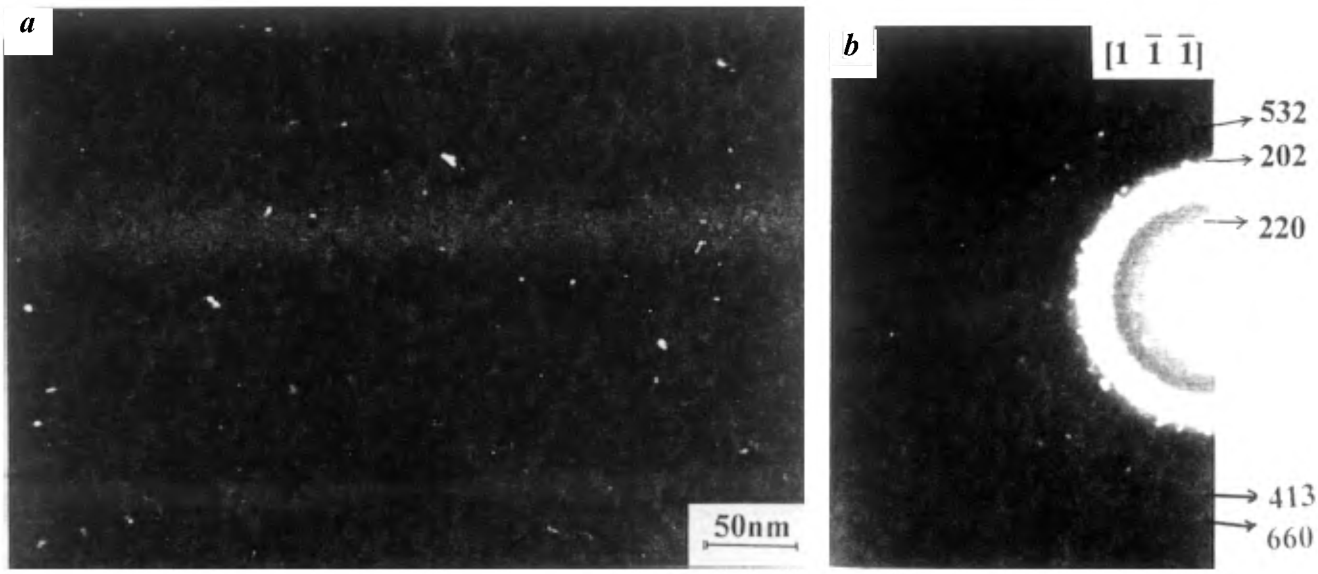


**Figure 2.** ***a***, Dark field micrograph of sample heated to 400°C; and ***b***, Corresponding diffraction pattern.

electron guns. The quality of vacuum was continuously monitored using a residual gas analyser, so that the multilayer could be deposited in a clean vacuum environment. Multilayers with ten pairs of Mo and Si layers were deposited with a periodicity of 90 Å (Mo layer thickness was 25 Å and Si layer thickness was 65 Å). The substrates used for deposition were formvar-coated copper grids (300 mesh) for end-on studies and Si wafer (111) for cross-sectional studies. The source-to-substrate distance was kept around 60 cm to ensure uniform deposition over the whole area. The quartz crystal monitor, mounted at the same height as the substrates, was used for monitoring thickness of the film. The TEM investigations were carried out on Philips CM-200 transmission electron microscope operated at 200 kV accelerating voltage. The microscope was used both in the imaging and diffraction modes. The thermal treatment of the sample was carried out *in situ* in TEM using a programmable, high-temperature sample holder with an accuracy of ± 10°C. The temperature of the sample holder was raised up to 750°C, the sample was kept at various temperatures for 1 h so that the sample movement (because of thermal gradient) stopped and the microstructure and diffraction pattern were recorded at various temperatures.

TEM investigations were carried out on samples grown on copper grids. Figure 1 *a* shows the micrograph of the ten-layer pair of as-prepared sample at room temperature. Figure 1 *b* shows the corresponding diffraction pattern. Diffuse rings are clearly visible on the diffraction pattern, which reveal that the film was amorphous and quite

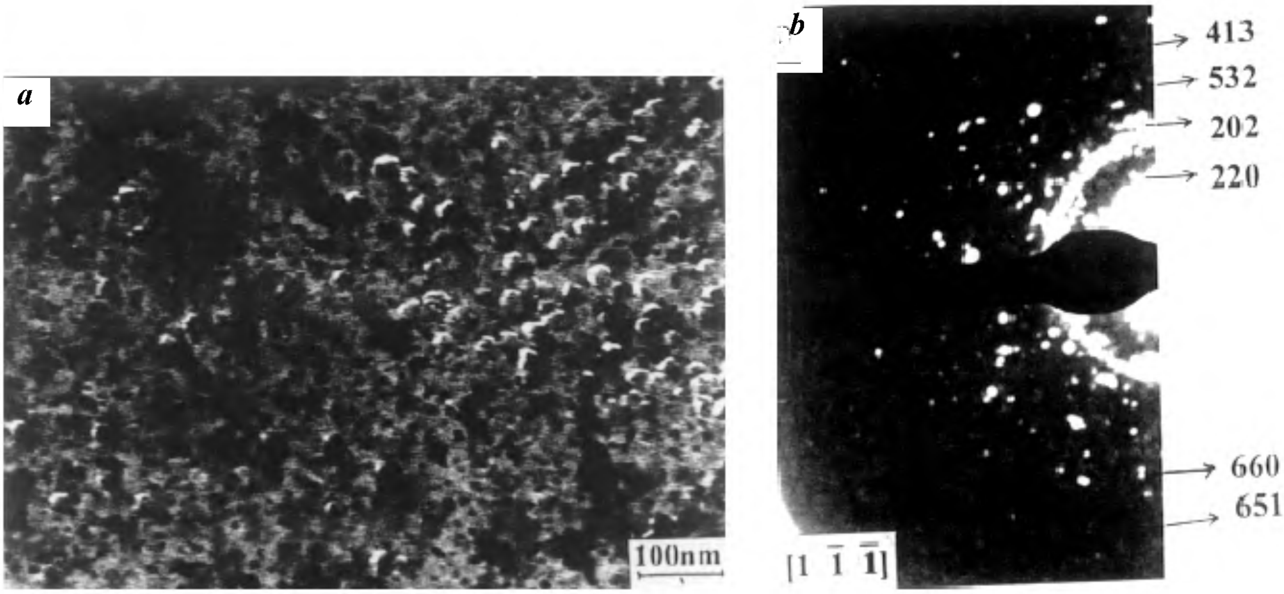


**Figure 3.** ***a***, Bright field micrograph of sample heated to 750°C; and ***b***, Corresponding diffraction pattern.

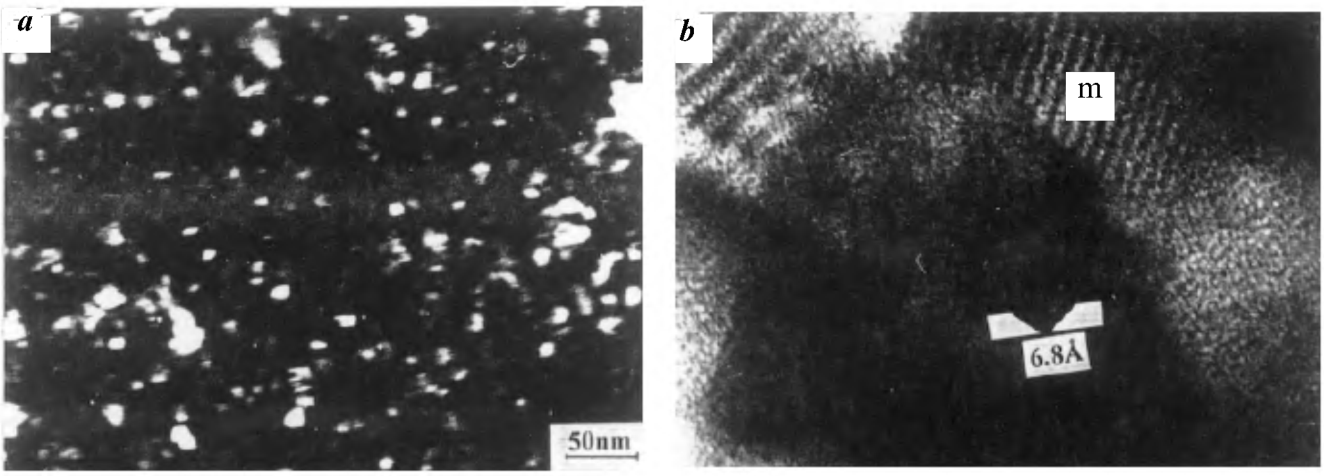


**Figure 4.** ***a***, Dark field micrograph of sample heated to 750°C; and ***b***, HREM showing lattice fringes corresponding to $Mo_5Si_3$ phase; m, regions showing moiré fringes.

smooth in nature. A representative cross-sectional micrograph (Figure 1 *c*) shows the formation of Mo–Si multilayer stack. The thickness corresponding to Mo and Si is approximately 25 Å and 65 Å respectively. This confirms the formation of a multilayer stack of 90 Å. In order to study the structural transformation at higher temperatures, the sample was heated from room temperature to 750°C in the steps of 100°C *in situ* using TEM. When the sample was heated from room temperature to 300°C, no change was observed. At 400°C, formation of precipitate was observed and the average precipitate size measured from dark field micrograph, was found to be less than 10 nm (Figure 2 *a*). The precipitates formed were limited in number and uniformly distributed throughout the film. The selected area diffraction pattern (Figure 2 *b*) taken from these regions showed some discrete spots on the ring. Faint spots on the ring correspond to (220) type of reflection, which are clearly visible. Ring corresponding to (202) type reflection is quite sharp and has intense discrete spots. Other rings corresponding to higher reflections are quite faint, but visible on the diffraction pattern. As the temperature was increased, the size as well as the number of crystallites grew and finally at 750°C, crystallization of the deposited multilayer was nearly complete. The bright field micrograph (Figure 3 *a*) reveals the presence of large amount of big precipitates. In the corresponding diffraction pattern (Figure 3 *b*), the spots are uniformly distributed along the ring. The diffraction pattern could be indexed with $Mo_5Si_3$ tetragonal crystal system with $a = 9.648$ Å and $c = 4.913$ Å. The size of the

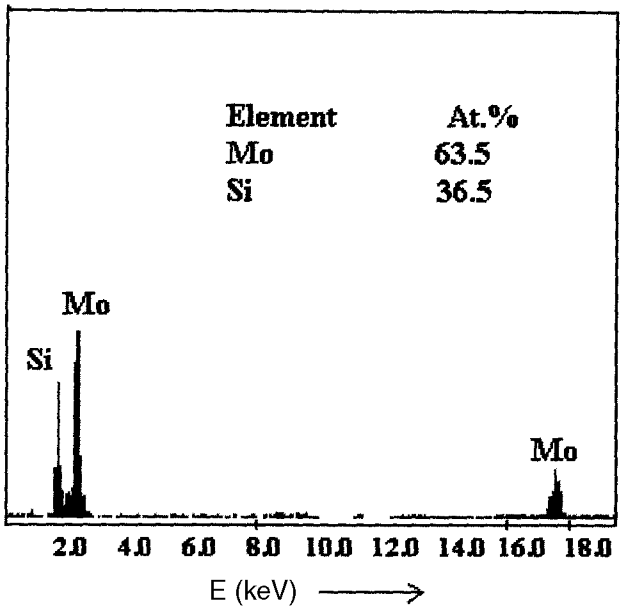


**Figure 5.** EDXA spectrum of Mo–Si multilayer.

precipitates was calculated by taking a dark field image (Figure 4 *a*) and was found to be 50–60 nm. The high-resolution micrograph (Figure 4 *b*) shows the lattice fringes with separation of 6.8 Å. The lattice spacing is found to be matching with (110) of $Mo_5Si_3$ phase. Some regions marked with 'm' show the moiré fringes originating due to the presence of two different lattice spacings, one on the top of the other. These types of moiré fringes are expected in these samples due to the presence of a number of interfaces, one on top of the other. The $Mo_5Si_3$ phase is stable up to 2180°C, with Si and Mo composition of 37% and 63% respectively. Calculations of Mo and Si composition from the thickness of the Mo and Si layers deposited, gives the same ratio as required to form the $Mo_5Si_3$ phase. This result was confirmed by energy dispersive X-ray analysis (EDXA; Figure 5). The cross-sectional studies on these multilayers are under investigation, and will be reported separately.

In the present investigation the Mo–Si multilayers were heated from room temperature to 750°C. The as-deposited film was found to be quite smooth. Above 400°C, the interfaces start diffusing into one another. We have observed the formation of $Mo_5Si_3$ crystalline phases at 750°C in these samples. The formation of $Mo_5Si_3$ phase was confirmed by high-resolution electron microscopy, selected area diffraction pattern and EDXA.

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# Proteolytic heterotrophic bacteria of cyanobacterial assemblage from Schirmacher oasis, Antarctica, capable of growing under extreme conditions

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**Physiologically diverse groups of bacteria were isolated from cyanobacterial assemblages of Schirmacher oasis Antarctica. Psychrotrophs have been the most dominant, with little population of thermo-tolerant and halo-tolerant bacteria. One-third of the isolates showed pigmentation, which has been temperature-dependent in thermo-tolerant strains. Almost half of the isolates produced extracellular proteases depending on temperature, pH or salt concentration. Isolates also produced other hydrolytic enzymes, e.g. urease, phosphatase, lipase, etc. Two isolates showed multiple antibiotic resistance; however one halo-tolerant has been sensitive to all the antibiotics tested. Isolates preferred different protein and carbohydrate sources for growth, and in most of the cases protease was maximally induced in the presence of glucose/lactose. The effect of temperature and pH on growth, and enzyme production and activity have also been studied.**

PROKARYOTES dominate the Antarctic ecosystems and play a major role in food chains, biogeochemical cycles and mineralization of pollutants. Recent investigations using modern molecular biology techniques as well as classical procedures, have demonstrated that many of the Antarctic microorganisms reported to date, represent new species and broad phylogenetic diversity with representatives from the Archaea and Bacteria domain[1–6]. Despite the extreme climatic conditions that persist in the icy

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