PLASTICITY OF HARD AND BRITTLE MATERIALS AT MICRON-METER SIZE SCALES

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There are many hard materials that are considered to be candidates for structural applications under extreme conditions such as very high temperatures. This stems from the fact that many of them possess peculiar properties such as high hardness, high melting temperature, and so on. But, one of the common characteristics for these hard materials is their brittleness. They usually fail in cleavage without showing any plastic deformation at ambient temperature. So, even, fundamentals for plasticity such as operating slip systems and their CRSS values have yet to be known for many of them. If we assume that fracture in these hard materials occurs in a brittle manner at a pre-existing micro-crack, the effective defect size of the microcrack to cause fracture is believed to vary with the fracture toughness (K_{IC}) at a given fracture stress. If the fracture stress is fixed at 1 GPa, the effective defect size of the micro-crack is calculated to be 320 nm for K_{IC} of 1 $MPam^{-1/2}$, but this value increases to about 8 mm if the K_{IC} values is increased to 5 $MPam^{-1/2}$. Then, there is a chance for these hard materials to plastically deform in the form of micropillars of the micron-meter size even at ambient temperature.
We have investigated the compression deformation behavior of transition-metal silicides as typical examples of hard materials such in the micropillar form with the specimen size ranging from 0.5 to 10 μm at room temperature. Those hard materials include transition-metal (M) silicides of the M_5Si_3-type such as Mo_5Si_3, Nb_5Si_3 and Mo_5SiB_2 and those of the MSi_2-type such as $MoSi_2$, VSi_2, $CrSi_2$, $NbSi_2$ and $TaSi_2$. Although none of them listed above deform plastically at room temperature in the bulk form, plasticity is clearly observed at room temperature for all of them in the micropillar forms. This is very surprising in particular for transition-metal silicides of the M_5Si_3-type, since they usually need more than 1300°C for their plastic deformation to occur in the bulk form. Because of such a high temperature, slip systems have never been identified with confidence for these transition-metal silicides of the M_5Si_3-type. However, plasticity observed in the micropillar form at room temperature has made us to clearly identify their operative slip systems with their CRSS (critical resolved shear stress) values. For transition-metal silicides of the MSi_2-type, slip systems operative at high temperatures in the bulk form are observed also to operate in the micropillar form at room temperature. The room-temperature bulk CRSS values for these slip systems can be obtained by extrapolating the power-law of the CRSS-specimen size dependence to the bulk size, which can be estimated to be 30-50 □m. The room-temperature bulk CRSS values thus estimated are on the extension of the CRSS-temperature curve of the corresponding slip system for some silicides but not for other silicides. The origin of the latter behavior is proved to be due to a transition of deformation mechanisms.