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Laser-shock compression of full density nano-polycrystalline diamond

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The strength of a material is affected by its grain size. This effect is known as grain boundary strengthening (or Hal-Petch effect[1]) and is recognized in many materials at ambient conditions. Since diamond is the hardest material in nature, the grain boundary strengthening effect in nano-polycrystalline diamond (NPD)[2] has been one of the major interests in the field of materials science.

In this study, we used high energy optical lasers to drive a strong shock wave(s) that compress the NPD samples. The Hugoniot (a locus of the shock state) was measured by using Velocity Interferometer Systems for Any Reflector (VISAR) which time-resolves the velocities of the shock waves and/or free-surface motions[3]. The maximum pressure achieved in this study is 1,600 GPa, much higher than the melting pressure of diamond. We found that the Hugoniot elastic limit of NPD is 202 (± 13) GPa, which is more than twice as high as that of single-crystal diamond[4]. The results also show that the Hugoniot of NPD is stiffer than that of single-crystal diamond at pressures below 1,000 GPa, while no significant difference is observed at higher pressures where diamond becomes liquid (Figure 1). The density change accompanied by melting or a phase transition to denser solid phase would be small, as also seen in single-crystal diamond[9].

Our findings confirm that the grain boundary strengthening effect recognized in static compression experiments is also effective against high strain-rate dynamic compressions. This is key to the development of ultrahard materials during and after high strain-rate compression, which could be extended to various applications such as spacecraft shielding, nanoceramics, and inertial confinement fusion targets.

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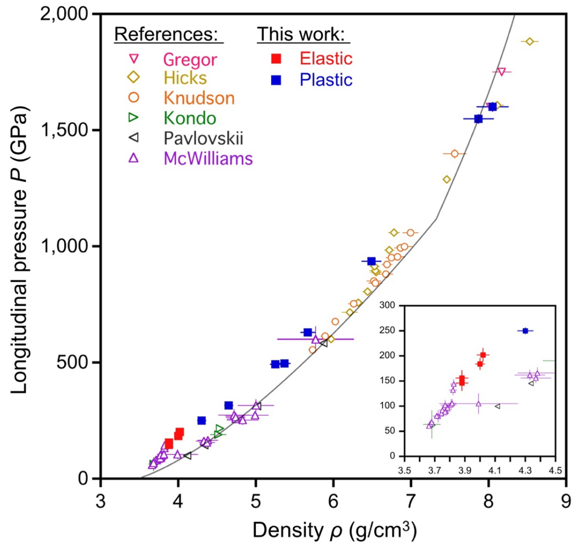

Figure 1. Density versus longitudinal pressure of shocked NPD[5]. Filled squares represent the elastic state (red) and plastic state (blue) obtained in this work. Other symbols are reference data of single-crystal diamond[4,8-10] and polycrystalline diamond[9]. The gray curves are the multiphase EOS of diamond calculated by DFT-MD[11]. Inset shows for more detail.

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