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Shock structures at ultrahigh strain rates: what can they tell us about material behavior on very fast time scales?

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In recent years, techniques based on table-top laser systems have shown promise for investigating dynamic material behavior at high rates of both compressive and tensile strain. Common to these techniques is a laser pulse that is used in some manner to rapidly deliver energy to the sample; while the energy itself is often comparatively very small, the intensity can be made high by tightly focusing the pump light. In this way pressures or stresses can be obtained that are sufficiently large to have relevance to a wide range of basic and applied fields. Also, when combined with established ultrafast diagnostics these experiments provide very high time resolution which is particularly desirable when studying, for example shock waves, in which the time for the material to pass from undisturbed to fully compressed (the "rise time") can be extremely short (order 10 ps or less) even at fairly small peak stresses. Since much of the most interesting physics comes into play during this process it is important to be able to adequately resolve the shock rise. In this context I will discuss our measurements on aluminum and iron thin films and compare the results with known behavior observed at lower strain rates. Specifically, for aluminum, I will compare our assumed steady wave data at strain rates of up to 10^{10} s^{-1} to literature data up to $\sim 10^7$ s^{-1} and show that the well-known fourth power scaling relation of strain rate to shock stress is maintained even at these very high strain rates. For iron, I will show how we have used our nonsteady data (up to $\sim 10^9$ s^{-1}) to infer a number of important properties of the alpha to epsilon polymorphic transition: 1. The transition can occur on the tens of ps time scale at sufficiently high strain rates and corresponding very large deviatoric stresses, and 2, most of the material appears to transform at a substantially higher stress than the nominal value usually inferred from shock wave experiments of about 13 GPa. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344 with Laboratory directed Research and Development funding (12ERD042), as well as being based on work supported as part of the EFree, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award No. DESC0001057.