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EFFECT OF SHOCK WAVES ON THE ABSORPTION SPECTRUM OF RUBY

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ABSTRACT

The effect of shock loading upon the unpolarized absorption spectrum of ruby has been measured. Experiments were performed both above and below the Hugoniot elastic limit (HEL), with the experiment above the elastic limit failing due to extinction of the light upon impact. The experiments below the elastic limit were both done at about the same pressure (~100 kbar) and show a shift of both absorption bands in the visible region toward shorter wavelength, the shifts agreeing well with those measured at a comparable hydrostatic pressure. The magnitudes of the shifts below the HEL complement shifts recently measured by Goto et al.[1]

INTRODUCTION

Absorption spectrum measurements on minerals under pressure can provide information on the compressed crystal structure, and so are of geophysical interest. Measurements of changes in the absorption spectrum of single crystals of various kinds have been performed by several workers[1-6] using both static and shock compression techniques.

The spectral properties of ruby have been studied extensively as a result of laser applications. The chromium doping results in ruby having two strong absorption bands in the visible range, one at 400 nm (25000 cm^{-1}), and one at 550 nm (18000 cm^{-1}), making it an excellent choice for experiments using a spectrometer tuned to the visible light region. The band at 400 nm corresponds to the electronic transitions $^4A_2 \rightarrow {}^4T_1$ and the 550 nm band to the $^4A_2 \rightarrow {}^4T_2$ transitions. In addition to the experimental information available there have also been very complete theoretical studies of the spectrum of Ruby[7-8].

EXPERIMENTAL TECHNIQUES

The experimental arrangement was that shown in Fig. 1. The crystallographic C-axis of the ruby sample was oriented at 60° with respect to the impact surface.

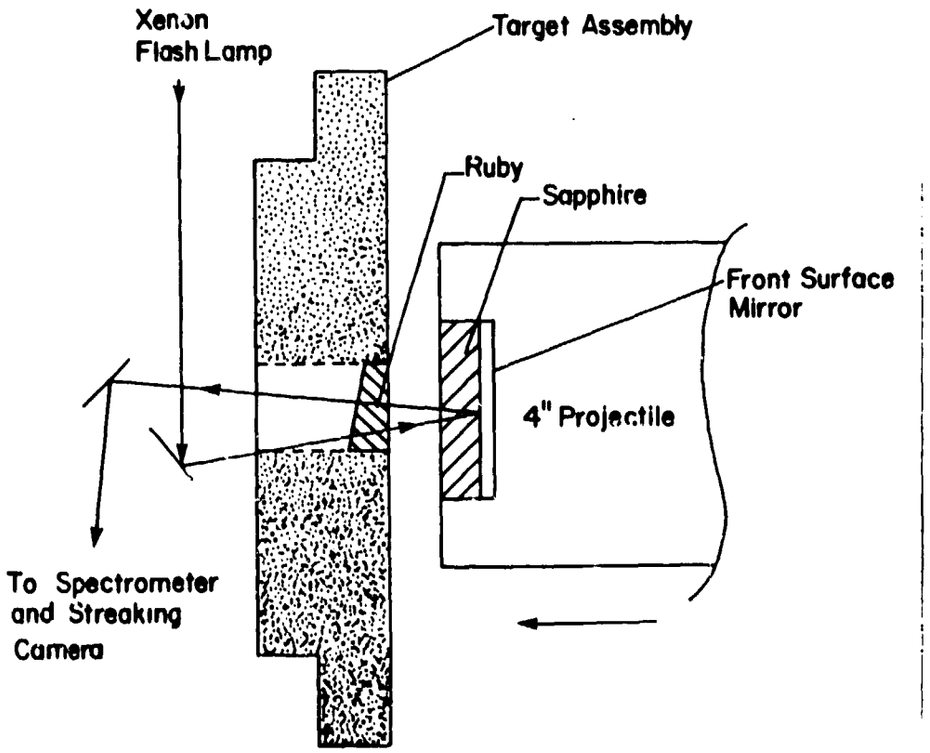

Figure 1. Experimental details.

A 10.2-cm-diameter aluminum projectile was accelerated by means of a light gas gun to velocities between 0.5 and 1.0 km/sec. A sapphire (Al_2O_3) plate backed by a front surface mirror was embedded in the front of the projectile, the sapphire positioned to strike the ruby (0.05% chromium doped) target producing a symmetric impact. The Hugoniot data of Graham and Brooks[9] was used to find the pressure corresponding to the known particle velocity in the ruby sample.

A coaxial pin in the target was shorted by the projectile impact triggering a xenon flashlamp and the oscilloscopes used to monitor a photomultiplier tube on the streaking camera. The light from the flashlamp was focused onto the target assembly, the reflection from the beveled first surface of the ruby sample being sent off axis so as not to add to background light on the film. The light then passed through the ruby and sapphire, was reflected by the mirror, and directed onto the entrance slit of a diffraction grating spectrometer with grating blazed to 500 nm. The spectrum produced by the spectrometer was directed onto the rotating mirror of a streaking camera (Beckman & Whitely 330) and projected onto Kodak #2475 spectrographic film, thus producing a

time resolved spectrum. A photograph of the spectrum for a 104 kbar experiment is shown in figure 2.

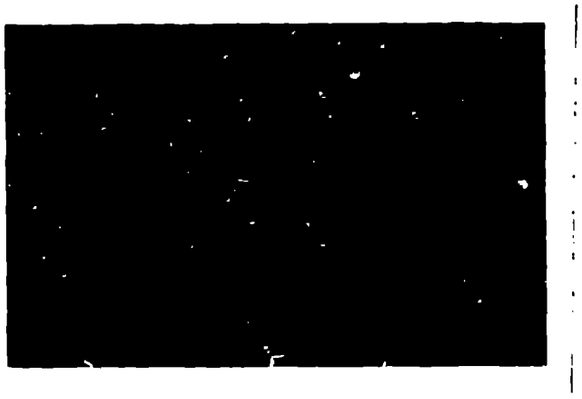

Figure 2. Time resolved absorption spectrum of ruby under shock loading. The xenon emission lines occur at the start of the streak, and the absorption shifts under compression can clearly be seen.

The film is sensitive to wavelengths of between 300 nm and 700 nm, and the maximum writing rate of the camera is 9 km/sec. The writing rate in figure 2 is about 7.2 km/sec.

EXPERIMENTAL RESULTS

The results of the three experiments are shown in Table I.

Table I Results of Ruby Experiments

Shot	P(kbar)	U_p(km/sec)	$\Delta\lambda$(550 nm)	$\Delta\lambda$(400 nm)
80-014	200	.512	--	--
80-015	104	.234	181±10	70±10
80-016	98	.227	--	--

Shot 80-016 was performed with an electronic streaking camera, with a wavelength window of approx. 120 nm, and was tuned to follow the $^4A_2 \rightarrow {}^4T_2$ transition. The results from the experiment using the electronic camera were unsatisfactory.

The data from shot 80-015 were digitized and stored on magnetic tape. A fixed-time densitometric scan of these data in the unshocked region is shown in figure 3, and the two absorption bands can clearly be seen.

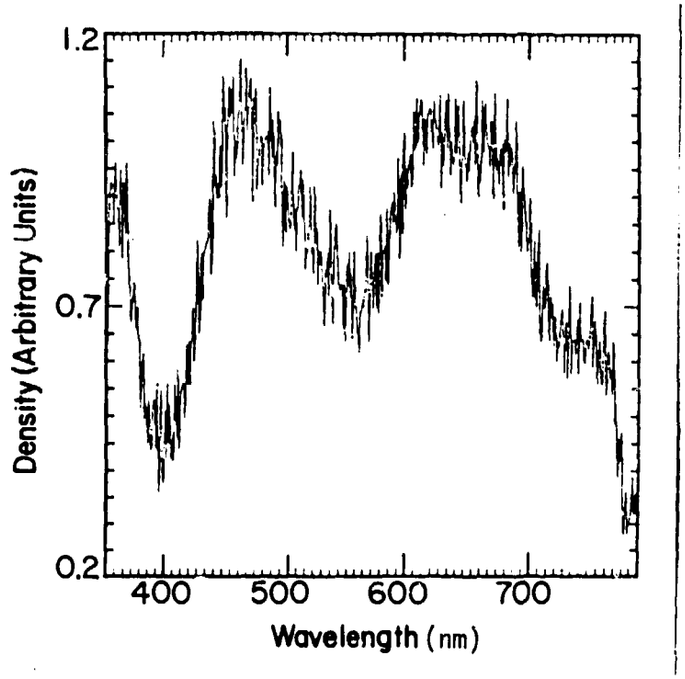

Figure 3. Absorption spectrum of ruby at 1 atm. at fixed time.

The digital information is contained within a matrix of 512 x 512 "pixels"; i.e. with a total of about a quarter of a million points. A wavelength calibration is achieved by looking at the xenon emission lines at the start of the streak, and noting the pixel location at which they occur.

DISCUSSION

In addition to the ruby shot performed above the elastic limit, one was also done using a sapphire plate as a target. Both of these shots showed similar behavior upon impact; the light was no longer able to pass through the target/impactor combination. This behavior may be related to the phenomenon of plastic yielding, and so possibly due to the stress deviator collapse seen previously in sapphire[9] and the mechanism of heterogeneous melting. Grady[10] has recently discussed a possible mechanism in which a brittle solid may lose bulk shear strength due to a heterogeneous yielding process and the formation of shear bands. Further evidence that this loss of light intensity is due to plastic yielding is provided by the experiment below the elastic limit in which no noticeable loss of intensity upon impact is seen.

The crystal field parameter 10Dq, and the Racah parameter B can be calculated from the results of shot 80-015, and the results compare well with the shifts observed by Stephens and

Drickamer[3] at an equivalent hydrostatic pressure. These parameters are calculated from the equations of Tanabe and Sugano:[7]

(1) $E(^4A_2 \rightarrow {}^4T_2) = 10\ Dq \equiv \Delta$

(2) $E(^4A_2 \rightarrow {}^4T_1) = 3\Delta/2 + 15B/2 - 1/2[(\Delta - 9B)^2 + 144B^2]^{1/2}$,

from the absorption band energy shifts. The results of this calculation are $\Delta = 18625\ cm^{-1}$, and $B = 665\ cm^{-1}$.

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