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TITLE: ATTEMPTS TO CHARACTERIZE MICROBALLOON SENSORS FOR SHOCK VELOCITY AND MATERIAL MOTION STUDIES

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# Attempts to characterize microballoon sensors for shock velocity and material motion studies

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## Abstract

Optimization of performance of gas filled microballoons mounted on optical fibers as sensors for shock and material motion studies, was attempted by variation of several parameters. In some cases, results were not predictable and, in general, results were not as reproducible as desired. Change of some parameters caused little effect but effects of the sleeve size and sleeve material seem to be significant. Recorded shape of optical spectra match black-body temperature of 8000°K when argon filled balloons were impacted with projectiles with velocity of 1 km/s, in close agreement with expected values based on ideal gas calculations.

## I. Introduction

Gas filled microballoons coupled to optical fibers have been developed and used previously[1] as sensors for shocks or moving surfaces. We have made additional investigation in order to utilize this technique in various applications where potential advantages appear to exist. These include the precise location of shock interactions and the inobtrusive nature because of its small size and immunity from electromagnetic effects. We are working to extend these applications to locations in high magnetic fields by eliminating all metal in the sensor and to locations in high dose ionizing radiation by incorporating radiation resistant optical fiber.

In the course of such testing, we find that results are sometimes unpredictable and nonreproducible. We have tried to optimize results by empirical investigation of a number of parameters in the hope that we might find a parameter that would control the reproducibility. The work to date is far from complete and conclusions are tentative, at best, because tests are destructive by nature, results vary greatly and a large number of parameters may be pertinent.

## II. Parameters Considered

Generally, we have used microballoons of glass, filled with 5 atmospheres of Argon.[2] Computations[3] indicate that Xenon would produce more light but is more difficult to produce. Glass balloons were chosen because of the belief that shelf life is greater for glass than for plastic balloons.

The elements in the assembly that we have used, appear in Fig. 1; associated parameters are the microballoon wall thickness, fiber diameter, sleeve material, sleeve diameter, cap material, and coupling material. Results also depend on the pressure of gas in the microballon and our confidence of satisfactory gas fill is quite high. The manufacturing controls appear reliable and destructive tests of balloons for pressure determination should be a valid test. In addition, local experiments are underway to allow inspection of filled balloons both by x-ray fluorescence and by soft x-ray transmission measurements.

Another parameter affecting performance in our tests is the velocity of the material impacting the balloon. We are confident of the bullet velocity commonly used on the basis of careful loading of propellant and velocity measurements of typical bullets.

## III. Experimental Systems

Generally, we fired bullets at the microballoon from a variety of sources: high pressure air, air rifle, 22 caliber rifle, and 30-06 rifle. We have succeeded in recording signals from microballoons only from the 30-06 bullets to date and further discussion will be restricted to that condition.

We mounted the 30-06 on a rigid assembly that also held the mount for the microballoon $\sim .6$ m away. The projectile consists of 4.27 g steel at velocity of 1.0 km/s, or by increasing the loaded charge, reaching velocity of 3.0 km/s. Bullets are flat on the end and strike the balloon/fiber assembly head-on in a direction parallel to the fiber axis.

In some cases we rigidly attach the microballoon assembly to wooden blocks by epoxy and hold this in a vise. Normally, however, the assembly is simply taped to a wooden block.

Fibers attached to the microballoon are normally 100 $\mu$m core/140 $\mu$m cladding, graded index doped fiber about 3 m long. Transmission to recording system was either a 35 m jumper or, in some cases, 1 km graded fiber (Corning ISDF-100/140) cabled by Andrews to Department of Energy specification DOE-NV-FO-5. Conversion to electrical signals was by photomultiplier (S20 response) for low velocity tests and for the 30-06 tests was a Si detector (EG&G FOD-100) with a transimpedance preamplifier, CLC-100, and CLC-102 wide-band video amplifier, known as a LOAM receiver. Nominal sensitivity of this unit is $\sim$ 40 mV/$\mu$watt. Response of the silicon photodiode peaks $\sim$ 900 nm and frequency response is 175 MHz. Oscilloscope recording was with Tektronix 485. Triggering was generally accomplished following the receiver with EGG TL-100.

For some tests, the bullet was replaced with high explosive driven Al plates. This standard configuration provided plate velocity of 2.95 km/s.

For some 30-06 tests, we added optical multichannel analyzer (OMA) as in Fig. 3. Normally, a spectrometer grating of 150 grooves/mm was used providing 2.0 nm resolution over the range of 450 to 850 nm. Wavelength calibration was obtained primarily from Kr light source. Amplitude calibration over the wavelength interval recorded was based on standard photometric technique using EGG Gamma Scientific spectrometer-radiometer and calibrated light sources. Such calibration included the fiber jumpers and coupler used in the system (see Fig. 3).

## IV. Experimental Results

Generally, we recorded time history of the optical signals both in high-time resolution for the first pulse and in low-time resolution to record signals over a period of several microseconds presumably due to fiber breakage.

Amplitudes are reported here in units of volts on the signal line from the LOAM receiver/amplifier after adjusting for attenuation of the optical coupler and ND filter, if present. Calibration of the various ND filters used has not been accomplished and this introduces significant errors in the reported amplitudes since the neutral density filters (Wratten) are far from neutral.

Another difficulty in the system is that of tracking receiver gain, optical connectors and fiber transmission, and alignment factors. Generally, one connection, leading to the microballoon, cannot be inspected by our present technique.

Although we feel confident about relative amplitude values within a series, we are less certain between series, because of the difficulties expressed above.

## A. Pulse Shape

Generally, the 30-06 tests gave clean first pulse signals from microballoons with width (FWHM) ~ 22 ns for the nominal bullet velocity (1 km/s) and 12 ns for the high velocity (3 km/s). A typical pulse is illustrated in Fig. 4. However, pulse widths vary perhaps a factor of 2 and sometime have structure (see Fig. 4).

A typical record over 2 μs is indicated in Fig. 5 along with a typical record without a microballoon. In the latter case, the shape and amplitude variations are large, perhaps a factor of 10.

Pulse width recorded through the 1 km fiber is typically 40 ns being broadened by dispersion over the long distance.

Results from several series of tests are described briefly as follows:

### Series I
### (Glass vs. Plastic Microballoon)

We recorded 10 signals in 12 attempts using 30-06 bullets (standard charge). We cannot attribute the two failures, necessarily, to the microballon. Fiber length was 1 km. Argon/glass microballons gave average peak of 50 V; Argon/plastic (with 15 atm) microballons gave average peak of 9 V; fiber alone, gave 2 V. We concluded good reliability of the microballons and that glass may be better to use than plastic for this case.

## Series II

## (Argon/Glass Microballoon on HE Tests)

We fired 4 HE tests incorporating a total of 9 microballoons, 6 of which gave reasonable signals (one HE test failed to provide optical trigger). Fiber length was 1 km. Amplitude range of signals was 60 to 150 V. Signals from background channels having no microballon gave peaks larger than 3 V but were off scale. We concluded that tests with HE were satisfactory and that the higher amplitude than 30-06 tests might be due to higher plate velocity.

## Series III

## (Argon/Glass Microballoons with 30-06)

In this series, the microballoon assembly had a glass sleeve, in order to eliminate the metal previously used, and the microballoon was mounted on the fiber that projected out beyond the glass sleeve about 1 mm. Fiber length was 30 m. Amplitudes of peaks from 3 tests were 0.6, 3, and 7 V. Cases for no microballoons gave 1.2 and 5.5 V. The lower amplitude was surprising but we were hesitant to blame the geometry of the glass sleeve.

## Series IV

## (Metal vs. Glass Sleeve)

Microballoon tests gave average peak of 8.2 V with range of 3.5 to 16 V, while no balloon cases gave average of 2.8 V. One test had metal sleeves, two had glass sleeves (one of which had balloon on fiber projecting out past the end of the glass sleeve). We began to be concerned about low amplitude signals.

## Series V

## (Large Fiber Diameter)

We fired 3 tests with 30-06 having fiber core of 200 μm instead of the normal 100 μm. Sleeves were glass, but was absent altogether for one test. Amplitudes were 12, 12 and 22 V, while no balloon cases gave 7.5 V.

We concluded that large fiber diameter gave no enormous improvement factor. Note that the increase in fiber size was not performed as a geometrical effect since the fiber components in the system remained at 100 μm.

## Series VI

### (Shell Thickness, Microballoon Batch, Sleeve Size)

In a total of 16 balloon tests, all gave recorded signals. Differences between two batches of argon-filled microballoon production were not apparent. In some tests, wall thickness was measured by KMS Fusion either thin (2.9 to 3.4 µm) or thick (6.3 to 8.7 µm). Differences in peak amplitude were not discernable.

The effect of the sleeve seemed significant. For 8 tests, stainless steel sleeve was 737 µm OD, 89 µm wall thickness giving peak of 84 to 255 V. For 4 tests the metal sleeve was 330 µm OD, 76 µm wall, and 4 tests had this sleeve plus an outer sleeve 635 µm OD, 114 µm wall that also contained a foil cap. Half of these 8 tests gave signals that looked like fiber only cases and 4 gave amplitude average of 27 V. One peak for fiber alone was 7.3 V.

We concluded that the single, large diameter steel sleeve gave significant improvement over the cases having smaller diameter sleeve.

## Series VII

### (Sleeve Cap, Bullet Velocity Variation)

In 26 tests we altered several parameters. Averaging several results, the peak amplitude was higher by 2.4 for the high velocity bullets (3 km/s) than for the standard velocity (1 km/s).

Additional results are tabulated in Table I.

Table I

Average Peak Voltage for Various Cases

| | | Volts |
|---|---|---|
| Steel sleeve 727 µm OD | 559 µm ID | 13.3 |
| " " " " | with radiation | |
| " " " " | hardened fiber | 10 |
| Glass Sleeve 1067 µm OD | 787 µm ID | 22.5 |
| " " 356 µm OD | 178 µm ID | 64 - ommitting 2 failures |

We also tested variation of the cap in the form of aluminum foil, polymer, or none at all. No obvious differences were apparent but results were inconclusive being too sparse in number.

We concluded that the small diameter glass sleeve may give significantly better results than the large glass sleeve but were further puzzled by the apparent low peak for the steel sleeve cases which had given much higher values in the previous series.

## V. Comparison of Series

We have attempted to compare results of these series for cases believed to be comparable in spite of the potential pitfalls in making such comparison as we have stated previously. In Table II we compare results for steel sleeve cases (737 μm OD) and glass sleeve cases (1067 μm OD, 787 μm ID). Peak values for high velocity bullets have been divided by 2.4 in the attempt to make them comparable to the low velocity bullet cases.

Table II

Average Peak Values, Volts from LOAM

| | Metal Sleeve | | Glass Sleeve | |
|---|---|---|---|---|
| Series | Volts | # of Cases | Volts | # of Cases |
| I | 50 | 4 | | |
| II | 88 | 3 | | |
| III | | | 3.5* | 3 |
| IV | 5. | 1 | 3.5*<br>16 | 1<br>1 |
| V | | | 17. | 2 |
| VI | 93 | 4 | | |
| VII | 7 | 10 | 15 | 2 |

*Microballoon on fiber 1 mm out of cylinder.

Naturally, we were concerned about the inconsistency illustrated in Table II for the steel sleeve cases, but we were encouraged by the consistency in the glass sleeve cases, in spite of poor statistics.

## VI. Spectral Results

We have obtained a spectrum of light from the microballoon for a few cases. In general, we gated the signal during 100 ns and the trigger effectively occurred at 13 ± 5 ns after the start of the gate.

Background count rate was measured frequently and was found nearly constant. This consists of switch noise in the microchannel plate trigger circuit and was independent of gate duration unless increased to greater than 10 ms.

Figure 6 illustrates a typical signal. Background signals were nearly constant with wavelength at a value about 31 counts/channel, or about 14% of the peak count rate in Fig. 6. This background was averaged and subtracted, giving rise to the spectrum appearing in Fig. 6.

The small amplitude peaks in Fig. 6 are not thought to be significant since similar structure is contained in the spectrum from a filament light source (see Fig. 7) having similar count rate as the spectrum in Fig. 6. We believe these are associated with ion feedback in the microchannel plate which we had operated at maximum gain in order to preserve sensitivity. We thus find no evidence of peaks in the spectrum that might be attributable to line emission.

The points in Fig. 6 result from computing the spectrum from $1.5 \cdot 10^4$ deg K black body and correcting for measured response of the system. These points are arbitrarily normalized to observed data in order to compare shapes. Projectile velocity for this case was 3 km/s.

All spectra recorded appear either quite similar to that in Fig. 6 or that in Fig. 8, containing a characteristic dip. We found that the dip appeared at different values on various tests (582, 597 nm and 614 nm).

We also attempted to record a spectrum of light created by a bullet but not in the microballoon. We delayed the 10 $\mu$s gate to the OMA by 150 ns to permit integration in the time domain illustrated in Fig. 9, thereby omitting the initial balloon pulse. While we cannot assert that this delayed signal is created in the fiber, we suspect that this is the case since late signals having similar shapes and amplitudes are obtained in cases having fiber but no microballoon.

The recorded spectrum for this possible fiber breakage appears in Fig. 10. It is narrower than that from the argon filled microballoon but is otherwise similar. The peak occurs at 670 nm.

We hope to build on the facts obtained and eventually offer explanation for the spectral shapes recorded, especially the dip illustrated in Fig. 9. At this time we can only conjecture that the dip may represent an absorption band but we have no explanation and the effect may be instrumental. This absorption is presumed to be produced as a result of shocks introduced by the bullet since it is not observed for the system components transmitting white light, nor is it observed in all tests.

We are unable to explain these puzzles in terms of absorption of the optical coupling material (see Fig. 1) between the balloon and the fiber. Such material (epoxy) shows no absorption bands in data supplied by KMS Fusion. It seems unlikely that this organic material absorbs in certain bands as it is heated by the shock interactions since the temperatures produced by shocks or absorption of light from the microballoon are thought to be low.

Assuming a black-body radiation source, one recorded spectrum with peak at 650 nm matches that of a black-body temperature of 8000°K, for projectile velocity of 1 km/s (the spectrum is normalized in order to compare shape). This may be a credible value since calculated estimates of ideal gas temperature in plane wave geometry for comparable velocity, as used in our experiments, is $\sim 10^4$ degrees K.[3]

We have weak evidence that the peak amplitude from a microballoon test varies inversely as the wavelength of the maximum in the recorded spectrum. These wavelength values change from 610 to 660 nm as peak amplitude drops a factor of 10. This implies that the lower peaks observed are due to lower gas temperature rather than to some absorption or geometrical attenuation factor.

## VII. Conclusions

We have found that signals recorded from microballoon sensors of material motion are not always reproducible. Further testing is required to determine if this is due to problems in our instrumentation but we suspect variation due to some parameter not yet controlled.

Investigation of effects on performance of several parameters have been conducted but generally with just a few tests and, therefore, with poor statistics. No effect has been noticed by the following:

1. altering the microballoon wall thickness;
2. altering the fiber size;
3. altering cap material;
4. altering the microballon source batch.

Significant effects appear to have been observed:

1. Mounting the microballoon outside the end of the cylinder reduces the signal.

2. Increasing the metal sleeve diameter from 330 μm OD, 178 μm ID, to 737 μm OD, 559 μm ID, may increase the signal.

3. Decreasing the glass sleeve diameter from 1067 μm to 356 μm OD, 178 μm ID may increase the signal.

4. Increasing the projectile velocity gives increased signal amplitude in direct proportion and correspondingly narrower signal width.

5. Light from fiber breakage may have narrower spectrum than argon/glass microballoons but the two spectra are similar.

6. The emitted light spectrum may shift to lower wavelength for higher recorded amplitude.

7. Recorded optical spectrum implies gas temperature around 0.8 and $1.5 \cdot 10^4$ deg K in separate tests in reasonable agreement with expectations.

## VIII. Future Directions

Clearly, tests of effects of the optical coupling material are required and are intended. A standardized control of our recording system sensitivity should be found. Computational treatment of shocks in various geometries as we have used, have commenced. Studies of amplitude at successively lower velocity will be scheduled to provide more definitive dependence law of signal on velocity. We also hope to document gas temperature from the recorded spectrum for a wider range of velocities. In view of the unexpected effects of sleeve material and size, confirmation is required.

As we find ways to produce signals from microballoons with lower velocity projectiles, radiation damage studies will commence.

## IX. Acknowledgement

We have benefitted from discussions with Robert Benjamin, Morris Klein, Joe Fritz, Stanley Marsh, and Robert Kelly, at Los Alamos National Laboratory. We are also grateful for full cooperation from Don Musinski and Diana Schroen at KMS Fusion in supplying specially fabricated microballoon units.

## X. References

1. R. F. Benjamin, F. J. Mayer, and R. L. Maynard, SPIE Vol. 506, Fiber Optics in Adverse Environments II (1984).
2. Microballons are produced and mounted on fiber by KMS Fusion, Ann Arbor, MI 48106.
3. Joe Fritz, Los Alamos National Laboratory, private communication, April 1986; F. J. Mayer, KMS Fusion, Inc., Internal Memorandum FJM-146, Dec., 1983.

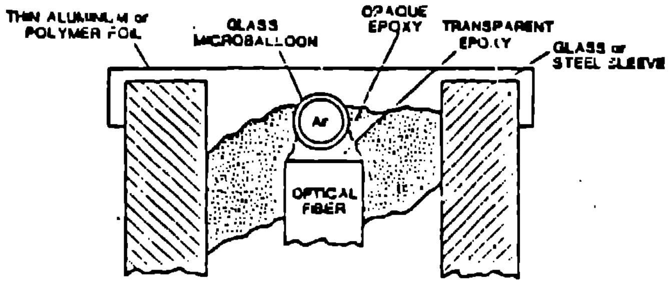

Fig. 1. General features of microballoon assembly.

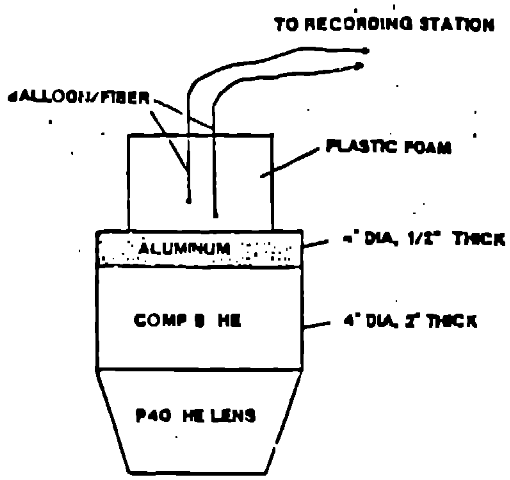

Fig. 2. High explosive (HE) driven aluminum plate geometry.

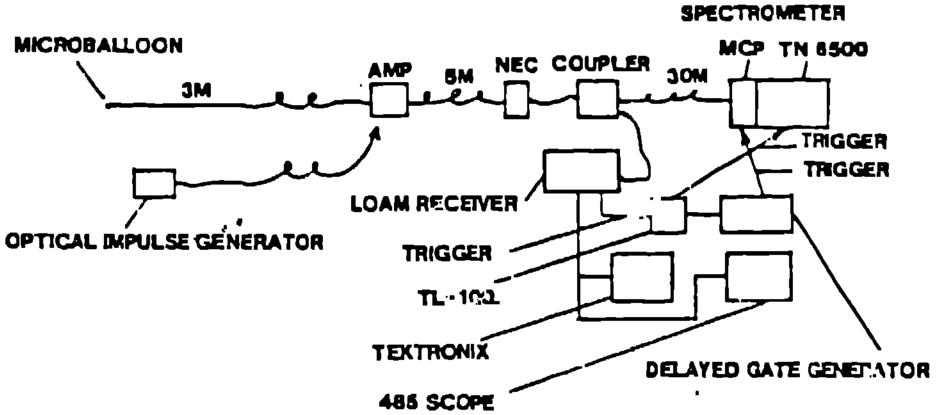

Fig. 3. Block diagram for recording optical spectra from microballoon tests.

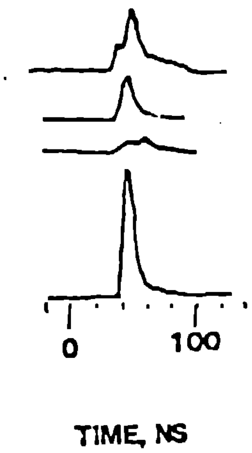

Fig. 4. Typical recorded signals from several microballoon tests.

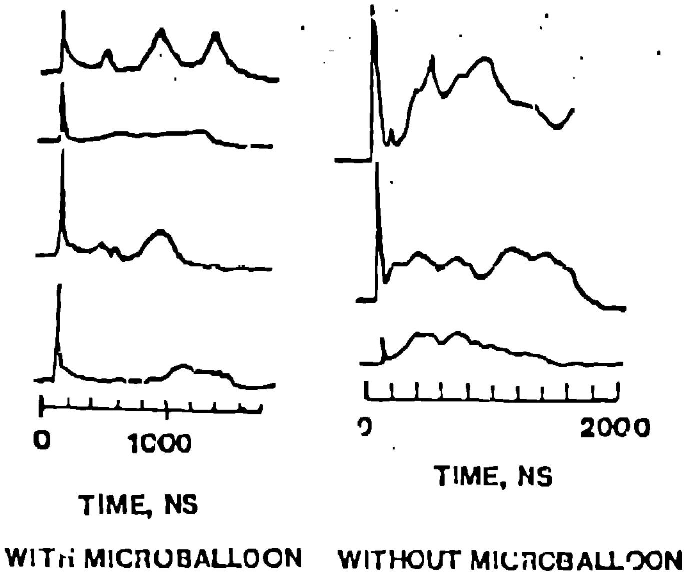

Fig. 5. Typical signals recorded over several microsecond time scale from tests with and without microballoon.

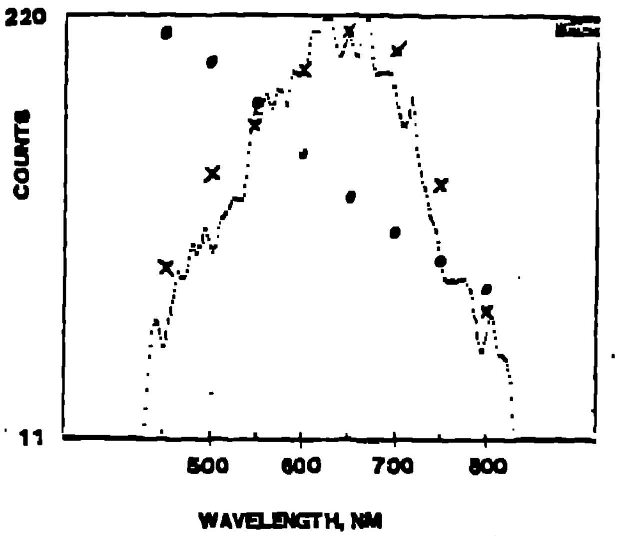

Fig. 6. Recorded spectrum from microballoon test integrated over 100 ns, after background subtraction and smoothing. Small amplitude pulses are due to instrumental effects. Symbol O represents calculated black-body spectrum for 8000°K and symbol X represent this spectrum after including correction for our experimental system.

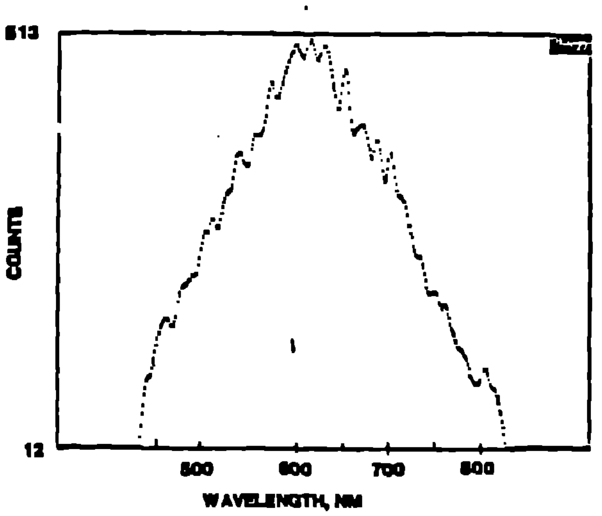

Fig. 7.

Recorded spectrum from incandescent, white, light source, after smoothing. Spectrum is not corrected for system response.

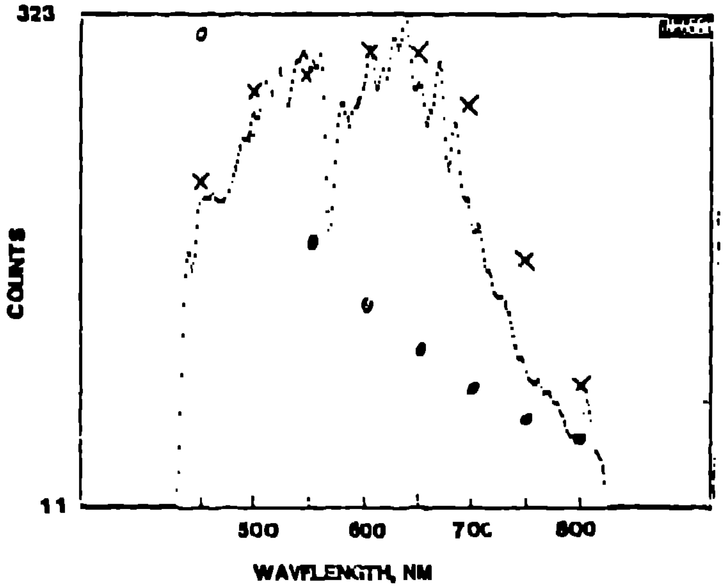

Fig. 8. Recorded spectrum from microballoon test after background subtraction and smoothing. Symbol O represent black-body spectrum at 1.5·10⁴°K and symbol X represents this spectrum after correction for our system response to enable comparison to observations.

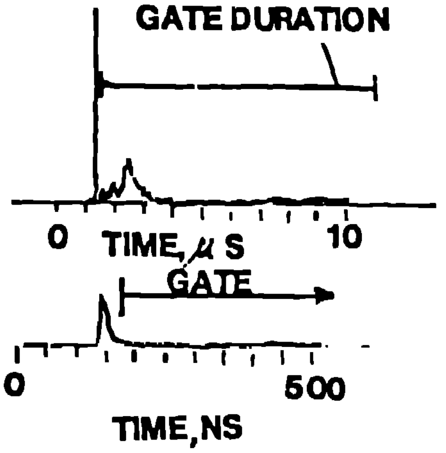

Fig. 9.

Relation of spectrometer gate to recorded signals from microballoon test. In this case the gate was 10 μs.

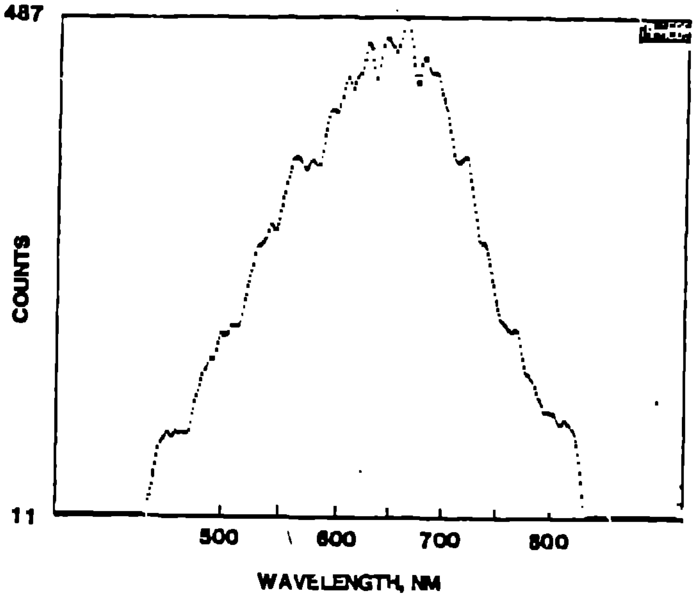

Fig. 10. Recorded spectrum from microballoon test. Gate was delayed 150 ns to eliminate the initial pulse from the microballoon. Spectrum is not corrected for system response.