**Measuring Triboluminescence Generated By Meso-Velocity Impacts.** W. A. Hollerman[1], C. A. Malespin[1], R. S. Fontenot[1], and P. J. Wasilewski[2], [1]Department of Physics, University of Louisiana at Lafayette, P.O. Box 44210, Lafayette, LA 70503, hollerman@louisiana.edu, [2]Astrochemistry Branch, Code 691, NASA Goddard Space Flight Center, Greenbelt, MD 20771, Peter.J.Wasilewski@nasa.gov.

**Background:** The generalized process of "cold light" emission is called luminescence. It refers to the absorption of energy by a material with the subsequent emission of photons. It is a phenomenon different from blackbody radiation, incandescence, or other such effects. For many luminescent materials, reduction in light intensity from the cessation of excitation is a simple decaying exponential [1,2]. The time needed to reduce the light intensity to $e^{-1}$ (36.8%) of its original value is defined as the fluorescence decay time.

The fluorescence decay time is unique to each material. It might be possible to use the fluorescence decay time as an indicator to gauge the production of TL from impacts. For this reason, it was decided to use the decay time as the figure of merit in our attempt to detect TL from lab-generated impacts. This phenomenon has been previously been measured for low velocity (1-10 m/s) and hypervelocity (>1 km/s) impacts using zinc sulfide doped with manganese (ZnS:Mn) as the active ingredient [1, 2].

**Triboluminescence:** Triboluminescence (TL) is light generated by mechanical action. The term comes from the Greek *tribein*, meaning "to rub," and the Latin prefix *lumen*, meaning "light". A good history and review of TL research can be found in Walton [3]. Since then, much work has been done to characterize materials, mechanisms, and possible applications of TL. Of particular interest is the work of Chandra and Zink [4] and Sweeting [5] on TL characterization and mechanisms. Recently, Sage et al. [6] and Xu et al. [7] completed research on the use of TL as a stress and damage sensor.

Triboluminescent light is a specific form of mechanoluminescence which is the production of cold light from any type of mechanical action or stress. A classic example of TL light is found in the crystals used for wintergreen flavored Lifesavers® [5]. The green/blue sparks seen when chewing the candy is TL light being emitted from the crystal breakage in the sucrose.

When excited, ZnS:Mn emits bright yellow light with a broad emission peak centered at 585 nm and a full width at half maximum (FWHM) of 65 nm. ZnS:Mn is strongly triboluminescent with a prompt fluorescence decay time of about 300 μs [8]. Since the decay time is unique to the material, it should be easier to observe and separate TL from other light sources, such as the impact flash.

**Objectives:** The objective for this research is to measure the production of TL looking on the front side of "meso-velocity" (100 m/s to 1 km/s) impacts. This research is intended to serve as a first stage for measuring a frontal meso-velocity impact on phosphor doped lunar regolith using TL emission.

**Experiment:** From June 2006 to August 2007, research was completed using the one-stage light gas gun located at the NASA Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. This gun fires projectiles to speeds of a maximum of 1 km/s. During this research, 4.7 mm diameter glass projectiles hit aluminum plates coated with "simulated regolith" and ZnS:Mn powder. Projectiles at meso-velocities mimic impacts caused by secondary debris produced when meteoroids hit the Moon [9].

*Sample description.* A two-part epoxy was applied to an aluminum plate and a combination of ZnS:Mn and simulant powders were sprinkled on top. The powder was then poured liberally to cover the entire area and was rolled and "smoothed" with a copper pipe (similar to rolling dough) to lightly press the powder to the epoxy. Samples were allowed to sit for 20 minutes before being moved. Most of the remaining powder was knocked off so that only a thin surface layer stuck to each plate. On several sample plates, JSC-1 simulant powder was added to the ZnS:Mn powder to mimic lunar regolith.

*Light detection system.* Two identical photodiodes were mounted to a sample table as light collecting instruments. A large piece of quartz was placed in front of the sensor inside a rubber cone to be used as protection from debris. The first detector was placed below the sample looking up at the impact area, while the second detector was mounted directly above the impact zone looking down on it. Signal cables ran to a pair of large dynamic range amplifiers to increase signal amplitude. Data was recorded using a four channel oscilloscope in single trigger mode.

**Results:** A total of twenty-four shots were completed at GSFC using glass projectiles hitting an aluminum plate coated with epoxy binder, thirteen using ZnS:Mn alone and ten using ZnS:Mn mixed with the JSC-1 regolith simulant.

*Epoxy and ZnS:Mn samples.* Seven shots were used to obtain an average fluorescence decay time as shown in Table 1. New plates were used in the gun before shots 2, 6, and 23.

Table 1. Measured decay times for ZnS:Mn powder on an epoxy binder hit with a glass projectile.

| Shot | Projectile Speed (m/s) | Measured Decay Time (μs) |
|---|---|---|
| 2 | 377 | 690 |
| 4 | 370 | 199 |
| 6 | 387 | 436 |
| 9 | 394 | 270 |
| 11 | 419 | 161 |
| 23 | 403 | 442 |
| 24 | 408 | 389 |
| Average | 394 ± 17 | 370 ± 68 |

The first run each on a plate produced an unusually long decay time, which is thought to be due to the fact that it had the most phosphor on the plate to be activated. This effect is likely caused by the TL light "shimmering", which is a period of time where excited phosphor grains are producing light, while light from other grains is decaying. In fact, TL shimmering was also observed in 45 caliber ACP projectiles at similar projectile speeds [10]. In this research, completed in the summer of 2007, several grains of ZnS:Mn powder was embedded in the tip of the ammunition and sealed with epoxy. A large cloud of bright yellow fluorescence was observed when each phosphor-augmented projectile hit an aluminum target [10]. The shimmering light appeared to last up to several seconds after each impact [10]. It appears that TL shimmering could lengthen the TL decay time for ZnS:Mn.

On a given epoxy plate hit by a glass projectile, the average decay time decreased as a function of shot number. After many shots, most of the ZnS:Mn powder was removed from each plate and the resulting decay time would approach like what was measured for plain epoxy (~100 μs). The average decay time for an epoxy coating struck with glass projectiles was measured to be 370 ± 68 μs, which is consistent with earlier TL ZnS:Mn results. Therefore, TL was likely produced in these impacts.

*Epoxy, ZnS:Mn, and JSC-1 samples.* The results for the ZnS:Mn and epoxy mixed with the JSC-1 regolith simulant produced results as shown in Table 2. This data shows that shot twelve had a longer decay time than shot 19 where there was more ZnS:Mn and regolith coating simulant present. After several impacts, the decay times are seen to decrease as previously discussed. The average decay time for an epoxy and regolith coating struck with glass projectiles was measured to be 284 ± 99 μs, which is totally consistent with earlier TL ZnS:Mn results. Therefore, TL was likely produced in these impacts.

Table 2. Measured decay times for ZnS:Mn and JSC-1 powders on an epoxy binder hit with a glass projectile.

| Shot | Projectile Speed (m/s) | Measured Decay Time (μs) |
|---|---|---|
| 12 | 430 | 383 |
| 19 | 415 | 185 |
| Average | 423 ± 8 | 284 ± 99 |

The results of this research indicate that TL light can be produced during meso-velocity impacts of about 400 m/s. However, it is sometimes difficult to separate TL from the other light sources, such as debris impact, sparks, or flashes caused by thermal effects or phase changes. TL is sometimes not intense enough to overcome the other time dependent sources. These other sources can cause the decay times to be much different depending on the combinations of projectile, materials used, and concentration of TL phosphor.

Since this work was intended to be a first experiment, it shows the direction of future research. Improvements in equipment sensitivity and filtering would greatly reduce the noise and highlight the sources producing the light seen. Improvements were made throughout the experiment to correct possible sources of outside light. The shots that produced the most consistent TL results were the epoxy-covered plates. This research used several different binder methods and projectiles to try and minimize the production of non-TL light in order to isolate the activation of ZnS:Mn.

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