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# OPTICALLY STIMULATED LUMINESCENCE OF METEORITE

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***Abstract:*** Optically stimulated luminescence (OSL) measurements were performed on several meteorites and terrestrial plagioclase, pyroxene and olivine to test the possibility of OSL characterization of meteorites. Intense OSL has been observed for the first time in Ca-Al rich inclusions (CAIs) of the Allende meteorite. The equivalent dose of 150 Gy was obtained from the growth of OSL intensity by artificial $\gamma$-irradiation.

## 1. Introduction

Lattice defects produced by natural radiation have accumulated over geological time. The cumulative defects whose concentration is proportional to the radiation dose or to the age can be detected by electron spin resonance (ESR) (IKEYA, 1993) and thermoluminescence (TL) (AITKEN, 1985). Optically stimulated luminescence (OSL) can also be used to determine the concentration of radiation-induced defects (AITKEN, 1985; IKEYA, 1993). Historically, luminescence dating using a nitrogen laser was proposed for cave deposits ($CaCO_3$) (UGUMORI and IKEYA, 1980) based on the principle of radiation effects used in TL dating. The method has been successfully applied to dating of quartz and feldspar in sediments, taking advantage of the sunlight-bleaching effects (HUNTLEY *et al.*, 1985). The light sensitive defects can be detected, and complement the TL characteristic of minerals.

Meteorites have been the object of ESR (YAMANAKA *et al.*, 1993) and TL studies (GUIMON and SEARS, 1986; NINAGAWA *et al.*, 1983; SEARS, 1988). Attempts to date the time of meteorite fall and characterization of meteorites have been reported. However, no OSL work has been done on meteorites so far as we know in spite of the fact that OSL could be a useful method to determine the terrestrial age and characterize meteorites just as TL and ESR. The age since minerals had last been exposed to sunlight might be obtained by detecting light sensitive defects just as in OSL dating of terrestrial sediments. Defects sensitive to a particular wavelength are detected by OSL, which may lead to mineral characterization including impurities.

The OSL method has several advantages in comparison with ESR and TL. OSL emission can be observed under the presence of iron ions which disturb ESR detection of radical signals due to their broad spectrum. A small amount of sample, about 10 mg in weight, is sufficient. In contrast to TL, which requires heating, a sample is not altered thermally by the OSL measurement during exposure to laser light at room temperature.

We report the successful observation of OSL for the first time for Ca-Al rich inclusions (CAIs), matrix of Allende meteorite, several other meteorites and terrestrial minerals. The equivalent dose was obtained using OSL.

## 2. Samples and Experimental Method

A beam from a commercial He-Ne laser (Japan laser, JLH-1PS-B, 1 mW) is used as the excitation light for the OSL as shown in Fig. 1. The laser light ($\lambda$=633 nm) passes an optical filter (R-60) to cut the unnecessary light from a plasma discharge tube and has been enlarged to ~10 mm$\phi$ by a beam-expander. The exposure light is uniformly illuminated on the powdered sample spreading on the aluminum holder. The beam intensity incident on the sample was estimated to be 0.3 mWcm$^{-2}$ using a photodiode detector. Other optical filters (V-40 and V-42) are used to cut the scattering light into the photomultiplier (Hamamatsu Photonics, R878). The photon counting method is used to detect the luminescence. Only 340–500 nm light can be detected with this system. The OSL emission spectrum is measured by a monochromator. Typically only 10 mg of sample is enough for OSL measurements. TL can also be measured by heating the sample holder at the heating rate of 5°C/s.

The CAIs (coarse-grained) and the matrix portion of the Allende meteorite were separated manually in a dark room. Chips of Lake Labyrinth (Olivine-hypersthene chondrite, amphoterite: LL6) and Holbrook (Olivine-hypersthene chondrite: L6) were also powdered in the dark room. Additionally, terrestrial minerals such as oligoclase (Tvedestrand, Norway), labradorite (near Nain, Labrador, Canada), bytownite (Crystal Bay, Minnesota, U.S.A.), anorthite (Yoichi, Hokkaido, Japan), olivine (San Carlos, Gila Co., Arizona, U.S.A.) and enstatite (Hyderabad, Andhra Pradesh state, India) were prepared. The meteorites and terrestrial minerals were irradiated by $\gamma$-rays from the source of $^{60}$Co up to 2000 Gy to calibrate the OSL intensity to radiation dose.

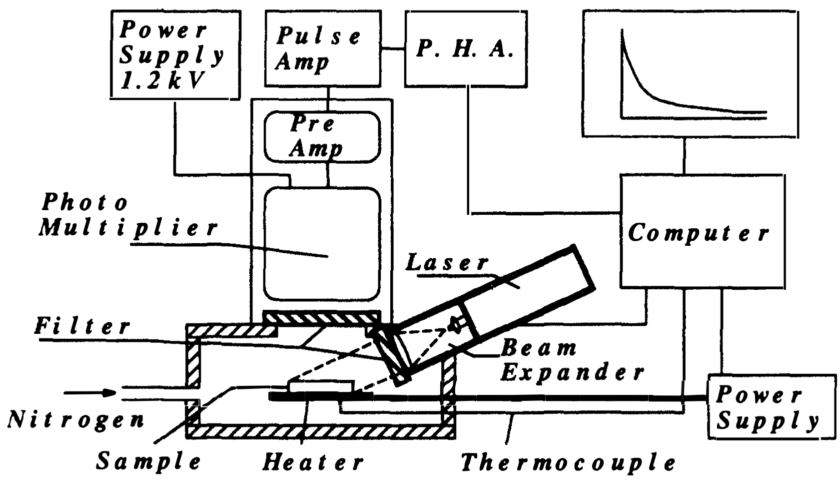


*Fig. 1. A home-made apparatus used for optically stimulated luminescence (OSL) and thermoluminescence (TL).*

## 3. Result and Discussion

Figure 2a shows the intensity of OSL for the CAIs (coarse-grained) in Allende as a function of the exposure time to laser light. OSL intensity decayed to half of initial value in $7\times10^2$ s and to a quarter of it in $2\times10^3$ s. The inverse intensity of OSL to time is shown in Fig. 2b. The OSL continued for more than 24 hours. A portion of the same CAIs exposed to sunlight for one hour did not show any OSL. We have also examined the dependence of OSL on the excitation power by dispersing the light with diffusers. The initial OSL intensity is proportional to the amount of stimulating light, and the total amount of OSL is independent of the power of the laser.

The OSL intensity decays hyperbolically. This suggests that the defects responsible for OSL recombine neither by first-order kinetics nor second-order kinetics: The OSL intensity should decay with a simple exponential function for first-order kinetics, and a quadratic function, $I=\alpha/(1+\beta t)^2$ in second-order kinetics. A hyperbolic decay model has been reported in a TL experiment at low temperature (MIKI and IKEYA, 1982). In this model, an electron center moves gradually to a hole center, repeating the diffusion process of trapping and detrapping as shown schematically in Fig. 3. The recombination process of the defects responsible for OSL in CAIs would involve such a diffusion process.

The OSL intensity after $\gamma$-irradiation is proportional to the radiation dose shown in Fig. 4. No OSL intensity was detected for the Allende matrix even after $\gamma$-irradiation up to 400 Gy. In OSL dating, the intensity is measured before and after artificial irradiation to assess the sensitivity to the radiation dose. The accumulated dose of natural radiation is deduced assuming the linear-growth relationship between the intensity and the additive irradiation dose. The OSL intensity observed in CAIs before $\gamma$-irradiation corresponds to a dose of as much as 150 Gy.

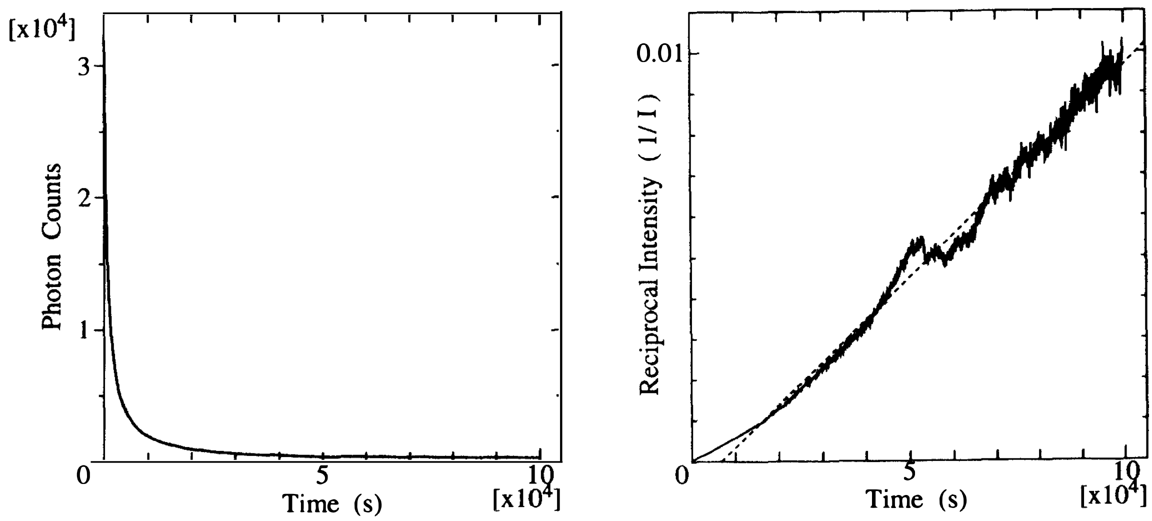


*Fig. 2. (a) Intensity of OSL as a function of the exposure time to the laser light. (b) The reciprocal OSL intensity as a function of the time.*

Natural TL was studied for meteorites for which orbital elements have been estimated (BENOIT *et al.*, 1991). The equivalent dose obtained by TL in the work was also around 300 Gy close to the present result. The equivalent dose of OSL might be related to the TL results, presumably due to thermal annealing in the orbit.

No OSL intensity was observed in Lake Labyrinth and Holbrook. The OSL intensity depends on the ratio of albite to anorthite in terrestrial plagioclase. No OSL was observed in anorthite but OSL intensity increased drastically as the ratio of albite content increases. The reason for no OSL observation in those meteorites may be that

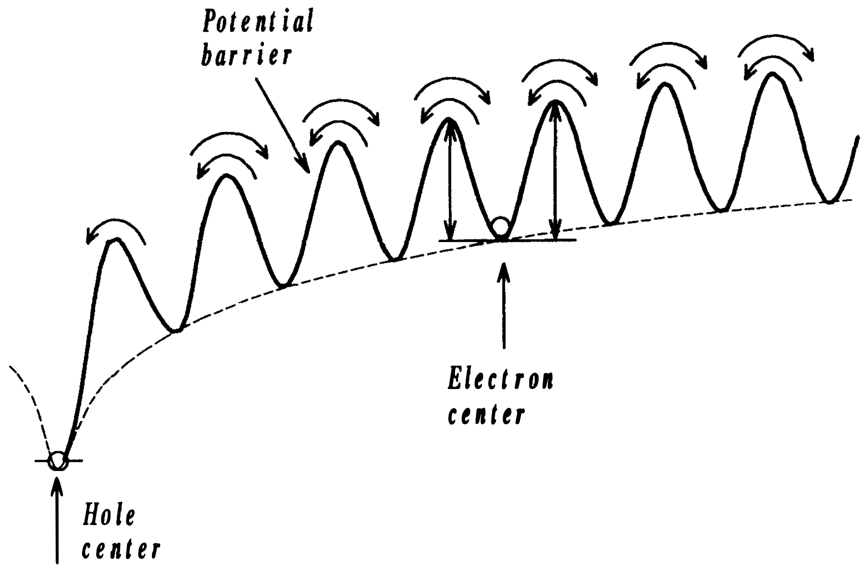


*Fig. 3. Schematic drawing of the potential barrier against the migration of an electron center in the vicinity of hole center. The trapping and detrapping of an electron in this model leads to the 1/t relation. The interaction between the electron center and the hole center is influenced by the deformed potential barrier.*

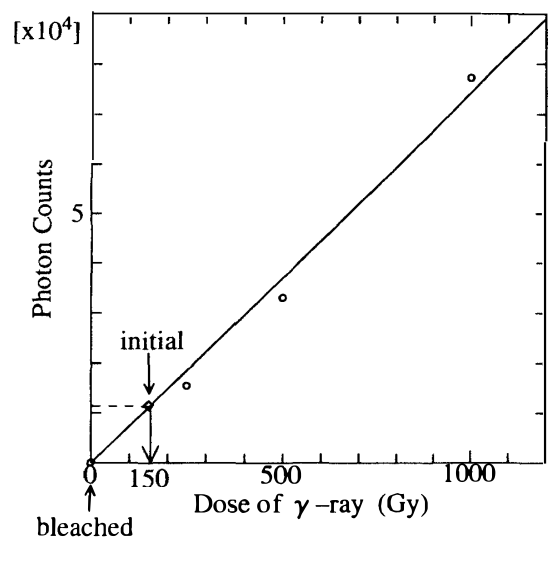


*Fig. 4. Growth of OSL intensity from Allende by γ-irradiation as a function of the radiation dose.*

the amount of albitic plagioclase in those meteorites is much too small for the OSL to be detected using present apparatus. OSL was detected neither in terrestrial olivine nor pyroxene, even after irradiation of 2000 Gy.

The OSL emission spectrum for CAIs showed a band at 380–400 nm. The OSL spectrum for oligoclase consists of broad bands (peak <340 nm and 400 nm). The observed OSL from CAIs may come not from plagioclase but from melilite, which is abundant in most CAIs and is known as a TL phosphor (GUIMON and SEARS, 1986).

TL glow curves for CAIs and for the matrix are shown in Fig. 5. The TL intensity of the matrix was three orders of magnitude less than that of CAIs above 100°C. It showed double peaks at 240°C and 310°C. The similar TL curve has been reported previously and ascribed to melilite (GUIMON and SEARS, 1986). An extensive work using TL and OSL for Allende is in progress; the results will be published separately.

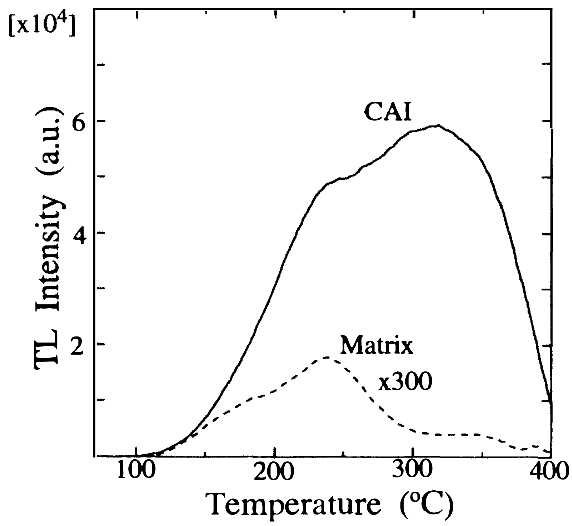


*Fig. 5. Thermoluminescence (TL) glow curves of CAIs and the matrix of the Allende meteorite. Note that the TL intensity for the matrix is multiplied by a factor of 300.*

## 4. Summary

The following observations were made from the preliminary results of the first OSL study of meteorites:

1) OSL has been observed in CAIs of the Allende meteorite. The OSL intensity observed in CAIs before $\gamma$-irradiation corresponds to a dose of as much as 150 Gy.

2) OSL was not observed in Lake Labyrinth (LL6) and Holbrook (L6) even after irradiation of 2000 Gy. Presumably, the amount of albitic plagioclase in those meteorites is much too small for the OSL to be detected using the present apparatus.

3) In terrestrial plagioclase, no OSL was observed in anorthite. The OSL intensity increased drastically as the ratio of albite content increased. The OSL emission spectrum for CAIs differed from that for oligoclase. No OSL was detected in terrestrial olivine or enstatite. Hence, OSL might be a method to complement the

characterization of meteorites with additional data.

4) The recombination process of the defect responsible for OSL in CAIs is tentatively ascribed to the diffusion process of trapping and detrapping from the OSL decay curve.

More systematic and extensive studies are required for characterization of meteorites using light sensitive defects with OSL to complement the TL characterization. This paper announces the first successful observation of OSL as a first step for further studies.

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