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LiF:Mg,Cu,P GLOW CURVE SHAPE DEPENDENCE ON HEATING RATE

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The glow curve shape of LiF:Mg,Cu,P (MCP) material is studied in this research. The study is focused on the effects of the heating rate on the dosimetric peaks. Different configurations of dosemeters (chips, cards and powder) are studied. The shifting of the dominant dosimetric peak is observed and analysed. The curves are deconvoluted using the new Harshaw Glow Curve Analyser (GCA) program. Results of the study are presented, as well as possible explanations as to the observed effects.

INTRODUCTION

In recent years, various studies on the dosimetric characteristics of the thermoluminescence material LiF:Mg,Cu,P (MCP) have been carried out in the international community, and great efforts have been made to improve its dosimetric performance. This material has proven to be an advanced thermoluminescence dosemeter (TLD) for personal, environmental and medical dosimetry[(1–3)].

The ability of TLD to generate glow curves provides a significant advantage as compared with other dosimetry techniques, such as OSL or RPL. The glow curve is very useful for quality control and quality assurance purposes[(4)]. The glow curve shape is used as the signature of a specific thermoluminescence material. Additionally, the unique shape of a radiation-induced glow curve provides an indication that the TL signal is indeed induced by radiation and is not spurious. By analysing the glow curve, it is possible to identify a contaminated or damaged dosemeter or a malfunctioning reader. In some cases, this identification process can be made automatically in real-time. Furthermore, the glow curve can be used to identify additional information, such as the heating rate.

Ben-Shachar *et al.*[(5)] studied the glow curve heating rate as a function of thermoluminescence in LiF:Mg,Ti. However, to the best of our knowledge there is no report on LiF:Mg,Cu,P of the glow curve shape as a function of the heating rate. The present study is intended to learn the effect of the glow curve heating rate on the dosimetric peaks in different detector formats for LiF:Mg,Cu,P.

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MATERIALS AND METHODS

Three format types of LiF:Mg,Cu,P material are used:

(1) Type A is the Harshaw TLD-700H (7 LiF:Mg, Cu,P) pelletised chip with a size of Φ3.6 mm × 0.38 mm.
(2) Type B is the Harshaw TLD card with the Type A chip mounted between two Teflon sheets.
(3) Type C is the Harshaw DXT-707 (7 LiF:Mg, Cu,P) ringlet with 7 mg cm^{-2} layer of powder mounted on Kapton.

The readout is performed on two Harshaw TLD readers, the Model 3500 and the Model 8800. The Model 3500, a planchet reader, is used for the Type A format. The Model 8800, a hot-gas linear heat reader, is used for Type B and Type C formats.

Two radiation sources are used. One radiation source is a ^{137}Cs source (J.L. Sheperd Model 70 Irradiator) for Type A bare chip exposure. The other radiation source is a ^{90}Sr/^{90}Y source (Model 8800 Reader Built-in Irradiator) for Types B and C (card and ringlet) exposure.

The dose levels are 10 mGy for Types A and C, and 5 mGy for Type B. Reader annealing is performed by two reading cycles. To observe the whole glow curve, no pre-heat procedure is used and the readout starts at 50°C. The maximum temperature is set to 240°C for chips and 260°C for cards throughout the entire study. The only variable is the glow curve heating rate. The rate starts at 1°C s^{-1}. initially, then increases incrementally to 30°C s^{-1}. The readout time is adjusted accordingly to ensure that the readout is completed.

GLOW CURVE ANALYSIS

The glow curve analysis (GCA) method used in this study is a Harshaw TLD program[(6)] in which each peak is approximated from first order TL kinetics expressed by Podgorsak *et al.*[7] as:

$$I_i = I_{mi} \exp\left\{1 + \left[\frac{E_i}{k}\left(\frac{1}{T_{mi}} - \frac{1}{T}\right)\right] - \exp\left[\frac{E_i}{k}\left(\frac{1}{T_{mi}} - \frac{1}{T}\right)\right]\right\}, \quad (1)$$

where I_i is the peak intensity of peak i, I_{mi} is the height of peak i, T_{mi} is the peak temperature of peak i, E_i is the activation energy of peak i and k is the Boltzmann's constant.

In general, a TL measurement is the integral of the total light emission during the heating process over a region of interest. It normally consists of the following elements:

- The photomultiplier dark noise background, which is temperature independent;
- The low temperature peaks, which are unstable peaks;
- The stable dosimetric peaks and infrared emission, which are temperature dependent.

A glow curve usually has several peaks at different temperatures and each peak has a different thermal stability. By using glow curve analysis to identify the individual peaks and their contribution, it is possible to discriminate the unstable peaks and use the stable peak(s) for dosimetry. For LiF:Mg,Cu,P, the dosimetric peaks are Peak 3, with a peak temperature of 155–160°C, and dominant Peak 4, with a peak temperature of 204–215°C.

The low temperature peaks are Peak 1 and Peak 2, both with peak temperatures <110°C. Additional higher temperature peaks can be observed, which are ~20°C higher than the main peak (Peak 4). However, they have been reported to have an insignificant dosimetric contribution.

To obtain the dosimetric information, the glow curve is first smoothed using the Savitzky-Golay filtering method. Then a constant noise background and the non-dosimetric signal are subtracted. The non-dosimetric signal is the infrared signal. This higher temperature peak signal can be separated from the main peak using the modified gaussian fit method[8]. The entire glow curve is then fitted by four individual peaks, 1–4, using the first order kinetic method mentioned above. In this method, the points (that are 50–80% of the peak value) on the higher temperature side of the main peak are first fitted by modified gaussian:

$$Y = Y_0 + I_{m4} e^{-0.5|(T - T_{m4})/b|c}, \quad (2)$$

where Y_0 is a constant offset, I_{m4} is the height of Peak 4, T_{m4} is the peak temperature of Peak 4, b is the FWHM, c is the power between 1.5 and 2.5.

The difference between unfitted and fitted is the non-dosimetric signal (see Figure 1, curve Δ).

RESULTS AND DISCUSSION

To make the comparison easier, it is assumed that the main peak (Peak 4) temperature remains the same. Everything is related to this temperature,

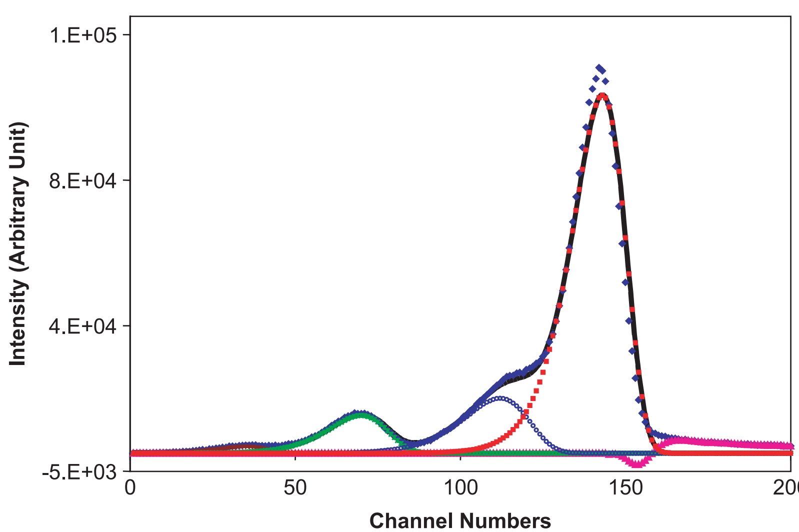

Figure 1. Glow curve from LiF:Mg,Cu,P following 10 mGy of ^{137}Cs gamma irradiation at room temperature and readout at 15°C s^{-1}. The glow curve has been separated into its non-dosimetric component (curve Δ) and its dosimetric component (Black curve) and analysed into the individual Peaks 1–4, using the first-order TL kinetic approximation.

which is obtained when the heating rate 1°C s^{-1} is used on the planchet reader Model 3500. For all three detector types, it is observed that when the heating rate increases the hypothetical peak temperatures[6] of Peaks 1–3 shift to higher temperatures as compared with Peak 4 (Tables 1 and 2). Note that the readout time–temperature profile consists mostly of a linear heating portion and a short temperature plateau portion. This closely represents the real dosemeter temperature. However, to use the Equation 1 in the study, it is assumed that the temperature is linear in the whole readout region. This temperature is referred to as hypothetical temperature.

Table 1. Peak temperatures (°C) for different detector types at the glow curve readout with a heating rate of 1°C s^{-1}.

Detector type	Peak 4	Peak 3	Peak 2	Peak 1
Bare chip	204	155	108	68
Teflon card	215	161	110	68
Kapton bounded powder	215	160	109	67

Table 2. Peak temperatures shifting upward in °C from 1 to 30°C s^{-1} heating rate, for different detector types.

Detector type	Peak 3	Peak 2	Peak 1
Bare chip	20	22	27
Teflon card	22	32	36
Kapton bounded powder	15	17	18

A temperature differential is noticed between Type A and Type B and C measurements on Peak 4. This is caused by the two different reader types being used. In the Model 3500, the dosemeter is in intimate contact with a planchet. A thermocouple is welded to the bottom of the planchet, just below the dosemeter. At low heating rates, the dosemeter temperature is essentially the temperature of the planchet and thermocouple. In the Model 8800, the dosemeter is suspended in air, just above a hot nitrogen gas heater jet. A thermocouple is located at the exhaust port of the jet. There is about a 0.5 cm (3/16'') air gap between the thermocouple and the encapsulation material just below the TLD element. Owing to this air gap and the encapsulation material, there is a temperature differential between the thermocouple and the actual TLD element temperature.

As the glow curve heating rate increases from 1 to 30°C s^{-1}, it is observed that:

For bare chip

(1) The hypothetical peak temperatures of Peaks 1, 2 and 3, shift ~20°C upwards.
(2) For the dosimetric Peaks 3 + 4, the peak integral remains almost unchanged at 90% of the

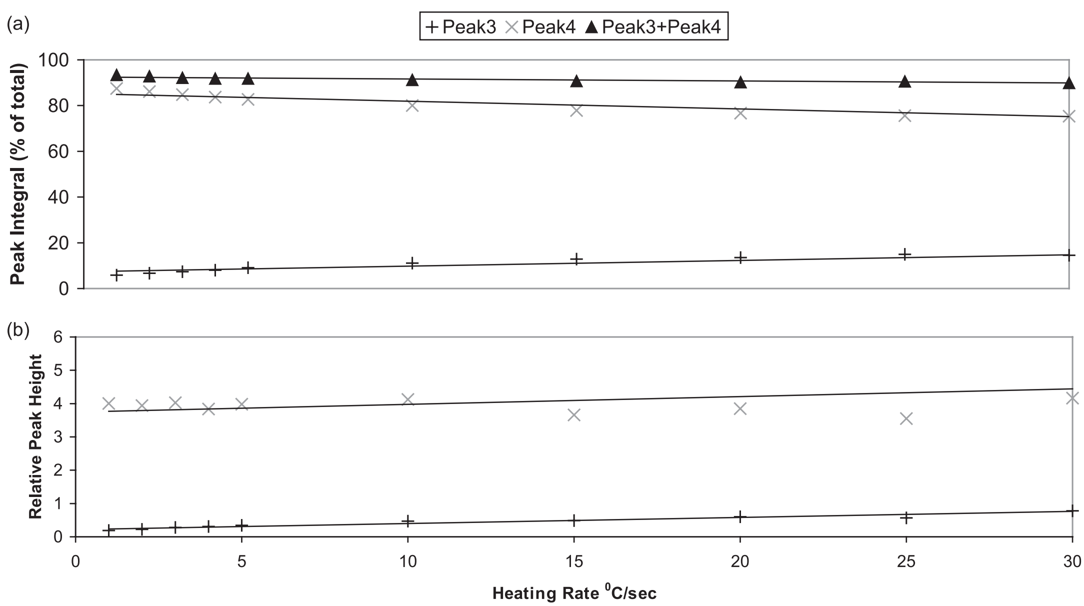

Figure 2. LiF:Mg,Cu,P bare chip (3.6 mm × 0.38 mm). (a) The percentage to the total TL integral of Peak 3, Peak 4 and Peaks 3 + 4. (b) The relative peak heights for Peak 3 and Peak 4 as a function to the glow curve heating rate. Based on the data, the total integral contribution of Peaks 3 + 4 remain constant throughout the entire heating rate range of 1–30°C s^{-1}.

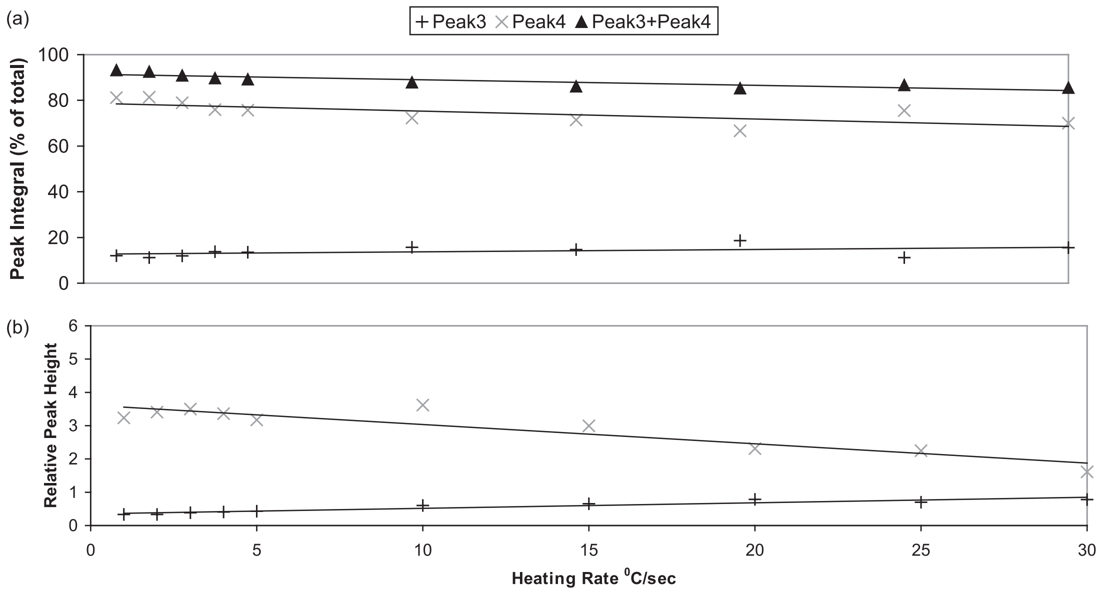

Figure 3. Harshaw LiF:Mg,Cu,P card (3.6 mm × 0.38 mm chip sandwiched between two Teflon sheets). (a) The percentage to the total TL integral of Peak 3, Peak 4 and Peak 3 + 4. (b) The relative peak heights for Peak 3 and Peak 4 as a function of the glow curve heating rate.

total glow curve integral. The Peak 3 integral increases from 6 to 16% of the total and the Peak 4 integral decreases from 87 to 73% of the total (see Figure 2a).

(3) The relative peak height for Peak 3 increases ~4–5 times and it remains unchanged for Peak 4 (see Figure 2b).

For Teflon card

(1) The hypothetical peak temperatures of Peaks 1, 2 and 3, shift 20°C ~ 30°C upwards.

(2) For the dosimetric Peaks 3 + 4, the peak integral decreases slightly from 93 to 86% of the total glow curve integral. The Peak 3 integral increases slightly from 12 to 16% of the total and the Peak 4 integral decreases from 81 to 70% of the total (see Figure 3a).

(3) The relative peak height for Peak 3 is doubled and it decreases by a half for Peak 4 (see Figure 3b).

For powder bonded to Kapton

(1) The hypothetical peak temperatures of Peaks 1, 2 and 3, shift ~15°C upwards.

(2) For the dosimetric Peaks 3 + 4, the peak integral remains at 90% of the total glow curve integral. The Peak 3 integral increases from 5 to 11% of the total and the Peak 4 integral decreases from 88 to 77% of the total (see Figure 4a).

(3) The relative peak height for Peak 3 is doubled and it increases slightly for Peak 4 (see Figure 4b).

CONCLUSION

As heating rate increases, the dosimetric Peak 3 moves upward to merge into the dosimetric dominant main Peak 4 (see Figures 5–7), and Peaks 3 + 4 remain almost unchanged at 90% of the total integral. Hence, the dose response is independent of the glow curve heating rate. If the readout starts at a temperature >110°C, the short-lived low-temperature Peaks, 1 and 2, will be eliminated.

A similar phenomenon is seen in Ben-Shachar's work for LiF:Mg,Ti[(5)]. For the detector in the card format, Peaks 3 and 4 can still be seen clearly as compared with the other two types. This may be owing to the increasing width of Peak 3 and the decreasing width of Peak 4. However, the widths are kept unchanged in the bare chip and powder bonded to Kapton cases. A probable cause may be that when in card format, the LiF:Mg,Cu,P chip is sandwiched between the Teflon sheets, causing the heat to be distributed differently. Based on the data shown in Figure 2, the total integral contribution of Peaks 3 and 4 remain constant throughout the entire heating rate range of 1–30°C s^{-1}.

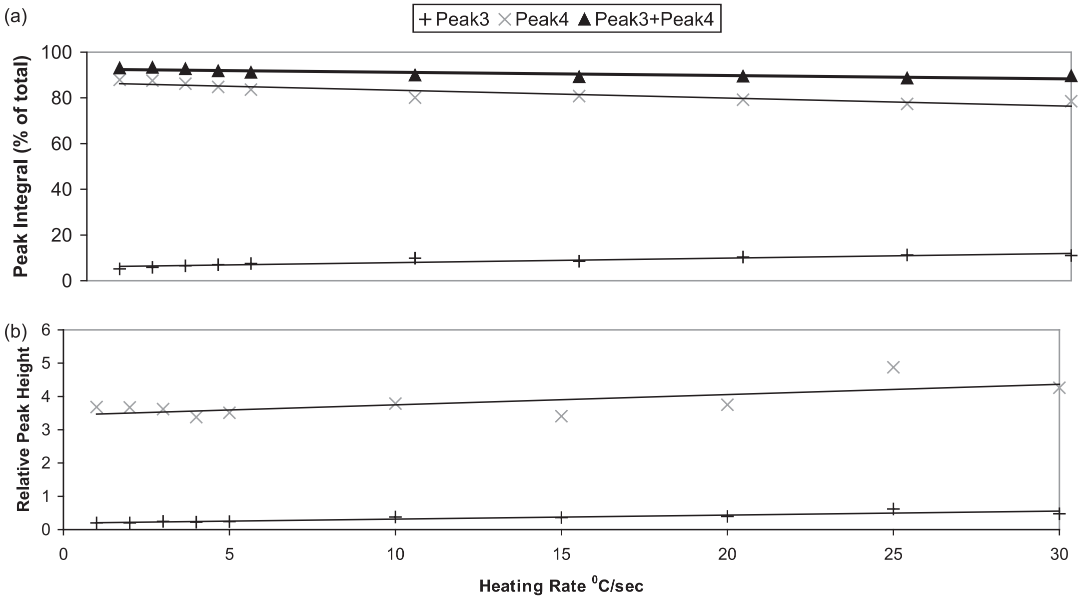

Figure 4. Kapton bonded LiF:Mg,Cu,P powder (7 mg cm^{-2}). (a) The percentage to the total TL integral of Peak 3, Peak 4 and Peak 3 + 4. (b) The relative peak heights for Peak 3 and Peak 4 as a function of the glow curve heating rate.

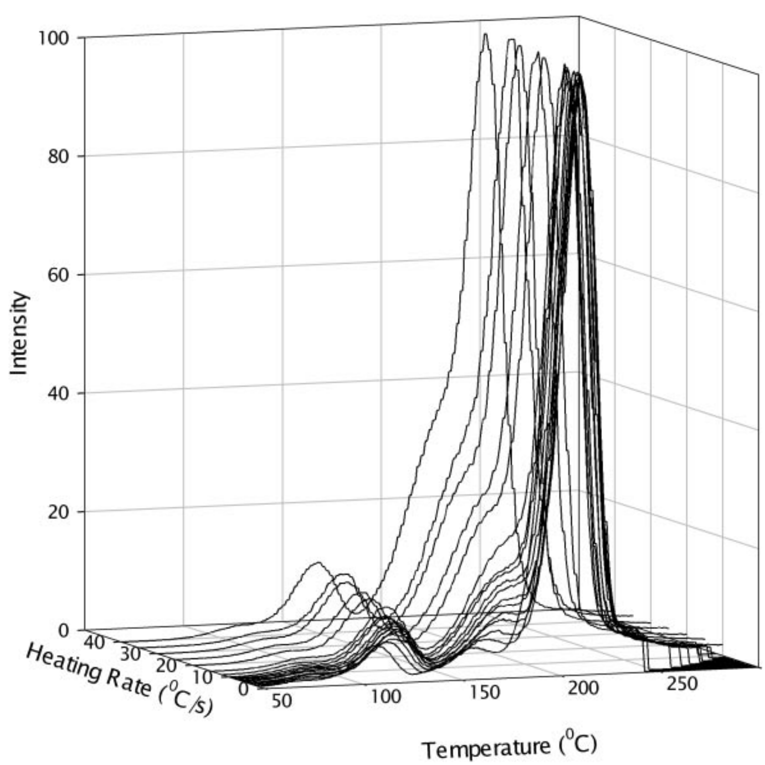

Figure 5. Glow curves for Harshaw TLD LiF:Mg,Cu,P bare chip (3.6 mm × 0.38 mm) as a function of the heating rate and temperature.

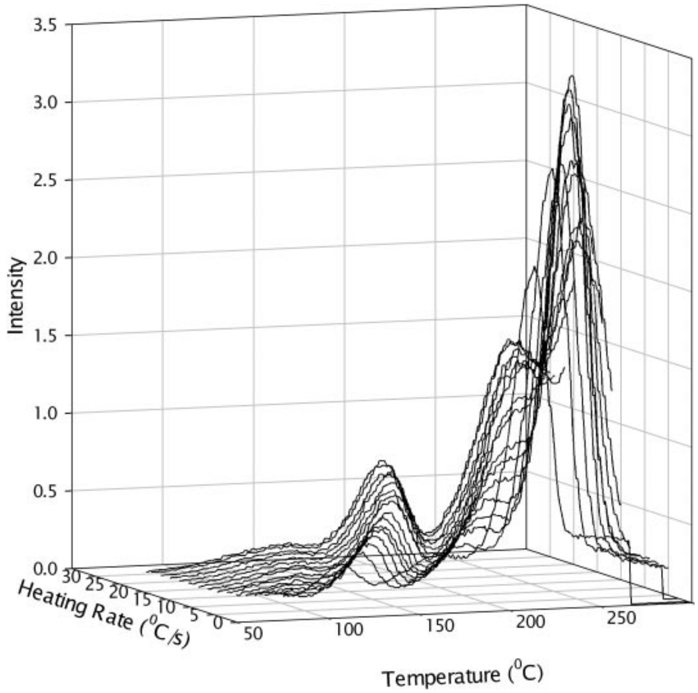

Figure 6. Glow curves for Harshaw TLD LiF:Mg,Cu,P card as a function of the heating rate and temperature.

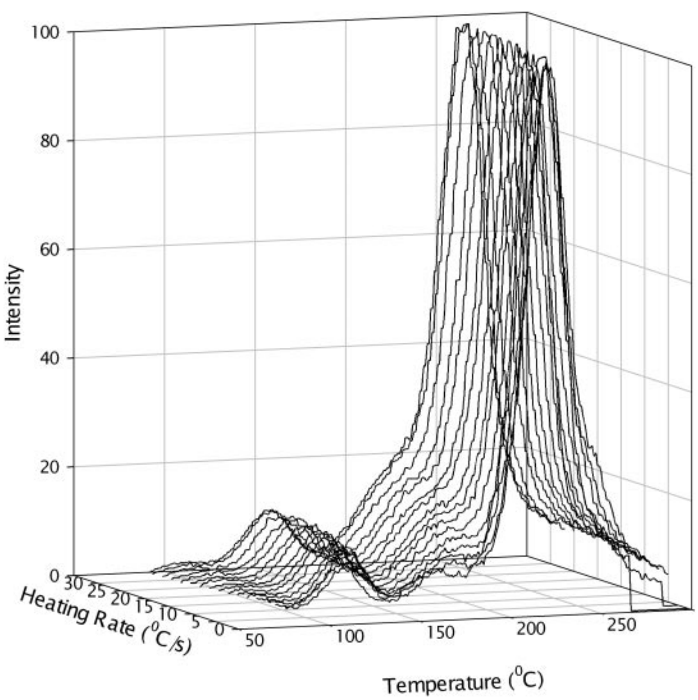

Figure 7. Glow curves for Harshaw Kapton bonded LiF:Mg,Cu,P powder (7 mg cm^{-2}) as a function of the heating rate and temperature.

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