The Emission of Visible Radiation by Peeling Adhesive Tape

E. Constable, Y. Hu, J. Horvat and R. A. Lewis

Institute for Superconductivity and Electronic Materials,
University of Wollongong, NSW 2522, Australia.

We have observed the emission of visible radiation on peeling adhesive tape from a spool. We have found that there is a fluctuation of light intensity in phase with the rotation of the spool from which the tape is being unwound. We have further found that the amount of light emitted initially increases as the unwinding speed is increased, then decreases at higher speeds.

1. Introduction

Very recently [1] it has been reported that peeling adhesive tape produces X-ray photons of intensity high enough to permit X-ray imaging and that the X-ray emission is correlated with the stick-slip friction of the peeling tape. This report may be regarded as an extension of the phenomenon of triboluminescence [2], which refers to the generation of visible light by the relative motion of two surfaces in contact. Triboluminescence has been observed in many materials, for example, sugar wafers [3]. Even though previous reports on triboluminescence from adhesive tape extend back seven decades [3,4], and related phenomenon involving the emission of light from the surface of mercury under vacuum go back as far as 1675 [4], the phenomenon is still only poorly understood. We have begun a study of the triboluminescence from readily-available adhesive tapes.

2. Experimental methods

The tape is driven from one spool to another in a similar way to that described in an earlier paper [1] and as shown in Fig. 1. The emitted radiation is collected with a silicon optical sensor (Coherent OP-2 VIS) sensitive to the wavelength range 0.4 to 1.06 μm. The data is collected on a digital storage oscilloscope (GW1002) and then transferred to computer.

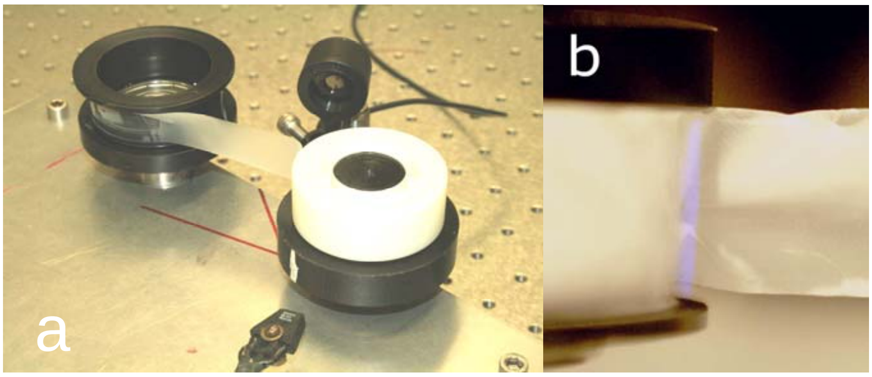

Fig. 1. Arrangement of the experimental apparatus used in this work (a). A variable-speed motor (not shown) is attached to the far spool. As the motor turns, the tape unwinds from the near spool to the far spool. Visible radiation is emitted from the peeling vertex (b) and collected by the optical sensor (background). The spool rotation is monitored by an optical encoder (foreground). An image of the spool taken under normal lighting and an image of the emission from the vertex photographed in a darkened room were combined to produce (b).

3. Results and discussion

3.1 Preliminary observations

Our initial observations concern the emission of light when using no special apparatus, peeling the tape by hand and using the unaided eye as the detector. While the intensity of the radiation produced in this way is not strong enough to be visible under normal room lighting conditions, in a darkened room and with a dark-adapted eye a bluish glow is seen as the tape is steadily pulled from the spool. The glow appears on the sticky (underside) of the tape along the line at which the unwound tape is separating from the non-sticky surface of the tape remaining on the spool. When the tape is then set up on the spools shown in Fig. 1(a) and mechanically unwound using the motor, the line of light emission may be photographed using time-exposure on a normal camera, as in Fig. 1(b). We have found an exposure time of 20 s with lens aperture f/2.8 and sensor sensitivity ISO1600 is suitable.

3.2 Survey of tapes

We have found a strong emission of light from Scotch Magic 810, Scotch Transparent 310, Scotch Transparent 600, Scotch Tartan 5142, Scotch SuperClear 3120, Scotch Fragile 3772, and Olympic cloth tapes. A weaker discharge is given by Scotch Double-sided 665, Scotch Tear-by-hand, Scotch Storage 3650, Scotch Strapping 8957, Scotch 310 Brown and OfficeWorks Invisible tapes. Very little emission has been observed from Scotch Removable 811, OfficeWorks double-sided, and OfficeWorks Super Strong Packing Tape. In considering these results together, it appears that the intensity of the emission is not directly related to the strength of the adhesive tape, possibly not even to the tape substrate, but to the chemical nature of the particular adhesive. We have not made a chemical analysis of the tapes at this stage. The ensuing results reported in this paper all refer to Scotch Magic 810.

3.3 Time analysis of the emission of visible light

Fig. 2 gives the power detected by the light sensor as a function of time as the tape is unwound. The signal appears abruptly above the background level once unwinding begins, then stops once the motor is disengaged. There is an oscillation in intensity in phase with the spool rotation, which we attribute to a geometrical factor. It has been noted that there is a stick slip effect when the tape peels [1] that leads to small changes in the peeling force. This is most probably responsible for the fine structure of the observed. As this phenomenon varies along the tape the fine structure does not remain constant with every cycle. So, for example, there is only a small signal for the seventh rotation and a broad signal at the eleventh rotation.

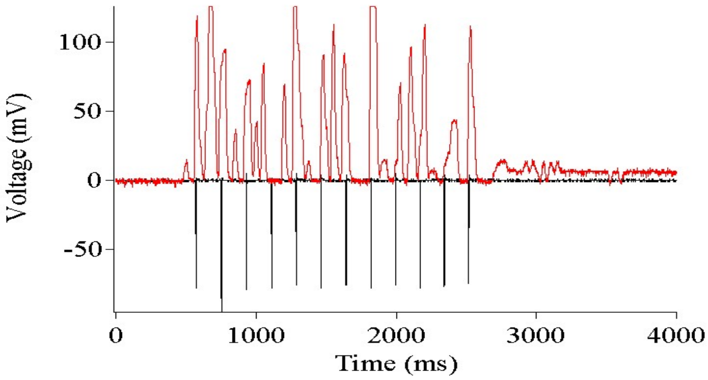

Fig. 2. Intensity of light emitted as tape is unwound from spool as a function of time. The upper trace is the signal recoded by the light sensor. The lower trace corresponds to a fiducial mark on the spool being optically detected. Each “spike” on the lower trace corresponds to the spool crossing the reference position.

3.4. Intensity of the emitted light as a function of tape speed

The experiment described in Section 3.3 and for which results are shown in Fig. 2 was repeated many times at different tape speeds. The variation of light intensity with the tape speed is given in Fig. 3. At each speed the tape was unwound for a total time of about 10 s and then the average value of the light intensity was calculated from the oscilloscope trace. Repeated runs (for example, at around 2 Hz in Fig. 3) gave reproducible results.

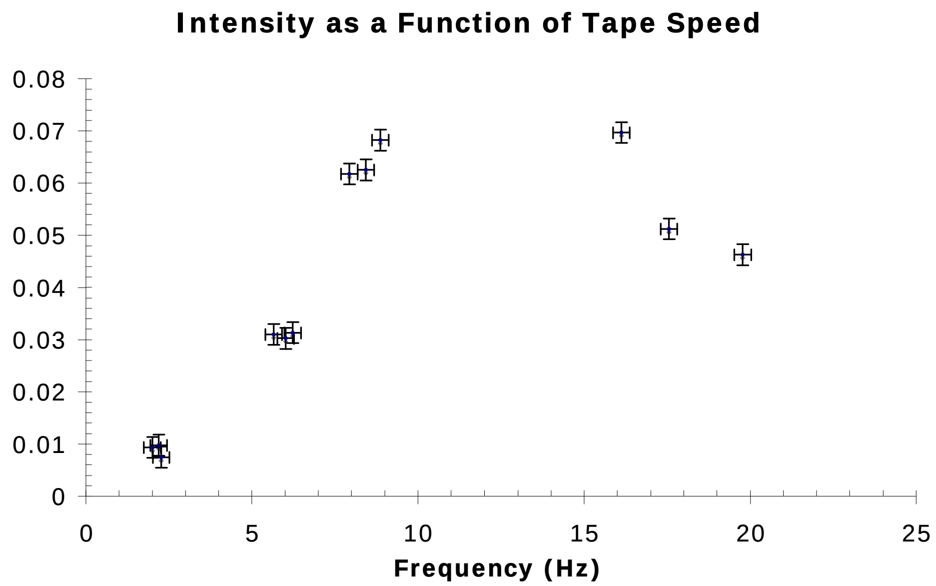

Fig. 3. Intensity of emitted radiation as a function of the frequency of rotation of the spool. The sensor is orientated front on to the vertex of peeling.

As the tape speed increases, there is initially an increase in intensity with speed. This might be expected on the basis of a number of possible mechanisms for the generation of light. There is a range of speeds, from about 10 to 15 Hz, which we find difficult to access with our motor. At higher speeds, corresponding to spool frequencies above 15 Hz, there is a reduction in light intensity with speed. We do not have a full explanation for this, but suggest it is related to the stick-slip phenomenon in which there is a large force exerted for a short time (in which the light emitted would be large), then a smaller force exerted for a relatively long time (during which little light would be emitted).

3.5. Intensity of the emitted light as a function of angle

To help establish the mechanism responsible for the emission of light, we have made preliminary measurements of the dependence of the light intensity on the orientation of the detector relative to the peeling vertex. In due course we aim to obtain a full π steradians angular dependence. Our initial results are given in Fig. 4. An interesting observation is that there seems to be more radiation emitted from the non-sticky side of the tape most likely due to the radiation transmission through the tape. Further study of this occurrence should help to explain the mechanism of the emission.

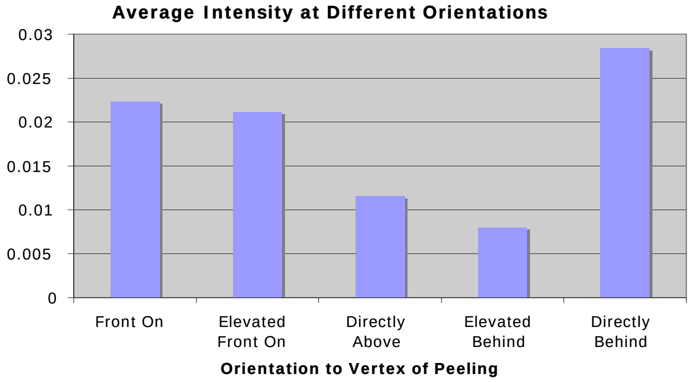

Fig. 4. Average intensity of visible radiation emitted by the adhesive tape for various orientations of the light sensor relative to the line of peeling of the tape. The average frequency of spool rotation for these measurements is 6.0 Hz.

3.6 Mechanisms

We now consider possible mechanisms. The most likely origin of the visible light is an electrical discharge instigated by the separation of charge between the tape being removed from the spool and the tape remaining on the spool. The process of "tribocharging" has been the subject of some previous studies but is still not fully understood. Here we relate it to the speed at which the two surfaces separate and to the direction of emission. In insulators, as is the case here, tribocharging appears to be associated with the transfer of ions, rather than electrons [5-7]. So a build up of charge, followed by dielectric breakdown in air, followed by the acceleration of free ions, followed by excitation of the molecules in air with subsequent optical emission is presumed to be the origin of the light emission we observe.

> **Comment [a1]:** For light emission, it is likely to have the emission from molecules of surrounding air as they are excited by accelerated ions. Bremsstrahlung radiation power decreases with the mass of charge carriers as m^{-4} or m^{-6}. Of course this is all just a guess….

3.7 Future work

We plan to extend the angular dependence measurements described in Section 3.5. We have attempted to measure the spectrum but so far have not been able to adequately couple the light into the spectrometer to obtain a substantial signal above the noise background. Much useful information is expected to be obtained by repeating the measurements at low pressure and in atmospheres of different gases. To this end, a purpose-built vacuum chamber is presently under construction.

Acknowledgments

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