Low Temperature Cathodoluminescence of Space Observatory Materials

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Abstract

In recent charging studies, a discernable glow was detected emanating from sample surfaces undergoing electron beam bombardment that resulted from a luminescent effect termed cathodoluminescence. This suggests that some of the materials used as optical elements, structural components, and thermal control surfaces in the construction of space-based observatories might luminesce when exposed to sufficiently energetic charged particle fluxes from the space plasma environment. If these visible, infrared and ultraviolet emissions are intense enough, they can potentially produce optical contamination detrimental to the performance of the observatory optical elements and sensors, and act to limit their sensitivity and performance windows. As future observatory missions push the envelope into more extreme environments and use more complex and sensitive detectors, a fundamental understanding of luminescent dependencies on time, temperature, flux, energy, and material structure will become critical.

Our observations are compared with similar previous studies and are described in terms of simple models of disordered band theory. This experimental study is tied to atomic scale models based on stochastic transport of electrons between extended-state bands and localized trapped states in highly disordered insulating materials. The observed luminescence occurs when an incident high energy, charged particle excites a valence band electron into the conduction band. Following the excitation, a transition takes place between the extended conduction states and the localized (trapped) states below the mobility edge. This final electron transition is the origin of the emitted photons. The trap sites are associated with structural or compositional defects in the dielectric materials; such a structure from which luminescence originates is known as a chromophore. The transport equations and models of the spatial and energy distribution of the trapped states, their occupancy, and transitions provide microscopic scale insights into this macroscopic phenomenon and its "megascopic" applications. The theoretical models provide a fundamental basis for understanding the dependence of cathodoluminescence for new materials and for ranges of temperature, flux, and energy.

A major focus of our experiments was the temperature dependence of the luminescent behavior. Because IR instrumentation is temperature sensitive and IR observatories are positioned in space accordingly, it is imperative to measure and understand the material luminescent behavior at such low operating temperatures. The temperature dependent trend observed over a range from 40 K to 400 K showed that luminescent intensity, in general, increased with decreasing temperature. Changes in apparent color with temperature were also observed. As many as four bands in the UV/VIS/NIR range from 300 nm to 1000 nm were observed in spectral measurements of different spacecraft materials. Depending on the specific chromophore, these different bands either increased or decreased in intensity and/or shifted slightly in energy with decreasing temperature. This dependence on temperature comes from a dynamic change in the filling of available trapped states within the gap. With less thermal energy available in the material, electrons fall into lower energy trapped states, thereby emptying higher energy states and allowing excited electrons to relax into lower energy trapped states; this complex relaxation process affects the intensity and energy range of the luminescence.