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Low Temperature Cathodoluminescence of Space Observatory Materials

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Low Temperature Cathodoluminescence of Space Observatory Materials

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Abstract

Disordered SiO₂ is commonly used for optical instrumentation and coatings. In space telescope applications, these materials can be exposed to low temperatures (particularly for IR telescopes) and simultaneously electron fluxes from the space plasma environment. During recent charging tests of this dielectric material, a discernible glow was detected emanating from the surface of the SiO₂, indicating that the incident electrons had a luminescent effect, termed cathodoluminescence. As the sample cooled from 300 K to 120 K, a change in the intensity and energy spectrum of the glow was observed between 250 nm and 1700 nm, demonstrating that the SiO₂ cathodoluminescence is temperature dependent. Cathodoluminescence occurs when a high energy electron excites a valence band electron into the conduction band, then a transition takes place between the extended conduction states and the localized states below the mobility edge resulting from structural defects. This final electron transition is the origin of the emitted photon, hence luminescence. As the temperature and the thermal energy among the defects vary, the trap state population, distribution of accessible trap states, and transitions between states also vary. A dynamic model of electrons in these localized trap states is proposed to explain the temperature dependence of experimental cathodoluminescence spectra collected. Using our experimental results in conjunction with literature references, the specific structural defects in SiO₂ responsible for distinct features in the cathodoluminescence spectra can be identified. From our experimental results, a simple qualitative model of disordered band theory has been developed to describe the states and electron dynamics in our SiO₂ samples. Ultimately, such knowledge is important in the optimal design of space telescope optics.

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1200
1200
400
800
200
200
3456.0x2592.0

Experimentation

Theory

Valence Band

Conduction Band

SiO₂ is an insulating material that has a band gap of about 8.9 eV. Hence thermal excitation from the valence to conduction band is highly improbable. Thus, there must be other states for the electrons to reside in within the band gap; there must be other energy bands or “trap” states. The localized states in disordered SiO₂ are due to defects in the crystalline structure or chemical defects that cause misfitting or substitutional dopants. These defects add energy states within the forbidden band. Now, when valence band electrons are excited into the conduction band by the high energy incident electron radiation and then relax, there are now ‘closer’ (in energy) trap states that the electrons can relax to. Some relaxation processes such as the electron photoemitting processes. These relax defect states, or chromophores, can be in the material or can be induced by the incident electron. In other words, our experiments or the space plasma may create these defect states which then cause them to luminesce.

Compared with a simple two band model, a model with multiple bands of disordered states in the band gap has been developed to qualitatively explain the temperature dependence of the observed luminescence spectra. We began with a simple two band model. In this model, the red band represents the band the red photon emitting band. The blue band represents the UV photon emitting band. A model with multiple bands of disordered states in the band gap has been developed to qualitatively explain the temperature dependence of the observed luminescence spectra. We began with a simple two band model. In this model, the red band represents the band the red photon emitting band. The blue band represents the UV photon emitting band. A model with multiple bands of disordered states in the band gap has been developed to qualitatively explain the temperature dependence of the observed luminescence spectra. We began with a simple two band model. In this model, the red band represents the band the red photon emitting band. The blue band represents the UV photon emitting band. A model with multiple bands of disordered states in the band gap has been developed to qualitatively explain the temperature dependence of the observed luminescence spectra. We began with a simple two band model. In this model, the red band represents the band the red photon emitting band. The blue band represents the UV photon emitting band.

Temperature Dependence Results

Figure 1: A model with multiple bands of disordered states in the band gap has been developed to qualitatively explain the temperature dependence of the observed luminescence spectra. We began with a simple two band model. In this model, the red band represents the band the red photon emitting band. The blue band represents the UV photon emitting band. A model with multiple bands of disordered states in the band gap has been developed to qualitatively explain the temperature dependence of the observed luminescence spectra. We began with a simple two band model. In this model, the red band represents the band the red photon emitting band. The blue band represents the UV photon emitting band. A model with multiple bands of disordered states in the band gap has been developed to qualitatively explain the temperature dependence of the observed luminescence spectra. We began with a simple two band model. In this model, the red band represents the band the red photon emitting band. The blue band represents the UV photon emitting band. A model with multiple bands of disordered states in the band gap has been developed to qualitatively explain the temperature dependence of the observed luminescence spectra. We began with a simple two band model. In this model, the red band represents the band the red photon emitting band. The blue band represents the UV photon emitting band.

Conductors are materials with partially filled energy bands, giving the electrons that occupy band high mobility, allowing electrons to move freely. Insulators have a full valence band and a large gap to the conduction band, such that even with large amounts of thermal energy valence band electrons have an extremely low probability of being thermally excited into the conduction band. This small mobility makes these materials electrically insulating. For intrinsic insulators and semiconductors with no defect states, the Fermi energy is at the middle of the band gap. Semiconductors have two bands that are separated by a small amount of energy so that, with sufficient thermal energy, electrons in the valence band have a small but significant probability of excitation into the higher bands, therefore leading to moderate conductivity.

Future Work and Acknowledgements

Right now, our model is only a qualitative one used to illustrate the behavior of our SiO₂ thin films. In the very near future, this model will be a quantitative one. Its validity will also be put to the test at experiments are conducted to lower temperatures, down to 4K.

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