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Luminescence Database I—Minerals and Materials

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Abstract: A luminescence database for minerals and materials has been complied from the literature, the aim being to create a resource that will aid in the analysis of luminescence spectral of ionic species in minerals and materials. The database is based on a range of excitation techniques and records both major and minor lines, and their activators. The luminescence techniques included in the database are cathodoluminescence, ion luminescence, and photoluminescence. When combined with other traditional X-ray measurements collected on the same region, use of the luminescence database will give additional insight into the chemistry of minerals and materials.

Key words: luminescence, cathodoluminescence, photoluminescence, ion, minerals

Introduction

Minerals and materials can luminescence when they are exposed to an electron, X-ray, ion, or photon beam. Luminescence is generally associated with light in the ultraviolet (UV) to infrared (IR) region and can exhibit both broad and narrow band spectra. From the spectra it is possible to identify both the activators responsible for the luminescence and their charge states. A large number of research groups routinely employ luminescence analysis as a key macro- and micro-characterization techniques in the study of minerals and materials.

For many years the microanalyst has had available KLM lines for identifying peaks in X-ray spectra; however, no such tool has been available for luminescence generated by electrons, light, protons, or ions. To address this problem a luminescence database of lines has been compiled that contains over 1,000 lines or bands from over 70 minerals and synthetic materials. In this article the luminescence database is described, and in a subsequent article software tools and web access will be described. It is the authors' intention to make the database easily accessible and provide a procedure for external users to add new lines and spectra from minerals and materials.

A number of minerals have distinguishing luminescence properties. These include: diamond, sulphides (chalcocite, sphalerite), oxides (periclase, corundum, cassiterite), halides (fluorite, halite), sulphates (anhydrite, alunite), wolframates (scheelite), phosphates (apatite), carbonates (calcite, dolomite, magnesite, witherite), or silicates (albite, feldspar, quartz, zeolites, kaolinite, forsterite, zircon, garnet, titanite, thorite, willemite). The presence of luminescence, in many cases, allows rapid identification of the different mineral constituents using cathodoluminescence microscopy. This is particularly important if samples consist of fine-grained material and/or of minerals with similar optical or crystallographic properties. These grains can then be further characterized by electron microprobe or optical microscopy.

Furthermore, many of the phases occurring in ceramics (Hagni & Karakus, 1989), glasses, refractory materials (Karakus, 2005), and biomaterials show distinct luminescence properties allowing a rapid identification of phase distribution and transformations. Luminescence spectroscopy is particularly important in the characterization of materials that contain significant proportions of noncrystalline components, multiple phases, or low concentrations of mineral phases.

Luminescence Fundamentals

Characteristic X-ray lines result from core level transitions, while the generation mechanism for luminescence is more complex. Characteristic X-rays are largely unaffected by bonding as the core orbitals do not take part and therefore a particular elemental transition is independent of the host lattice. However, the luminescence emission is sensitive to material composition and structure of the host lattice, because it originates from effects such as conduction to valence transitions and phonon modes (Marfunin, 1979). This makes luminescence sensitive to subtle effects such as trace

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level dopants and their valence, the host lattice, and quenching ions. This sensitivity results in luminescence providing extremely useful characterization information, but its interpretation is more difficult than that of characteristic X-rays.

Dopant Ions

Minerals and materials often contain optically active dopants ions. Generally there are considered to be three types of dopant ions that influence and determine the net emission of a particular mineral. They are referred to as activators, sensitizers, or quenchers. Activators produce emission by releasing the absorbed energy as photons. The most common activators are transition metal ions such as Cr^{3+}, Mn^{2+}, Mn^{4+}, Sn^{2+}, Pb^{2+}, Fe^{3+} (Gotze, 2002), and rare earth elements (Marfunin, 1979). Sensitizers are ions that work in combination with an activator by absorbing the energy and subsequently transferring the energy to the activator. Quenchers trap part or all of the absorbed energy resulting in nonradiative decay of the energy. As a result, quenchers tend to eliminate the emission of light from minerals. The presence of the quencher causes new closely spaced energy levels to be set up, and the electron can easily return to the ground state with the emission of a succession of low-energy photons (IR) or by losing energy to the lattice as heat (Marshall, 1988). An example of a well-recognized quencher ion in minerals is Fe^{2+}.

Types of Emission

Luminescence emission is generally grouped into two types: intrinsic and extrinsic. Intrinsic luminescence is native to host materials and involves band-to-band recombination of electron and hole pairs. Intrinsic luminescence emission may also be associated with lattice defects (anion vacancies) within the minerals or material. This type of luminescence is also referred to as "defect center" luminescence. The second type of emission, referred to as extrinsic, is the most common form of luminescence. Extrinsic emission is attributed to the presence of trace element impurities, transition metal, and rare earth ions. This type of luminescence is referred to as an "impurity center."

The emission process involves an electronic transition from an excited state (E_e) to a lower energy level or ground state (E_g). When an electron beam interacts with a surface and produces light, this process is known as cathodoluminescence (CL). Similarly, an ion beam interacting with a surface and producing light is often referred to as ion luminescence (IL). Emission occurring when a photon beam interacts with a surface is referred to as photoluminescence (PL), and for X-ray beams the process is referred to as roentgenoluminescence. Cathodo- and photo-luminescence are the most effective methods of observing the glow of minerals, roentgenoluminescence and ion luminescence playing a lesser role. The cathodoluminescence acquires additional importance in connection with the use of X-ray microanalyzer in which an electron probe induces the glow of luminescent minerals and synthetic materials (Pagel et al., 2000; MacRae & Miller, 2003).

Generation of Luminescence

Cathodoluminescence can be observed with a variety of electron beam instruments (Petrov, 1996). One simple type of instrument is the electron beam flood gun that mounts directly onto the optical stage of a petrographic microscope (Marshall, 1988). Another approach is to mount a spectrometer onto a scanning electron microscope. This typically collects light with a mirror that is usually on a retractable arm, and the light is measured using a grating-type spectrometer (Katona et al., 2004; Vernon-Parry et al., 2005). A more recent approach is to integrate cathodoluminescence capture into an electron probe microanalyzer using the existing collection optics and to employ an optic fiber coupled to a CCD spectrometer to measure the luminescence (MacRae et al., 2001, 2005; Edwards et al., 2003). All these collection systems measure cathodoluminescence with differing lateral and spectroscopic resolutions. They each have their own benefits and virtues.

Photoluminescence spectra can be induced by monochromatic light in the band of the ion absorption or by means of UV radiation with a spectrum necessary to excite the ion absorption bands. Ultraviolet radiation is necessary to excite the ion up to energy levels lying above the emission level, which is usually in the visible to near IR region (Marfunin, 1979).

Other Effects

Luminescence lifetime or decay time can provide information on the nature of the center and is a measure of the transition probability from the emitting state. The transition probability is unique for each center and therefore can be used to differentiate centers. Time-resolved luminescence spectra have been studied using pulsed or chopped electron or laser-induced excitation and lock in amplifiers coupled to spectrometers to measure the decay spectra (Gorton et al., 1997; Pagel et al., 2000; Edwards et al., 2003; Merano et al., 2005).

Polarized luminescence has been observed with cathodoluminescence, and this can enhance differentiation of minerals and materials and offers information about site symmetries of the luminescence centers (Gorz et al., 1970; Chandrasekhar & White, 1992). The database does not indicate whether minerals or materials have polarized emission. Only a few studies have considered this effect; for example, information on polarization has been studied in silicates (Bhalla & White, 1970, 1972; Gorz et al., 1970; Chandrasekhar & White, 1992; Remond et al., 2000), and diamonds (Kiflawi & Lang, 1974).

The intensity of luminescence varies as a function of sample temperature. Typically, temperature quenching of the luminescence arises at high temperature because of the increased probability of nonradiative transition from the excited to the ground state. Some samples will show an increase in intensity with decreasing temperature. While peaks shapes are narrower at lower temperatures, they can also shift with temperature (Lozykowski et al., 1999). The luminescence decay time can also alter at low temperatures; for example, in calcite the Mn^{2+} peak has a measurably shorter decay time at lower temperature (Mason et al., 2005).

Temperature is not the only mechanism that can affect positions and intensities of luminescent lines. Some cathodoluminescence measurements performed using intense electron beams can cause disruption within the mineral or material by such processes as heating, sputtering, or ion migration. These disruptions can lead to modified spectra and sometimes to rapid decreases in intensity with time of bombardment. Some spectra may have been collected with long dwell times leading to the recording of only the slow decay processes as the faster ones have been extinguished. Spectra collected on beam sensitive materials can be done routinely with automated collection systems (Lee et al., 2005; MacRae et al., 2005).

Scope of the Luminescence Database

The luminescence database encompasses an extensive range of lines from minerals and materials that have been reported in the literature. Previously, a number of smaller tables have been constructed but these usually focused on specific minerals or materials (Marshall, 1988; Yacobi & Holt, 1990; Stevens-Kalceff & Phillips, 1995; Pagel et al., 2000; Gaft et al., 2005). While the database presented here is not exhaustive, it nonetheless provides a powerful resource. The lines in the database are listed as given in the cited publications and, when reported, the full width at half maximum (FWHM) of the peak has also been listed in brackets after the line. In addition, for publications that did not report the FWHM but gave spectra, we have measured and included it where possible.

Effects not recorded in the database but that may modify the luminescence spectra include luminescent decay, polarization, and temperature. While these all provide additional information about the material, they are outside the scope of the database, which is aiming to provide only an initial identification of the line.

In general, the samples analyzed by cathodoluminescence in this database were carbon-coated polished sections. It is worth noting that these carbon films have the ability to change intensity of cathodoluminescence peaks. Further, the types of optical components such as mirrors, lenses, fibers, and optical spectrometers employed to measure many of the luminescence spectra were not necessarily corrected for their optical response, and this can lead to shifts in the maximum intensity of peaks and their shape. Errors in detection of luminescence for UV emitting materials may also have arisen in some measurements due to the use of glass in many older style spectrometer systems. Glass has strong absorption of UV, and emission lower than 350 nm is difficult to observe.

The Luminescence Database

The luminescence database is structured to provide luminescence information on an extensive list of minerals (Table 1) and nonminerals (Table 2). Information provided includes the particular elemental or molecular activator(s), ionic charge(s), experimental temperature, technique employed to measure the luminescence, and the associated reference. A determination of the line intensity, where possible, has also been made to aid in the interpretation of luminescence spectra, with major lines listed in bold. When available the FWHM of the line has been included; however, if the line is nonsymmetric, a measure of the bandwidth is recorded. In all cases the reference to the line or band is included, which in most cases contains original spectra and further interpretation. Wherever possible a number of luminescence techniques (photoluminescence, cathodoluminescence, ion-luminescence, thermal luminescence, and proton luminescence) have been included for each mineral and material to provide the researcher with a range of techniques offering differing sensitivities and resolutions. This should aid in the determination of crystal field information regarding the coordination of the activator and its ionic charge. This is particularly important where quantitative spectroscopic luminescence studies are being undertaken (Habermann, 2002). In addition, the instrumental technique used to excite the luminescence is recorded, where known. For example, cathodoluminescence has been categorized into scanning electron microscopy (SEM), optical microscope (OM), transmission electron microscope (TEM), while photoluminescence has been divided to UV, laser induced (L), photoluminescence (PL). Other methods recorded are thermal luminescence (TL), proton or ion luminescence (IL), and X-ray excited luminescence (XL). Where emission is known to be cathodoluminescence in origin but unknown instrumentally, it has been listed as OM cathodoluminescence; similarly where the photoluminescence is unknown in detail, it is listed simply as photoluminescence.

Where site specific information about the location of the ionic species is described, it has been included. For example, beryl can be activated by Cr^{3+} in two specific sites and these give rise to different lines Similarly Eu^{3+} in calcite can sit in one of two Ca sites referred to as Ca(I) and Ca(II), giving rise to different peak positions. Where the activator is not simply an ionic species but a form of intrinsic excitation, then additional information about the origin of the luminescence has been included where it is commonly employed, e.g., quartz activators. In the wide number of

Table 1. Luminescence Lines, Activators, Temperature and Technique for Minerals

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
Albite	Dy^{3+}	480,[1] 560,[1] 660[1]	Room	SEM
$NaAlSi_3O_8$	Nd^{3+}	870,[1] 880,[1] 900[1]	Room	SEM
	Sm^{3+}	600,[1] 645,[1] 650,[1] 700,[1] 800[1]	Room	SEM
	Tb^{3+}	415,[1] 420,[1] 470,[1] 490,[1] 500[1]	Room	SEM
Alforsite	Yb^{2+}	648[2]	Room	—
$Ba_5(PO_4)_3Cl$				
Alumina	Cr^{3+}	692,[3] 694[3]	—	—
Al_2O_3	Fe^{3+}	760(130)[3]	873	—
	Mn^{2+}	515(70)[3]	873	—
	Mn^{4+}	673,[3] 676[3]	—	—
	—	443[4]	Room	SEM
Amazonite	Pb^{2+}	300[5]	Room	—
$KAlSi_3O_8$				
Anhydrite	Ce^{3+}	319[6]	Room	L
$CaSO_4$	Dy^{3+}	480,[7] 570[7]	Room	—
	Dy^{3+}	481,[6] 576[6]	Room	L
	Eu^{2+}	385[6]	Room	L
	Eu^{3+}	575,[6] 591,[6] 617,[6] 703[6]	Room	L
	Gd^{3+}	312[6]	Room	L
	Mn^{2+}	500,[8] 460–610[7]	Room	—
	Nd^{3+}	892[6]	Room	L
	Pr^{3+}	228,[6] 239,[6] 258,[6] 268[6]	Room	L
	Sm^{2+}	632(50),[6] 732,[6] 744[6]	Room	L
	Sm^{3+}	595,[7] 640[7]	Room	—
	Tb^{3+}	380,[6] 414,[6] 436,[6] 483,[6] 543[6]	Room	L
	Tm^{3+}	452[6]	Room	L
	Yb^{2+}	377[2]	Room	—
Anorthite	Fe^{3+}	700[9]	Room	—
$CaAl_2Si_2O_8$	Mn^{2+}	570[9]	Room	—
	Mn^{2+}	550–565,[10] 550–560[10]	Room	OM
	Mn^{2+}	323,[54] 339,[54] 352,[54] 403,[54] **417**,[54] 476[54]	Room	OM
	Sm^{3+}	598,[10] 643[10]	Room	OM
	Ce^{3+}	490[11]	Room	—
	Eu^{2+}	470[11]	Room	—
	Eu^{2+}	**420**[12]	Room	OM
Apatite	Ce^{3+}	350–380,[13] 365,[14] 458[13]	Room	SEM
$Ca_5(PO_4)_3$	Ce^{3+}	**365**[15]	Room	L
	Ce^{3+}	365[16]	Room	—
	Ce^{3+} Ca(I) site	360[6]	Room	L
	Ce^{3+} Ca(II) site	430[6]	—	—
	Dy^{3+}	470,[14] **480**,[17] **482**,[13] **568**,[17] **570**,[14] 577,[13] 667[13]	Room	SEM
	Dy^{3+}	**480**,[15] **481**,[6] **485**,[6] **570**,[6] **575**,[6,15] 578,[6] 579,[6] **663**,[15] **750**[15]	Room	L
	Dy^{3+}	480,[7,16] 575,[7] 580[16]	Room	—
	Er^{3+}	**403**(75)[13]	Room	SEM
	Er^{3+}	544,[6] **545**,[15] **1540**[15]	Room	L
	Eu^{2+}	**451**,[13] 410–445[14]	Room	SEM
	Eu^{2+}	450,[6] 430–450[15]	Room	L
	Eu^{2+}	410(75)[12]	Room	OM
	Eu^{2+}	450[17]	Room	UV
	Eu^{2+}	410,[12] 450[7,12,16]	Room	—
	Eu^{3+}	585,[17] **615**,[17] 645,[17] 690[17]	Room	SEM
	Eu^{3+}	**579**,[15] **590**,[15] **618**,[15] **653**,[15] **700**[15]	Room	L
	Eu^{3+}	590,[7] **615**,[7] **695**[7]	—	—
	Eu^{3+} in Ca(I) site	589,[6] 617,[6] 651,[6] 695[6]	Room	L
	Eu^{3+} in Ca(II) site	574,[6] 601,[6] 623,[6] 630,[6] 696[6]	LN	L

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
	Gd^{3+}	**312**[13]	Room	SEM
	Intrinsic	345,[13] 377,[13] 432[13]	Room	SEM
	Mn^{2+}	**560**,[17] **565**,[14] **577**[13]	Room	SEM
	Mn^{2+}	**565**,[12] 595[12]	Room	OM
	Mn^{2+}	**565**(80)[15]	Room	L
	Mn^{2+}	590[18]	Room	XL
	Mn^{2+}	562,[7] 570,[7] 576,[16] 600[19]	Room	—
	Mn^{5+}	**1170**,[15] 1171[6]	Room	L
	Mn^{2+} in Ca(I) site	569(60)[6]	Room	L
	Mn^{2+} in Ca(II) site	583(80)[6]	Room	L
	Nd^{3+}	884,[6] **890**,[15] 909,[6] 1066,[6] 1068,[6] **1070**,[15] 1074,[6] **1340**[6,15]	Room	L
	Nd^{3+}	**870**(10)[14]	Room	OM
	Pr^{3+}	485,[6] **600**,[15] 607,[6] **650**[15]	Room	L
	Sm^{2+}	734[6]	LN	L
	Sm^{3+} Ca(I) site	**565**,[15] **599**,[15] **645**[14]	—	—
	Sm^{3+} Ca(II) site	**607**,[15] **654**[14]	—	—
	Sm^{3+}	598,[6] 604,[6] **645**,[6,15] 652,[6] **654**[6,15]	Room	L
	Sm^{3+}	420,[14] **566**,[13] 595,[17] **599**,[13] 600,[14] 640,[14] 645,[17] **649**,[13] 690,[14] 800[14]	Room	SEM
	Sm^{3+}	560,[7,16] 600,[7,16] 645,[7] 648,[16] 710[7]	Room	—
	Tb^{3+}	380,[6,15] **414**,[6] **415**,[14] 436,[6] 437[14]	Room	L
	Tb^{3+}	381,[13] 416,[13] 438,[13] 490,[13] 540,[17] 546[13]	Room	SEM
	Tb^{3+}	545[7]	Room	—
	Tb^{3+} in Ca(I) site with Dy	487[6]	Room	L
	Tb^{3+} in Ca(II) site	545[6]	Room	L
	Tm^{3+}	363,[6] **364**,[15] **452**,[6,15] 453,[6] **700**[15]	Room	L
	UO_2	467,[6] 486,[6] 505,[6] 526[6]	Room	L
	UO_2	508,[6] 524,[6] 546[6]	LN	L
	Yb^{3+}	993[6,15]	Room	L
Apophyllite	$(UO_2)^{2+}$	530(50)[6]	Room	L
$KCa_4(Si_4O_{10})_2F.8H_2O$	Ce^{3+}	343,[6] 365[6]	Room	L
	Mn^{2+}	600(100)[6]	Room	L
Aragonite	Mn^{2+}	630[8]	Room	TL
$CaCO_3$	Mn^{2+}	540[20]	Room	—
Baddeleyite	Anion-vacancy	500[21]	Room	OM
ZrO_2	Dy^{3+}	490[22]	Room	UV
	Dy^{3+}	579[22]	LN	UV
	Eu^{3+}	617(15)[6]	Room	L
	Sm^{3+}	549[22]	Room	UV
	Tb^{3+}	546[6]	Room	L
Barite	Ag^{+}	635(150)[6]	Room	L
$BaSO_4$	Bi^{2+}	625[6]	Room	L
	Bi^{3+}	426[6]	Room	L
	Ce^{3+}	302,[6] 330,[6] 360[6]	Room	L
	Eu^{2+}	375[6]	Room	L
	Nd^{3+}	446,[6] 589[6]	Room	L
	Yb^{2+}	381[2]	Room	—
Benitoite	Ti^{3+}	650[6]	Room	L
$BaTiSi_3O_9$	TiO_6	419[6]	Room	L
Beryl	Cr^{3+}	680[23]	Room	—
$BeAl_2Si_6O_{18}$	$Cr(1)^{3+}$	693,[15] 694[15]	Room	L
	$Cr(2)^{3+}$	680,[5] 682[5]	Room	—
	Fe^{3+}	720(110)[5]	Room	—
	Mn^{2+}	480,[5] 570[5]	Room	—
	VO_4	433[15]	Room	L

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
Boehmite $AlO \cdot OH$	Cr^{3+}	692[15]	Room	L
Calcite $CaCO_3$	Ce^{3+}	**345**,[24] **380**,[24] **545**,[24] **700**[24]	—	—
	Ce^{3+}	357(70)[6]	Room	L
	Ce^{3+}	**345**,[24] **370**[24]	LN	SEM
	CO_3^{2-}	450[24]	Room	SEM
	Dy^{3+}	**500**,[25] **580**,[25] **680**,[25] **760**[25]	Room	SEM
	Dy^{3+}	485,[6] 576[6]	Room	L
	Eu^{3+}	619[6]	Room	L
	Eu^{3+} in Ca(I) site	618[6]	Room	L
	Eu^{3+} in Ca(II) site	575[6]	Room	L
	Fe^{3+}	695[24]	Room	SEM
	Mn^{2+}	588,[26] **605**(100),[27] **610**,[24] 615(15),[28] 667[26]	Room	SEM
	Mn^{2+}	560–630,[15] 620(100)[6]	Room	L
	Mn^{2+}	630[29]	Room	UV
	Mn^{2+}	630[18]	Room	XL
	Mn^{2+}	610[30]	Room	—
	Nd^{3+}	889[6]	Room	L
	Pb^{2+}	300[24]	Room	SEM
	Pb^{2+}	312[6]	Room	L
	Intrinsic	400(40)[27]	Room	SEM
	Sm^{3+}	565,[25] 570,[25] 600,[25] 610,[25] **650**,[25] 710[25]	Room	SEM
	Tb^{3+}	488[6]	Room	L
	Tm^{3+}	452[6]	Room	L
	Defect center	520(100),[31] 560(130)[31]	Room	OM
	Intrinsic	420,[30] 580[30]	Room	—
	—	545,[24] 560,[24] 648,[27] 695[27]	Room	SEM
	—	580[24]	LN	SEM
	—	578[32]	Room	SEM
	—	670[8]	Room	UV
	—	605[7]	Room	—
Cassiterite SnO_2	Intrinsic	475(160)[6]	Room	L
	Tb^{3+}	416,[33] 440,[33] 462,[33] 472,[33] **490**,[33] **542**,[33] 588,[33] **622**,[33] 650,[33] 686[33]	Room	OM
Celestine $SrSO_4$	Yb^{2+}	381[2]	Room	—
Chalcocite Cu_2S	Cd^{2+}	**1020**(100)[34]	90	SEM
	Intrinsic	**960**(50)[34]	90	SEM
Charoite $K_2NaCa_5(Si_{12}O_{30})F.3H_2O$	Ce^{3+}	335,[6] 360[6]	Room	L
	Eu^{2+}	408(80)[6]	Room	L
Chlorapatite $Ca_5(PO_4)_3Cl$	Yb^{2+}	435[2]	Room	—
Collophane $Ca_5(PO_4)_3(OH, F, Cl)$	Dy^{3+}	480,[35] 575[35]	Room	OM
	Eu^{2+}	410[35]	Room	OM
	Sm^{3+}	590,[35] 645[35]	Room	OM
	Tb^{3+}	550[35]	Room	OM
Chrysoberyl $BeAl_2O_4$	Cr^{3+}	680[36]	Room	OM
Colquirite $CaLiAlF_6$	Yb^{2+}	393[2]	Room	—
Corundum Al_2O_3	Cr^{3+}	694[10]	Room	OM
	Intrinsic	400–450,[10] 500–550,[10] 525–550[10]	Room	OM

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
Cristobalite	Intrinsic	450[10]	Room	OM
SiO_2	Intrinsic	445[37]	173	—
Danburite	Ce^{3+}	346,[6] 367[6]	Room	L
$CaB_2(SiO_4)_2$	Ce^{3+}	330,[18] 350[18]	Room	XL
	Eu^{2+}	437[6]	Room	L
	Eu^{3+}	611[6]	Room	L
	Sm^{3+}	610[18]	Room	XL
Datolite	Ce^{3+}	335,[6] 360[6]	Room	L
$CaB(SiO_4)(OH)$	Ce^{3+}	340,[18] 360[18]	Room	XL
	Eu^{2+}	455[6]	Room	L
	Eu^{3+}	610,[6] 617[6]	Room	L
	Mn^{2+}	565(60)[6]	Room	L
	Yb^{2+}	525[2]	Room	—
Diamond	Band A	443–517[38]	Room	SEM
C	Dislocation	439.7[38]	Room	SEM
	Dislocation	425[38]	89	SEM
	N	388.9[38]	Room	SEM
	Neutral vacancy	740.2[38]	Room	SEM
	A center	452[6]	Room	L
	H3 center	520(100)[6]	Room	L
	Intrinsic	380–600,[6] 507(100)[6]	Room	L
	S3 center	519[6]	Room	L
	GR1 center	794[6]	LN	L
Diaspore	Cr^{3+}	693,[15] 694[15]	Room	L
$AlO \cdot OH$				
Dickite	—	**410**(70)[39]	Room	SEM
$Al_2Si_2O_5(OH)_4$				
Diopside	Mn	585,[40] 670[40]	Room	—
$CaMgSi_2O_6$	Ti	415[19,40]	Room	—
Dolomite	Mn^{2+}	650[24]	Room	SEM
$CaMg(CO_3)_2$	Mn^{2+} in Ca site	**575**(25)[25]	Room	SEM
	Mn^{2+} in Mg site	**661**(50)[25]	Room	SEM
	Fe^{3+}	630–720[25]	Room	SEM
	—	640,[7] 670[8]	Room	—
Enstatite	Mn^{2+}	674[19]	Room	—
$MgSiO_3$	—	400,[41] 670[41]	Room	IL
Esperite	Ce^{3+}	400(40)[6]	Room	L
$Ca_3PbZn_4(SiO_4)_4$	Mn^{2+}	545(50)[6]	Room	L
Feldspar	Al-O^--Al	380–500[1]	Room	SEM
$(K, Na)AlSi_3O_8$	Ce^{3+}	335(50)[15]	Room	L
	Co	430[7]	Room	—
	Cr^{3+}	405[7]	Room	—
	Dy^{3+}	479,[7] 572,[7] 653[7]	Room	—
	Dy^{3+}	576[15]	Room	L
	Er^{3+}	504,[15] 532[15]	Room	L
	Er^{3+}	404,[7] 472,[7] 526,[7] 540,[7] 549,[7] 559,[7] 668[7]	Room	—
	Eu^{2+}	404(50)[15]	Room	L
	Eu^{3+}	614[15]	Room	L
	Eu^{2+}	420[1]	Room	SEM
	Fe^{3+}	765(120)[15]	Room	L
	Fe^{3+}	700,[1] 710(20)[25]	Room	SEM
	Fe^{3+}	700[7]	Room	—
	Gd^{3+}	316[15]	Room	L

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
	Intrinsic	430[42]	120	SEM
	Mn^{2+}	**560**,[1] **570**[25]	Room	SEM
	Pb^{2+}	296(40)[15]	Room	L
	Intrinsic	**470–620**[1]	Room	SEM
	Sm^{3+}	603,[15] 640[1]	Room	L
	Tb^{3+}	383,[15] 413,[15] 437,[15] 546[15]	Room	L
	—	450,[9,43] 559,[43] 560,[9] 770[9]	Room	—
Fluorite	Ce^{3+}	340[44]	Room	SEM
CaF_2	Ce^{3+}	320[6]	Room	L
	Dy^{3+}	480,[44] 570,[44] 666,[44] 754[44]	Room	SEM
	Dy^{3+}	477,[6] **480**,[15] 573,[6] **575**,[15] 588,[6] **663**,[15] 673,[6] **750**,[15] 765[6]	Room	L
	Er^{3+}	542[44]	Room	SEM
	Er^{3+}	**545**,[15] **1540**[15]	Room	L
	Eu^{2+}	424[45]	—	SEM
	Eu^{3+}	588[45]	—	SEM
	Eu^{2+}	425[44]	Room	SEM
	Eu^{2+}	423,[6] 430–450[15]	Room	L
	Eu^{2+}	**430**[12]	Room	OM
	Eu^{3+} + Sm	595[6]	Room	L
	Eu^{3+} in Ca(I) site	622[6]	Room	L
	Eu^{3+} in Ca(II) site	573,[6] 614[6]	Room	L
	Fe	425[7]	Room	—
	Fe^{3+}	678[44]	Room	SEM
	Gd^{3+}	310[6]	Room	L
	Gd^{3+}	413,[7] 435,[7] 543[7]	Room	—
	Ho^{3+}	546,[6] 657[6]	Room	L
	Ho^{3+}	537[7]	Room	—
	Ir	405[7]	Room	—
	M center	725,[15] 730(70)[6]	Room	L
	Mn^{2+}	510[18]	Room	XL
	Nd^{3+}	415,[6] 795,[6] 866[6]	Room	L
	Nd^{3+}	450,[7] 512,[7] 525,[7] 585,[7] 640,[7] 655,[7] 687[7]	Room	—
	Pr^{3+}	405,[7] 428,[7] 488,[7] 525,[7] 537,[7] 606,[7] 642[7]	Room	—
	Sm^{2+}	685[6]	Room	L
	Sm^{3+}	600[44]	Room	SEM
	Sm^{3+}	562,[6] 640[6]	Room	L
	Sm^{3+}	564,[7] 584,[7] 602,[7] 650[7]	Room	—
	Sm	567,[19] 606,[19] 613[19]	Room	—
	Tb^{3+}	380,[15] 414,[6] 486,[6] 544[6]	Room	L
	Tb^{3+}	385,[7] 416,[7] 436,[7] 470,[7] 487,[7] 542,[7] 544,[7] 581,[7] 619[7]	Room	—
	Tm^{3+}	451[6]	Room	L
	Tm^{3+}	453,[7] 515,[7] 660[7]	Room	—
	U^{3+}	410[7]	Room	—
	U^{4+}	500[7]	Room	—
	Yb^{2+}	500,[7] 575[2]	Room	—
	—	407,[7] 410,[7] 490[7]	Room	—
Fluoroapatite	Eu^{2+}	**460**(60)[12]	Room	OM
$Ca_5(PO_4)_3F$	Eu^{3+}	**617**(10),[12] 700(10),[12] 590(10)[12]	Room	OM
	Mn^{2+}	565 (60)[7]	Room	—
Forsterite	Cr^{3+}	**720**[46]	296	TEM
Mg_2SiO_4	Cr^{3+}	693,[46] **698**,[46] **715**[46]	LN	TEM
	Lattice defect	428,[10] 432,[10] 452,[10] 460[10]	Room	OM
	Mn^{2+}	630[10]	Room	OM
	Mn^{2+}	630[46]	Room	TEM
	Ni^{2+}	1360,[47] 1450[47]	20	SEM

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
	—	410,[46] 420,[46] 790[46]	296	TEM
	—	693,[46] 698,[46] 708,[46] 717,[46] 721,[46] 739,[46] 790,[46] 800[46]	LN	TEM
Francolite	Pr^{3+}	611,[6] 619,[6] 634,[6] 645[6]	Room	L
$Ca_5(PO_4, CO_3)_3F$	U^{6+}	522[6]	LN	L
	UO_2	530[6]	Room	L
Garnet	Mn^{2+}	590(70)[15]	Room	L
	Nd^{3+}	482[15]	Room	L
	V^{2+}	717[15]	Room	L
Halite	Ag	249[19]	Room	—
NaCl	Cu	358[19]	Room	—
	Yb^{2+}	434[2]	Room	—
Hardystonite	Ce^{3+}	378,[6] 400[6]	Room	L
$Ca_2ZnSi_2O_7$	Dy^{3+}	480,[6] 575[6]	Room	L
	Gd^{3+}	312[6]	Room	L
	Mn^{2+}	575(100)[6]	Room	L
	Pb^{2+}	355(40)[6]	Room	L
	Tm^{3+}	452[6]	Room	L
Hibonite	Dy^{3+}	486,[10] 570[10]	Room	OM
$(Ca, Ce)(Al, Ti, Mg)_{12}O_{19}$	Mn^{2+}	521[10]	Room	OM
	Sm^{3+}	560,[10] 603,[10] 642,[10] 705[10]	Room	OM
Hydroxylapatite	Intrinsic	420(60)[48]	Room	SEM
$Ca_5(PO_4)_3(OH)$	Mn^{2+}	600[48]	Room	SEM
Hydrozincite	Mn^{2+}	525[6]	Room	L
$Zn_5(CO_3)_2(OH)_6$	Pb^{2+}	430[6]	Room	L
Jadeite $Na(Al, Fe)Si_2O_6$	Mn^{2+}	400,[49] 460[49]	Room	—
Kaolinite	—	**400**(100)[39]	Room	SEM
$Al_2Si_2O_5(OH)_4$	Fe^{3+}	650–800[39]	Room	SEM
Kunzite $LiAlSi_2O_6$	Mn^{2+}	625[50]	Room	L
Kyanite	Cr^{3+}	706,[15] 750(100),[15] 790(100)[15]	Room	L
$Al_2O(SiO_4)$	Cr^{3+}	694[21]	Room	OM
Labradorite	Eu^{2+}	420(20)[1]	Room	OM
$(Ca,Na)(Si,Al)_4O_8$	Fe^{3+}	710(40)[1]	Room	OM
	Mn^{2+}	560(30)[1]	Room	OM
Leucophane	Ce^{3+}	411[6]	Room	L
$NaCaBe(Si_2O_6)F$	Dy^{3+}	478[6]	Room	L
	Eu^{2+}	466[6]	Room	L
	Eu^{3+}	573,[6] 620,[6] 701[6]	Room	L
	Mn^{2+}	600(65)[6]	Room	L
	Sm^{3+}	603[6]	Room	L
	Tm^{3+}	806,[6] 879[6]	Room	L
Magnesite	Intrinsic	**425**[21]	Room	OM
$MgCO_3$	Mn^{2+}	**650**,[21] **654**[30]	Room	OM
	—	**640**,[7] **660–680**[8]	Room	—
Magnetite Fe_3O_4	Intrinsic	387,[51] 477[51]	Room	OM
Monticellite	Sm^{3+}	460,[10] 560,[10] 600,[10] 688[10]	Room	OM
$CaMgSiO_4$	—	525[52]	Room	—
Mullite	Cr^{3+}	694[21]	Room	OM
$Al_{(4+2x)}Si_{(2-2x)}O_{(10-x)}$	Eu^{2+}	426[10]	Room	OM

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
	Intrinsic	475(25)[21]	Room	OM
	Sm^{3+}	600[10]	Room	OM
Muscovite $KAl_2(AlSi_3O_{10})(OH)_2$	—	680[53]	Room	F
Nacrite $Al_2Si_2O_5(OH)_4$	—	**410**(70)[39]	Room	SEM
Neighborite $NaMgF_3$	Yb^{2+}	419[2]	Room	—
Oldhamite	Ce^{3+}	523[10]	Room	OM
(Ca, Mg, Fe)S	Mn^{2+}	584[10]	Room	OM
Oligoclase	Mn^{2+}	361,[54] **384**,[54] 490,[54] 521[54]	Room	OM
$(Na,Ca)(Si,Al)_4O_8$	Fe^{3+}	700[7]	Room	—
	Fe^{3+}	382,[54] 425,[54] **441**,[54] 450,[54] 494,[54] 508,[54] 575,[54] 615,[54] 657[54]	Room	OM
Otavite $CdCO_3$	Mn	595[20]	Room	—
Pectolite	Mn^{2+}	580(60)[6]	Room	L
$NaCa_2Si_3O_8(OH)$	Pb^{2+}	356(60)[6]	Room	L
Pegmatite Apatite $Ca_5(PO_4)_3(OH, F, Cl)$	Mn^{2+}	565(65)[7]	Room	—
Periclase	Cr^{3+}	750[55]	Room	OM
MgO	Cr^{3+}	750(80),[48] 770,[56] 800[56]	Room	SEM
	Fe^{3+}	720,[57] 735(15)[10]	Room	OM
	Fe^{3+}	**704**,[56] 720,[56] **726**,[56] 750[58]	Room	SEM
	Fe^{3+}	**685**[59]	Room	UV
	Intrinsic	526,[10] 535,[10] 720–750[10]	Room	OM
	Intrinsic	450(100)[48]	Room	SEM
	F center	520[57]	Room	SEM
	F^+ center	390[57]	Room	SEM
	Lattice defect	400–500[55]	Room	OM
	Mn^{2+}	615[55]	Room	OM
	Mn^{2+}	610,[57] 615,[48] 745[57]	Room	SEM
	Phonon assisted	790,[56] 810,[56] 830,[56] 837,[56] 857[56]	LN	SEM
	Zero phonon	588[10]	Room	OM
	V^{2+}	870[56]	Room	SEM
Plagioclase	Cu^{2+}	420[60]	Room	—
$(Na,Ca)AlSi_3O_8$	Eu^{2+}	420[12]	Room	OM
	—	420[60]		—
	Fe^{2+}	550(80)[60]	Room	—
	Fe^{3+}	700[60]	Room	—
	Mn^{2+}	321,[54] 340,[54] 355,[54] **404**,[54] 421,[54] 487,[54] 559[54]	Room	OM
	Mn^{2+}	580[18]	Room	XL
	Mn^{2+}	560,[43] 570(90)[60]	Room	—
	Ti^{4+}	400–550[60]	Room	—
Pyrochlore	Dy^{3+}	479[6]	Room	L
$(Ca,Na)_2Nb_2O_6(OH,F)$	Eu^{3+}	618[6]	Room	L
Pyromorphite	Ce^{3+}	375[6]	Room	L
$Pb_5(PO_4)_3Cl$	Eu^{3+}	613[6]	Room	L
	Sm^{3+}	566,[6] 603,[6] 652,[6] 714[6]	Room	L
	Tb^{3+}	482[6]	Room	L

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
Pyrope $Mg_3Al_2(SiO_4)_3$	Cr^{3+}	675,[6] 684,[6] 687,[6] 699,[6] 730[6]	Room	L
Pyrophyllite $Al_2Si_4O_{10}(OH)_2$	—	400[39]	Room	SEM
Quartz	Defect	380(120),[61] 440(120),[61] 450,[62] 510(200)[61]	Room	SEM
SiO_2	Defect	470(140),[61] 570(200)[61]	Room	SEM
(See also Table 2, SiO_2)	NBOHC	620–650,[63] 636,[64] 649[64]	Room	SEM
	Oxygen Vacancy	**620**(140),[65] 650(140)[65]	Room	SEM
	Oxygen π orbital	420(100)[65]	Room	SEM
	Intrinsic	175,[63] 290,[63] 340,[63] 420,[63] 450,[63] 580[63]		—
	Intrinsic	423[64]	295	SEM
	Intrinsic	477[61]		OM
	Impurity	387[61]		SEM
	$AlO_4\|M^+$ center	385(10),[63] 500[63]		—
	Nonbridging oxygen	653[66]	—	—
	Associated with Al-O-Al bonds	620[67]	—	TL
	STE	477[68]	—	UV
	STE	477,[66] 544[64]	—	SEM
	STE	564[61]	80	OM
	STE	456,[64] 461[64]	80	SEM
	$(AlO_4)^0$ hole trap	468[69]	—	—
	$(H_3O_4)^0$ hole trap	381[69]	—	—
	E′ center	290,[70] 459[71]		SEM
	$Al\text{-}M^+$ center	397[64]	295	SEM
	Extrinsic	504[64]	295	SEM
	Extrinsic	496[72]	—	—
	—	400,[73] 481,[73] 605[73]	—	SEM
	—	450,[10] 625[10]	Room	SEM
	—	505[62], 585[62]	Room	OM
	—	564[66]	—	—
Rhodochrosite $MnCO_3$	Mn^{2+}	620(100)[15]	Room	L
Rhodonite $CaMn_4Si_5O_{15}$	Mn^{2+}	640(100)[15]	Room	L
Rorisite CaFCl	Yb^{2+}	394[2]	Room	—
Ruby Al_2O_3	Cr^{3+}	694[15]	Room	L
Sapphire	Cr^{3+}	694[74]	Room	SEM
Al_2O_3	Cr^{3+}	692.9,[63] 694.3[63]	Room	—
	Eu^{3+}	598,[75] 614,[75] 690[75]	Room	OM
	Eu^{3+}	622(12)[74]	Room	SEM
	F-center	340[74]	Room	SEM
	F-center	415[63]	Room	—
	Fe^{3+}	710–950[15]	Room	L
	Fe^{3+}	715[76]	Room	SEM
Scheelite	Cr	420–470[19]	Room	—
$CaWO_4$	Dy^{3+}	490,[12] 576[12]	Room	OM
	Dy^{3+}	480,[15] 575,[6,15] 663,[15] 750[15]	Room	L
	Er^{3+}	527,[6] 545,[15] 553,[6] 615,[6] 1540[15]	Room	L
	Er^{3+}	616,[12] 703[12]	Room	OM
	Er^{2+}	442[6]	Room	L
	Ho^{3+}	543[6]	Room	L

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
	MoO_4^{2-}	560[15]	Room	L
	Nd^{3+}	417,[6] 900,[6] 1070,[6] 1340[6]	Room	L
	Pr^{3+}	607[6]	Room	L
	Sm^{3+}	600,[12] 649[12]	Room	OM
	Sm^{3+}	609,[6] 647[6]	Room	L
	Tb^{3+}	380,[15] 414,[6] 436,[6] 488,[6] 545[6]	Room	L
	Tb^{3+}	415,[33] 436,[33] 458,[33] 475,[33] **490**,[33] **544**,[33] 590,[33] **625**,[33] 655,[33] 675[33]	Room	OM
	Tm^{3+}	364,[15] 452,[15] 453,[6] 700[15]	Room	L
	WO_4^{2-}	**480**(120)[12]	Room	OM
	WO_4^{2-}	**460**(140),[15] **465**(150),[6] **505**(200)[6]	Room	L
	WO_4^{2-}	**435**[77]	Room	
	Yb^{3+}	1013[6]	Room	L
Sellaite MgF_2	Yb^{2+}	482[2]	Room	—
Smithsonite $ZnCO_3$	—	650[78]	Room	—
Sodalite $Na_8(Al_6Si_6O_{24})Cl_2$	S_2^{1-}	633,[15] 655,[15] 678,[15] 708[15]	Room	L
Spinel $MgAl_2O_4$	Cr^{3+}	698[15]	Room	L
	Cr^{3+}	690[57]	Room	OM
	Mn^{2+}	521.6,[10] 525(50)[57]	Room	OM
Spodumene $LiAlSi_2O_6$	Mn^{2+}	417,[79] 602[79]	—	SEM
	Mn^{2+}	596[15]	Room	L
	Mn^{2+}	595[18]	Room	XL
Strontianite $SrCO_3$	Dy^{3+}	485,[52] 575,[52] 660[52]	Room	OM
	Dy^{3+}	477,[7] 575[7]	Room	—
	Eu^{2+}	410(80)[12]	Room	OM
	Eu^{2+}	417[7]	Room	—
	Mn^{2+}	625[12]	Room	OM
	Mn^{2+}	590[20]	Room	—
	Sm^{3+}	600,[52] 642,[52] 700[52]	Room	OM
	Sm^{3+}	569,[7] 600,[7] 640,[7] 700[7]	Room	—
	Tb^{3+}	545[52]	Room	OM
Sylvite KCl	Yb^{2+}	432[2]	Room	—
Thorite $ThSiO_4$	Eu^{3+}	591,[15] 615,[15] 702[15]	Room	L
	Nd^{3+}	872[15]	Room	L
	Sm^{3+}	642[15]	Room	L
	UO_2	530(60)[15]	Room	L
Titanite $CaTiSiO_5$	Cr^{3+}	686,[6] 790(110)[6]	Room	L
	Er^{3+}	820,[6] 978[6]	Room	L
	Eu^{3+}	563,[6] 620,[6] 703[6]	Room	L
	Nd^{3+}	735,[6] 756,[6] 867,[6] 880,[6] 906,[6] 1089[6]	Room	L
	Pr^{3+}	487[6]	Room	L
	Sm^{3+}	562,[6] 600[6]	Room	L
	Tm^{3+}	805[6]	Room	L
Topaz $Al_2SiO_4F_2$	Cr^{3+}	684,[15] 711,[15] 734[15]	Room	L
	Ti^{4+}	455(80)[15]	Room	L
Willemite Zn_2SiO_4	Mn^{2+}	525[80]	Room	SEM
Witherite $BaCO_3$	—	**525**,[7] **550**[7]	Room	—

(*continued*)

Table 1. *Continued*

Mineral	Identification/ Activation	Lines (nm)	Temperature (K)	Method
Wollastonite	Cr^{3+}	840[6]	Room	L
$CaSiO_3$	Fe^{3+}	700[6]	Room	L
	Mn^{2+}	603[6]	Room	L
	Mn^{2+}	550(120)[21]	Room	SEM
	Mn^{2+}	560,[2] 565,[52] 620[2]	Room	—
Zircon	Dy^{3+}	**483**,[81] **580**[81]	300	IL
$ZrSiO_4$	Dy^{3+}	**485**,[82] **580**,[82] 665,[82] 755,[82] 840[82]	205	SEM
	Dy^{3+}	480,[52] 575[52]	Room	—
	Er^{3+}	1530,[6] 1568[6]	Room	L
	Er^{3+}	**325**,[82] **405**,[82] **480**,[82] 530,[82] 550–560,[82] 620[82]	205	SEM
	Eu^{3+}	560,[82] 595,[82] 620–635,[82] 710[82]	205	SEM
	Fe^{3+}	783(120),[6] **790**[15]	Room	L
	Gd^{3+}	**314**[81]	300	IL
	Gd^{3+}	315,[82] 630[82]	205	SEM
	Ho^{3+}	**550**,[82] **660–670**,[82] **760**[82]	205	SEM
	Ho^{3+}	546(10),[6] 660(10),[6] 673[6]	Room	L
	Ho^{3+}	320,[81] 360,[81] 415[81]	300	IL
	Intrinsic	230,[82] 290,[82] 310,[82] 330,[82] 355,[82] 380[82]	205	SEM
	Intrinsic	590[52]	Room	—
	Intrinsic	590[15]	Room	L
	Pr^{3+}	490,[81] 530,[81] **595**,[81] **618**,[81] 719,[81] 742,[81] 791,[81] 837,[81] 870,[81] 903,[81] 923,[81] 986,[81] 1026[81]	300	IL
	Pr^{3+}	595,[82] 620[82]	205	SEM
	SiO_m^{n-}	620[81]	300	IL
	SiO_m^{n-}	590[15]	Room	L
	Sm^{3+}	575,[82] 655–670,[82] 610–620,[82] 725[82]	205	SEM
	Tb^{3+}	385,[82] 415,[82] 440,[82] **490**,[82] **550**,[82] 590,[82] 625,[82] 655–685,[82] 765,[82] 835[82]	205	SEM
	Tm^{3+}	348,[6] 457,[6] 483[6]	Room	L
	Tm^{3+}	290,[82] **345–360**,[82] 380,[82] **455–480**,[82] 510–520,[82] 580,[82] 650–665,[82] 700,[82] 730,[82] 755,[82] 790–800[82]	205	SEM
Zirconia ZrO_2	TiO_6	500(150)[57]	Room	SEM
Zoisite	Dy^{3+}	575[15]	Room	L
$Ca_2Al_3(SiO_4)_3(OH)$	Eu^{2+}	440(80)[15]	Room	L
	Tb^{3+}	544[15]	Room	L
	V^{2+}	718[15]	Room	L

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[75]Hirata et al. (2005)
[76]Ponahlo (1999)
[77]Randall (1939)
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[81]Finch et al. (2004)
[82]Cesborn et al. (1995)

Table 2. Luminescence Lines, Activators, Temperature, and Technique for Materials

Material	Identification/ Activation	Lines (nm)	Temperature (K)	Method
Al_2O_3 nanoceramic	—	288,[1] 326,[1] 387[1]	Room	SEM
	Anion vacancies	517[1]	Room	SEM
Al_2O_3 (β-Alumina)	Cr^{3+}	689[2]	Room	SEM
	Mn^{2+}	518[2]	Room	SEM
AlN	Er^{3+}	405,[3] 475,[3] 540,[3] 560,[3] 625,[3] 670,[3] 770,[3] 810,[3] 870,[3] 910,[3] 1000[3]	Room	SEM
BN (cubic)	—	413[4]	Room	SEM
BaFBr	Yb^{2+}	500[5]	Room	—
BaFCl	Yb^{2+}	525[5]	Room	—
$BaLiF_3$	Yb^{2+}	467[5]	Room	—
$Ba_3(PO_4)_2$	Yb^{2+}	435[5]	Room	—
$BaTiO_3$	Intrinsic	465(120)[6]	Room	SEM
$CaB_2O(Si_2O_7)$	Yb^{2+}	538[5]	Room	—
CaFBr	Yb^{2+}	410[5]	Room	—
$CaGa_2S_4$	Yb^{2+}	580[5]	Room	—
$Ca_3MgSi_2O_8$	Eu^{2+}	475(50)[7]	Room	—
Ca_2PO_4Cl	Yb^{2+}	455[5]	Room	—
CaS	Yb^{2+}	747[5]	Room	—
CaS:As	—	615[8]	Room	OM
CaS:Cu	—	475[8]	Room	OM
CaS:Pb, Cu	Cu^{+}	420[9]	Room	OM
CaS:Pb, Cu	Cu^{+}	430[9]	Room	UV
Cd_4SiS_6	—	481,[10] 514,[10] 521,[10] 538,[10] 591,[10] 920[10]	LN	SEM
CdS	—	488,[10] 492[10]	LN	SEM
CdS (Si doped)	—	494,[10] 509,[10] 514,[10] 520[10]	LN	SEM
CdSe	—	685,[10] 688[10]	LN	SEM
CdSe (Si doped)	—	719,[10] 940,[10] 990[10]	LN	SEM
CdTe	—	886[11]	Room	SEM
	Defect	1033[11]	Room	SEM
	—	789,[10] 808[10]	LN	SEM
CdTe (Si doped)	—	786,[10] 880[10]	LN	SEM
CsBr	Eu^{2+}	440,[12]520[12]	290	OM
GaP	Intrinsic	827[13]	Room	SEM
GaN (hexagonal)	Donor-acceptor pair	365,[14] 387[14]	85	SEM
	Exciton	355,[14] 357[14]	85	SEM
	Near band edge	365[15]	Room	SEM
	Cr^{3+}	694[16]	11	OM
	Tb^{3+} (major lines)	383,[16] 419,[16] 423,[16] 487,[16] 545,[16] 547,[16] 551,[16] 558,[16] 586[16]	11	OM
	Yb^{3+}	932,[17] 945,[17] 953,[17] 975,[17] 979,[17] 980,[17] 987,[17] 993,[17] 994,[17] 1001,[17] 1006,[17] 1015,[17] 1022,[17] 1033,[17] 1038[17]	11	OM
	—	420,[15] 564[15]	Room	SEM
	—	425,[14] 556,[14] 614,[14] 678[14]	87	SEM
GaN(Si) (hexagonal)	Dy^{3+}	456,[18] 482,[18] 488,[18] 564,[18] 580,[18] 602,[18] 660,[18] 670,[18] 742,[18] 755,[18] 767,[18] 827,[18] 843[18]	411	SEM
	Er^{3+}	383,[18] 409,[18] 478,[18] 488,[18] 539,[18] 560,[18] 625,[18] 757,[18] 768,[18] 811,[18] 822,[18] 878,[18] 987,[18] 1000[18]	411	SEM
	Tm^{3+}	478,[18] 511,[18] 536,[18] 560,[18] 592,[18] 648,[18] 655,[18] 774,[18] 781,[18] 804,[18] 841[18]	411	SEM
InP	Intrinsic	886[13]	Room	SEM
InGaN	—	430–490[19]	Room	SEM
$(InN)_x(InGaN)$	Intrinsic	360–480 ($x = 0$–0.23)[20]	Room	SEM

(continued)

Table 2. *Continued*

Material	Identification/ Activation	Lines (nm)	Temperature (K)	Method
KBr	Yb^{2+}	442[5]	Room	—
KI	Yb^{2+}	431[5]	Room	—
$KMgF_3$	Yb^{2+}	408[5]	Room	—
$LiSrAlF_6$	Yb^{2+}	440[5]	Room	—
$MgTiO_3$	O defect	410[21]	Room	UV
	Eu^{3+}	615[21]	Room	UV
Mg_2TiO_4	Eu^{3+}	658[21]	Room	UV
$Mg_2Ti_2O_5$	Eu^{3+}	615[21]	Room	UV
$PbWO_4$	—	540(40),[22] 620(60)[22]	Room	L
RbCl	Yb^{2+}	426[5]	Room	—
SiC-6H (polytype)	Al	500(100)[23]	Room	SEM
	B	700(100)[23]	Room	SEM
	Be	600(100)[23]	Room	SEM
	Defect	520(120)[23]	Room	SEM
	Sc	570(100)[23]	Room	SEM
SiO_2	Intrinsic	460[24]	300	UV
(*See also* Table 1, Quartz)	Si related center	460[25]	—	UV
	Defect	636[26]	—	UV
	Intrinsic	451,[27] 561[28]	—	OM
	Intrinsic	288,[29] 400,[30] 468[29]	—	UV
	Intrinsic	(Low OH) 590,[31] (high OH)620[31]	—	—
	Eu^{3+}	622[32]	Room	SEM
	Fe^{3+}	695[33]	873	—
	Ge	400[25]	293	UV
	Mn^{2+}	510[33]	873	—
	E′ center	459[34]	—	SEM
	Impurity	415[28]	—	—
	Interstitial oxygen	1273,[35] 1281[35]	—	UV
	Interstitial oxygen	1278,[36] 1281[37]	290	SEM
	Oxygen defect	282,[36] 459[36,37]	290	SEM
	O vacancy	459[38]	Room	L
	$O(^1D) - O(^3P)$	653[39]	—	UV
	NBOHC	620,[40] 653,[30,40,41] 670[26]	—	—
	NBO defect	653[42]	—	—
	STE	470[26]	—	UV
	STE	539[36]	—	—
	—	400–800[32]	Room	SEM
	—	649[28]	—	SEM
	—	558,[27] 636[27]	—	OM
	—	310–620,[30] 460,[30] 468[31]	—	UV
$SrAlF_5$	Yb^{2+}	405[5]	Room	—
SrB_4O_7	Yb^{2+}	361[5]	Room	—
$Sr_2B_5O_9Cl$	Yb^{2+}	421[5]	Room	—
$Sr_2B_5O_9Cl$	Yb^{2+}	420[5]	Room	—
$SrCl_2$ (cubic)	Yb^{2+}	408[5]	Room	—
SrF_2	Yb^{2+}	800[5]	Room	—
SrFBr	Yb^{2+}	416[5]	Room	—
SrFCl	Yb^{2+}	401[5]	Room	—
$Sr_2MgSi_2O_7$:Eu, Dy	Eu^{2+}	450–550[43]	Room	PL
$Sr_3(PO_4)_2$	Yb^{2+}	442[5]	Room	—
$Sr_5(PO_4)_3Cl$	Yb^{2+}	450,[5] 560[5]	Room	—
α-$Sr_2P_2O_7$	Yb^{2+}	453[5]	Room	—
SrS:Cu	—	530[8]	Room	OM

(*continued*)

Table 2. *Continued*

Material	Identification/ Activation	Lines (nm)	Temperature (K)	Method
Y_2SiO_5 on nano SiO_2	Ce^{3+}	443[44]	Room	UV
	Eu^{3+}	320,[44] 364,[44] 384,[44] 397,[44] 468,[44] 612[44]	Room	UV
	Tb^{3+}	247,[44] 489,[44] 543,[44] 585,[44] 625[44]	Room	UV
ZnO	—	387,[45] 620[45]	Room	SEM
ZnS (thin film Sn doped)	—	405[46]	Room	SEM
ZnS (thin film Al doped)	Al^{3+}	490[46]	Room	SEM
	Defect	430[46]	Room	SEM
	Self-activated center	399[46]	Room	SEM
	—	600[46]	Room	SEM
ZnS (bulk)	Bandgap	346[47]	Room	PL
	Mn^{2+}	588[47]	Room	PL
	Mn^{2+}	578[48]	Room	SEM
ZnS (nanocrystal)	Cu	460(60),[49] 507(60)[49]	Room	L
	Cu^{2+}	480(130)[50]	Room	L
	Cu^{2+}	470(130)[51]	4	SEM
	Cu^{2+}	600[51]	Room	SEM
	Defect	426(35)[52]	40	PL
	Defect	433(45)[52]	275	PL
	Defect	520[47]	Room	PL
	Eu	518(120)[49]	Room	L
	Mn^{2+}	590(60)[49]	Room	L
	Mn^{2+}	435(25)[52]	275	PL
	Mn^{2+}	600(20)[52]	40	PL
	Mn^{2+}	585,[47] 610[47]	Room	PL
	Mn-Mn pair	700,[47] 720[47]	—	—
ZnSe	—	477,[53] 585,[53] 660[53]	—	SEM
	—	459[53]	—	UV

[1]Gorbunov et al. (2005)
[2]Karakus (2005)
[3]Gurumurugan et al. (1999)
[4]Manfredotti et al. (2006)
[5]Dorenbos (2003)
[6]Kobayashi et al. (1998)
[7]Lin et al. (2001*a*)
[8]Singh et al. (1981)
[9]Choi et al. (2004)
[10]Odin et al. (2001)
[11]Petrov (1996)
[12]Zorenko et al. (2006)
[13]Tiginyanu et al. (2004)
[14]Díaz-Guerra et al. (2003)
[15]Sun et al. (2002)
[16]Gruber et al. (2002)
[17]Jadwisienczak and Lozykowski (2003)
[18]Lozykowski et al. (1999)
[19]Choi et al. (2003)
[20]Martin et al. (2002)
[21]Kominami et al. (2006)
[22]Anicete-Santos et al. (2007)
[23]Saparin et al. (1996)
[24]Guzzi et al. (1987)
[25]Skuja and Trukhin (1989)
[26]Griscom (1985)
[27]Wang et al. (1988)
[28]Koyama (1980)
[29]Skuja et al. (1984*b*)
[30]Nishikawa et al. (1992)
[31]Friebele et al. (1985)
[32]Can et al. (1995)
[33]Pott and McNicol (1971)
[34]McKnight and Palik (1980)
[35]Skuja et al. (1998)
[36]Stevens-Kalceff et al. (2002)
[37]Stevens-Kalceff (2000)
[38]Tohmon et al. (1989)
[39]Awazu and Kawazoe (1990)
[40]Munekuni et al. (1990)
[41]Skuja et al. (1984*a*)
[42]Sigel and Marrone (1981)
[43]Lin et al. (2001*b*)
[44]Lin et al. (2006)
[45]Mei et al. (2006)
[46]Hichou et al. (2004)
[47]Toyama et al. (2000)
[48]Bulanyi et al. (2003)
[49]Xu et al. (1998)
[50]Bhagwat et al. (1995)
[51]Bol et al. (2002)
[52]Chen et al. (2002)
[53]Godlewski et al. (2003)

quartz and SiO_2 studies, a range of terms such as Defect, Non-Bridging Oxygen Hole (NBOHC), Oxygen π, Self-Trapped Exciton (STE), and $AlO_4|M^+$ have all been used to describe the intrinsic luminescence and are recorded in the database. Historically, where a mineral has had significant interest and study, such as diamond, then other terms have been introduced to describe the luminescence origin. In diamond the usual designation of center in the infrared spectra is labeled A, while the usual designations of the luminescence and absorption centers are labeled H3, S3, and GR1. These have all been recorded within the luminescence database.

One of the key points that luminescence database demonstrates is that many activators change their emission wavelength or energy depending upon the structure type, symmetry, and associated atom, thus reflecting the local crystal field information. For example, the activator Yb^{2+} has been studied in a range of materials, and peak shifting has been attributed to local crystal symmetry (Dorenbos, 2003). This illustrates the importance of knowing the local chemistry and crystal information when trying to determine the activator present by observing the luminescence emission spectra.

Conclusions

The analysis of luminescence spectra of ionic species in minerals and materials can be enhanced by the ability to inspect major and minor lines in the luminescence database. Understanding of the factors that control luminescence activation and quenching in minerals and materials is also possible by studying shifts in peak position and intensity with structural variation. This is important where new minerals or materials are being analyzed. Continuing developments in the understanding of the origin of lines and spectral features will aid in the quantification of luminescence spectroscopy. Through the use of the luminescence database, additional insight into the chemistry can be gained and by combining with other traditional X-ray measurements collected on the same region, will result in faster understanding of minerals and materials. The wealth of information presented in this luminescence database indicates that a large number of research groups routinely employ luminescence analysis as a key macro- and microcharacterization technique in the study of minerals and materials.

A subsequent article will describe software tools and Web access to the database. It is the author's intention to make the database easily accessible and provide a procedure for external users to add new lines and spectra from minerals and materials.

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