Energy transfer and luminescence properties of novel Na$_{3.6}$Y$_{1.8-x}$(PO$_4$)$_3$:Dy$^{3+}$ phosphor

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Inorganic materials with intense luminescence are widely applied in lighting, security systems, medicine, high energy physics, etc. The requirements for their properties depend on the potential application and can differ significantly. However, for the overwhelming majority of phosphors a high light output and temperature stability of luminescence intensity is important. At present thermal quenching is still a main obstacle for phosphor applications in pcLEDs. Dy doped phosphors are attractive for such application because emission spectrum of Dy$^{3+}$ consists of several narrow groups of lines, which covers visible spectral region. In recent years, an active search for novel materials with zero-thermal-quenching has been provided [Y.H. Kim et al. // Nature Materials. – 2017. – Vol. 16. – S43-505].

Here we present the results of the study of the luminescence properties of novel Na$_{3.6}$Y$_{1.8-x}$(PO$_4$)$_3$:Dy$^{3+}$ (NYP:xDy) phosphor.

**Motivation**

The samples were single-phased and crystallized in a NASICON-type structure isomorphous to Na$_4$Sc$_3$(PO$_4$)$_2$. Refined space group is P6$_3$. There is a maximum at $x = 0.04$ in the concentration dependence of the unit cell. It can be related to substitution Y$^{3+}$ ($x = 5.90$ A) by Dy$^{3+}$ ($x = 0.11$ A) ions. Decrease of the unit cell volumes at $x > 0.04$ is connected with a changing of the cathionic ordering.

**Experimental details**

The luminescence intensity reaches its maximum at $x = 0.02$.

The luminescence intensity at $x = 0.04$ is due to concentration quenching. Linear fit of log(I/x) vs $x$ dependence allowed to determine that the concentration quenching in NYP:Dy$^{3+}$ occurs due to the dipole-dipole interaction between neighbouring Dy$^{3+}$ ions.

The brightest sample with $x = 0.04$ is characterized by colour coordinates (0.361, 0.394) and the highest CCT value - 4629 K.

**Crystal structure**

The temperature dependence of the intensity of the intrinsic emission (230 nm) demonstrates a strong thermal quenching (more than an order of magnitude).

The intensity of the 420 nm emission from the defect-related center decreases only slightly.

The intensity of the Dy$^{3+}$ emission (580 nm) decreases by 23% under the interband excitation.

The absence of thermal stability may be an obstacle for application of NYP:Dy phosphors in lighting.

**Conclusions**

1. A series of Na$_{3.6}$Y$_{1.8-x}$(PO$_4$)$_3$:Dy$^{3+}$ ($x = 0.01-0.4$) phosphors was synthesized by high-temperature solid-state method for the first time. PXRD study reveals that continuous solid solution with NASICON-type structure forms at $0 \leq x \leq 0.4$.

2. Luminescence properties of the phosphors were studied using the methods of UV and VUV spectroscopy. Narrow emission bands originating from incoherent transitions in Dy$^{3+}$ were detected and optimal concentration of the dopant determined. The concentration quenching of Dy$^{3+}$ emission is shown to be due to dipole-dipole interaction.

3. Two broad bands were detected in the UV and blue spectral regions, which were ascribed to the intrinsic emission of self-trapped excitons and defect-related centers, respectively. Optical bandgap energy of Na$_{3.6}$Y$_{1.8-x}$(PO$_4$)$_3$ was estimated to $E_g = 7.1$ eV. Influence of temperature on luminescence characteristics was studied.