

## Erbium (III) tris(8-hydroxyquinoline) (ErQ): A potential material for silicon compatible 1.5 $\mu\text{m}$ emitters

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Samples of erbium (III) tris(8-hydroxyquinoline) (ErQ) have been prepared and their photoluminescence measured. Clearly resolved peaks due to intra-atomic transitions between the  $^4I_{13/2}$  and  $^4I_{15/2}$  levels can be observed at room temperature. The possibility of depositing ErQ on to silicon to produce organic electroluminescent diodes offers the possibility of a cheap 1.5  $\mu\text{m}$  emitter based on silicon technology. © 1999 American Institute of Physics. [S0003-6951(99)02006-9]

Erbium doped materials have attracted considerable attention due to their potential applications in optoelectronics. This is because the  $\text{Er}^{3+}$  ion shows sharp luminescence centered around 1.5  $\mu\text{m}$  due to an intra- $4f$  shell transition between the first excited state ( $^4I_{13/2}$ ) and the ground state ( $^4I_{15/2}$ ). In order to produce a 1.5  $\mu\text{m}$  emitter technology based on silicon, a number of groups have investigated the incorporation of erbium into silicon often with the incorporation of co-dopants, such as oxygen and fluorine.<sup>1</sup> Whilst this approach does show some promise, there are still problems in obtaining efficient luminescence at room temperature.

Electroluminescence from organic materials has been the subject of increasing interest in recent years. In 1987, Tang and VanSlyke<sup>2</sup> showed that it was possible to obtain visible electroluminescence, with a peak emission wavelength of  $\sim 510$  nm, from aluminium tris(8-hydroxyquinoline) (AlQ) based diodes. Since then considerable work has been done on improving the brightness, efficiency, and reliability of organic light emitting devices (OLEDs) and AlQ has remained one of the most widely used emitting materials. In this letter, we present some preliminary photoluminescence studies of the organic chelate erbium (III) tris(8-hydroxyquinoline) (ErQ) (see Fig. 1), which shows bright 1.5  $\mu\text{m}$  photoluminescence at room temperature and we discuss its potential for integration into a silicon compatible light emitting diode.

Samples of ErQ were placed in a quartz curvette and excited using various lines from an argon ion laser at power densities between 0.1 and 10  $\text{W}/\text{cm}^2$ . Photoluminescence spectra were recorded, at room temperature, for both the ‘‘band-edge’’ luminescence, using a 0.5  $\mu\text{m}$  Blaze grating and a S-20 photomultiplier, and for the 1.5  $\mu\text{m}$  erbium related luminescence, using a 1  $\mu\text{m}$  Blaze grating and a liquid nitrogen cooled Ge detector. The resolution of the system was 0.8 nm for all spectra.

Figure 1 shows the band-edge photoluminescence spectra of a sample of ErQ excited with a defocused 70 mW, 351 nm line from an argon ion laser. This band-edge luminescence is slightly weaker than the corresponding emission from the related group III metal chelates, and the main peak

is considerably shifted towards lower energies with a peak at  $\sim 600$  nm (cf.  $\sim 520$  nm for the group III chelates) and a weaker peak at  $\sim 415$  nm. Figure 2 shows the erbium related photoluminescence excited using the 457 nm argon ion line. From this spectra, it can be seen that there are sharp, clearly resolved lines with the brightest line, due to the first excited state ( $^4I_{13/2}$ ) to ground state ( $^4I_{15/2}$ ) occurring at 1525 nm. This is shifted somewhat from the  $\sim 1535$  nm emission seen from erbium in other matrices<sup>1</sup> and is probably a reflection of the site symmetry in this host. Although the absorption spectra of ErQ shows only weak absorption for wavelengths longer than  $\sim 470$  nm (see Fig. 3), we found very little difference in the erbium related photoluminescence intensity for excitation with any of the argon ion laser lines, 351, 363, 457, 476, or 488 nm. This may be due to the thick powdered samples used in these experiments which allowed all of the beam energy to be absorbed independent of the excitation wavelength. Figure 3 also shows the absorption between 470 and 570 nm on an expanded scale, this inset clearly shows a sharp absorption line at 520 nm which is probably due to the  $^2H_{11/2}$  or  $^4S_{3/2}$  levels. A sharp feature can also be seen at

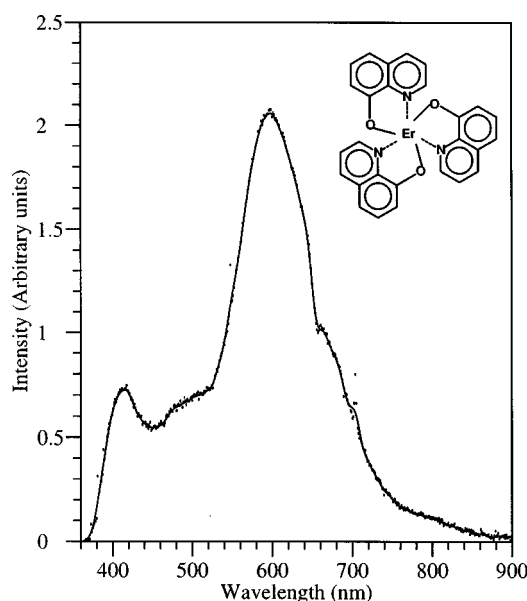


FIG. 1. The 300 K band-edge photoluminescence of ErQ (inset) excited using the 351 nm line from an argon ion laser.

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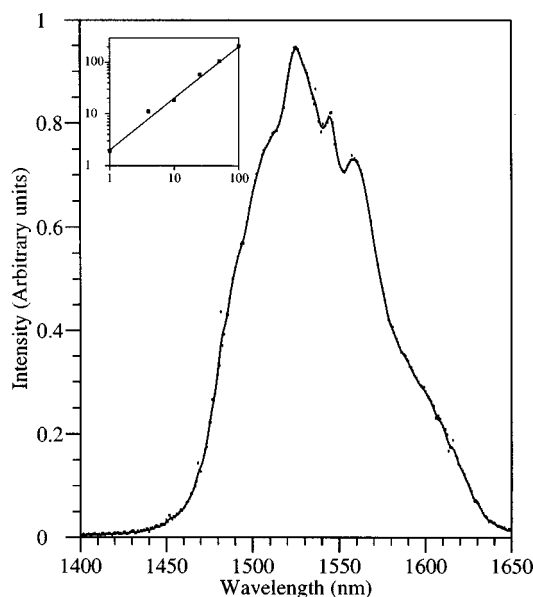


FIG. 2. The 300 K erbium related photoluminescence excited using the 457 nm line from an argon ion laser. The inset shows the integrated intensity of the erbium photoluminescence as a function of excitation power (1–100 mW).

~485 nm which may also be erbium related. Whilst our explanation for the flat response over such a wide range of excitation energies is only a suggestion, the observation of the sharp erbium related features in the absorption precludes direct absorption of the pump in to the  $\text{Er}^{3+}$  ion as being the dominant excitation mechanism in our experiments. It should be noted that all these photoluminescence spectra were recorded at 300 K and the luminescence intensities are at least equal to those obtained from silicon at low temperature which is known to quench as the temperature is increased.<sup>1</sup> The inset to Fig. 2 shows the integrated intensity of the erbium related photoluminescence as a function of the excitation power. This shows a clear linear dependence up to an excitation density of  $\sim 10 \text{ W/cm}^2$ , above this excitation density we started to get “burning” of the ErQ. This result is important as it shows that there are no inherent factors limiting the luminescence up to the excitation intensities we have used. This result also implies that the energy transfer process between the organic ligands, where we believe the absorption is occurring, and the erbium ion is linear, thus with carriers provided through electrical excitation we should be able to get high luminescence intensities.

In 1994, Kim *et al.*<sup>3</sup> produced silicon compatible organic light emitting diodes which were manufactured using *p*-type

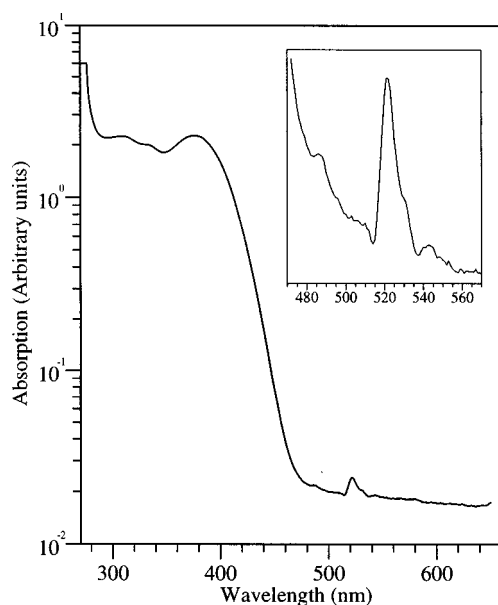


FIG. 3. The 300 K absorption spectrum of ErQ dissolved in 1,1,1-trichloromethane. The inset shows detail of the direct absorption into the erbium ions, the vertical scale on this inset is linear.

silicon as a hole injector with Triphenyl diamine as an organic hole conductor and AIQ as an emitting/electron conducting layer. These diodes produced visible light, from the AIQ, with turn on voltages of  $\sim 10 \text{ V}$ . As a number of other metal chelates of 8-hydroxyquinoline have been successfully used in place of AIQ in OLEDs,<sup>4,5</sup> the replacement of the AIQ with ErQ provides a technologically feasible route to the development of a  $1.5 \mu\text{m}$  light source which can be integrated directly with silicon devices. It may even be possible to use this approach to produce vertical surface cavity emitting lasers operating at  $1.5 \mu\text{m}$  grown on silicon wafers.

In conclusion, we have shown bright  $1.5 \mu\text{m}$ , room temperature luminescence from ErQ and have highlighted the possibility of integrating this material into silicon based light sources.

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