Observation of new vibronic luminescence band in semiconducting diamond

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Steady state and time-resolved photoluminescence studies have been carried out for a new vibronic emission band, with a zero phonon line at 2.395eV, that is observed in type IIb semiconducting diamond. This band exhibits a relatively slow (228 ns) photoluminescence decay that is exponential, and is believed to be due to an internal transition at a defect site.

While the optical properties of natural diamond have been investigated for many years, recent advances in the growth of high quality diamond films by chemical vapour deposition (CVD) have generated a renewed interest in this material for the development of electronic devices for use in adverse conditions. The optical characterisation of these CVD films has relied heavily on the wealth of information that exists from studies of bulk natural and high pressure high temperature (HPHT) synthesised diamonds.

We report the observation of a new vibronic emission band in an HPHT semiconducting diamond (type IIb: boron-doped). Given that diamond has been studied optically for more than four decades, with scores of emission and absorption bands identified, the observation of a new band is relatively unexpected. We believe that our observation of a new emission band may be due to the fact that there have not been very many photoluminescence (PL) studies carried out in bulk semiconducting diamond with exciting photon energies that are well below the ~5.5eV indirect gap. It has been known for some time that in III-V compounds, for example, such excitation conditions are ideal for probing emission bands that involve deep levels or internal transitions [3]. In the present case, we believe that above- or near-gap excitation created by photons (PL) or electrons (cathodoluminescence, CL) creates a situation whereby some emission bands which can be excited efficiently by excitation near midgap cannot compete effectively with the more dominant, and consequently more well-known emissions, and have thus gone unobserved.

The present measurements have been carried out under both steady state and pulsed excitation. The CW measurements employed both visible and UV emission lines of an argon ion laser, and were carried out at 6K. Time-resolved measurements were performed at 10K with the 355 nm frequency-tripled output of a 10ns Q-switched YAG laser. Two boron doped HPHT synthetic samples were studied. Sample 1 was grown using Ni as a solvent-catalyst, whereas for sample 2 Fe-Al was employed. Al was used to getter nitrogen (N), thus lowering the concentration of N and increasing the concentration of neutral boron acceptors through diminished compensation.

In both spectra represented in Fig. 1 we observed the 2.156eV vibronic band associated with N-vacancy complexes [4]. The CW spectra also exhibit a new vibronic system with a zero-phonon line (ZPL) at 2.395eV, and with the main phonon replicas spaced ~51 meV apart. To our knowledge, this band has not previously been reported, because the ZPL (2.395eV) and the main phonon replicas (~51meV) do not appear to match any of the vibronic bands appearing in the literature. Note that both sets of vibronic bands are superimposed on a broad green emission band at ~2.2eV [5] that is observed when excited at 351.1nm, but not under 488.0nm excitation. The dependence of the relative intensities of the 2.156 and 2.395eV bands on excitation wavelength was found to be consistent with a small lattice distortion (i.e. symmetric absorption and emission spectra) of both bands. Absorption measurements are presently under way to confirm this. Under electron excitation (CL), emission in the region of the green band totally dominates that of the 2.395eV band [5]. This, taken with the above results, tends to suggest that excitation near or above the band edge excites efficient processes that dominate the 2.395eV emission, whereas at much lower excitation energies this band is easily seen, as the competing processes are much less important in comparison.

The spectra are all normalised at 2.156eV, so that the slower 2.395eV system appears more intense for later time windows. Inset: exponential PL decay of the 2.395eV band, which is compared to the much faster, nonexponential behaviour of the 2.156eV band at the 2.2eV green emission.

The new vibronic band at 2.395eV is more efficiently excited at 2.156 eV, whereas at much lower excitation energies this band is easily seen, as the competing processes are much less important in comparison.

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2.156 eV band decay is consistent with the literature value of 29 ns [4]. In contrast, the 2.395 eV decay exhibits a sharp decrease at early times, which is associated with the fast decay of the broad green band background (see Fig. 2), followed at later times by the decay of the 2.395 eV ZPL itself, which we have observed to be accurately exponential for well over two orders of magnitude (not evident in Fig. 2). The 228 ns exponential decay time is relatively long for a vibronic band in diamond, as most of the reported decay times of defect emissions in diamond are a few to tens of nanoseconds [6]. The enhanced intensity of the 2.156 eV phonon sidebands in the 0–50 ns time window is the result of contributions from both the broad green band as well as a broad red emission that has been reported recently [5].

At present, a precise identification of the origin of the 2.395 eV band is not possible. However, from the exponential nature of the decay it can be concluded that this emission band most likely results from an internal transition associated with a point defect or complex centre, and that there are no efficient recombination pathways to compete with the emission under these excitation conditions. The latter may not be the case under above-gap excitation. While the 2.395 eV system is observed quite easily in sample 2, it is not observed in sample 1, and it is seen to be very weak in two natural type IIb diamonds. The presence of this band seems to correlate with higher concentrations of uncompensated boron acceptors. It is thus tempting to identify this band with a complex involving boron, but measurements on a wider range of specimens will be necessary to confirm this interpretation.

References

High temperature superconductor lumped element resonator

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The authors have studied a high temperature superconducting (HTS) lumped element resonator consisting of an inductance and capacitance in parallel. It has a low power unloaded quality factor  of Q, in excess of 9000 at 5.7 GHz and 1 K. The resonator is just over 1 mm square significantly smaller than any other device with comparable Q at this centre frequency. The authors also investigate the implementation of the resonator in a bandstop filter.

Introduction: The aim of these designs and investigations is to demonstrate the application of planar lumped elements in the gigahertz range and the effect of using HTS material, in this case thin films of YBa2Cu3O7 (YBCO) on MgO substrates. Lumped element devices, with dimensions smaller than a wavelength, can offer considerable size-saving while still maintaining the performance of equivalent larger devices made using normal metal. The use of a coplanar structure has also made mounting and fabrication easier because only one side of the film requires deposition. Details of the film deposition and device packaging are given in [1].