

IMPROVED FLUORIDE GLASSES FOR 1.3 $\mu$ m OPTICAL AMPLIFIERS

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## ABSTRACT

We report preliminary materials results of a study to develop novel fluoride glasses exhibiting maximum phonon energies lower than ZBLAN with the objective of realising an efficient optical amplifier for the coveted 1.3 $\mu$ m wavelength domain. Pertinent material attributes including peak phonon energy,  $^1G_4$  lifetimes and thermal properties are reported for each glass host.

## 1. INTRODUCTION

Silica telecommunications fibres exhibit a low-loss window in the wavelength region  $\sim 1.29$  to  $1.32\mu$ m, where the majority of existing optical telecommunications operate. An optical fibre amplifier operating in this region is sought in order to fully utilize the available capacity and to upgrade previously installed networks. Likely dopant candidates for fibre amplifiers operating at this wavelength are Nd<sup>3+</sup> and Pr<sup>3+</sup> with the latter emerging as the most promising following the pioneering work of Ohishi et al [1]. In silica and other high phonon energy glasses, emission from the  $^1G_4$  level of Pr<sup>3+</sup> is heavily quenched owing to multiphonon relaxation to the underlying  $^3F_4$  level. In fluorozirconate glasses Pr<sup>3+</sup> emits at the required wavelength but the resulting amplifier is comprised by a low gain coefficient. The best reported gain coefficient for a Pr<sup>3+</sup>-doped ZBLAN fibre amplifier is 0.21dB/mW [2]. This compares with 11dB/mW for an erbium-doped silica fibre amplifier operating in the 1.5 $\mu$ m wavelength region. This low gain coefficient is a direct result of the dominant multiphonon decay from the  $^1G_4$  level to the underlying  $^3F_4$  level leading to low radiative quantum efficiency for the  $^1G_4$ - $^3H_5$  transition. Carter et al [3] have measured the quantum efficiency for the  $^1G_4$ - $^3H_5$  transition at 1.3 $\mu$ m to be  $0.7 \pm 0.5\%$  in a ZBLANP fibre.

The non-radiative decay rate  $\omega_p$  due to multiphonon relaxation depends on the energy gap

### 3. RESULTS

#### 3.1 Spectroscopic Analysis

Table 1 summarizes the multi-phonon cut-off edge, the centre position of the highest phonon energy peak and the measured  ${}^1G_4$  lifetimes for the different fluoride glasses melted. Figure 1 shows the pertinent Raman spectrum for each glass-type, except ZBLAN. The cadmium fluoride glass Cd1 is seen to exhibit a maximum phonon energy peak centred at  $\sim 378\text{cm}^{-1}$ , associated with the Cd-F bond (Figure 1(a)). On varying the composition of glass Cd1 to Cd2 we see a weakening of the vibration around  $378\text{cm}^{-1}$  and the strengthening of the peak at  $236\text{cm}^{-1}$ , (Figure 1(b)). The strengthening of this peak is mirrored by an increase in the multi-phonon cut-off edge. The radical difference between the two cadmium fluoride glasses arises from a progressive replacement of Cd-F bonds by Cd-Cl bonds, with the  $\text{CdCl}_2$  being formed at the glass making temperature from a  $\text{CdF}_2$  containing starting mixture.

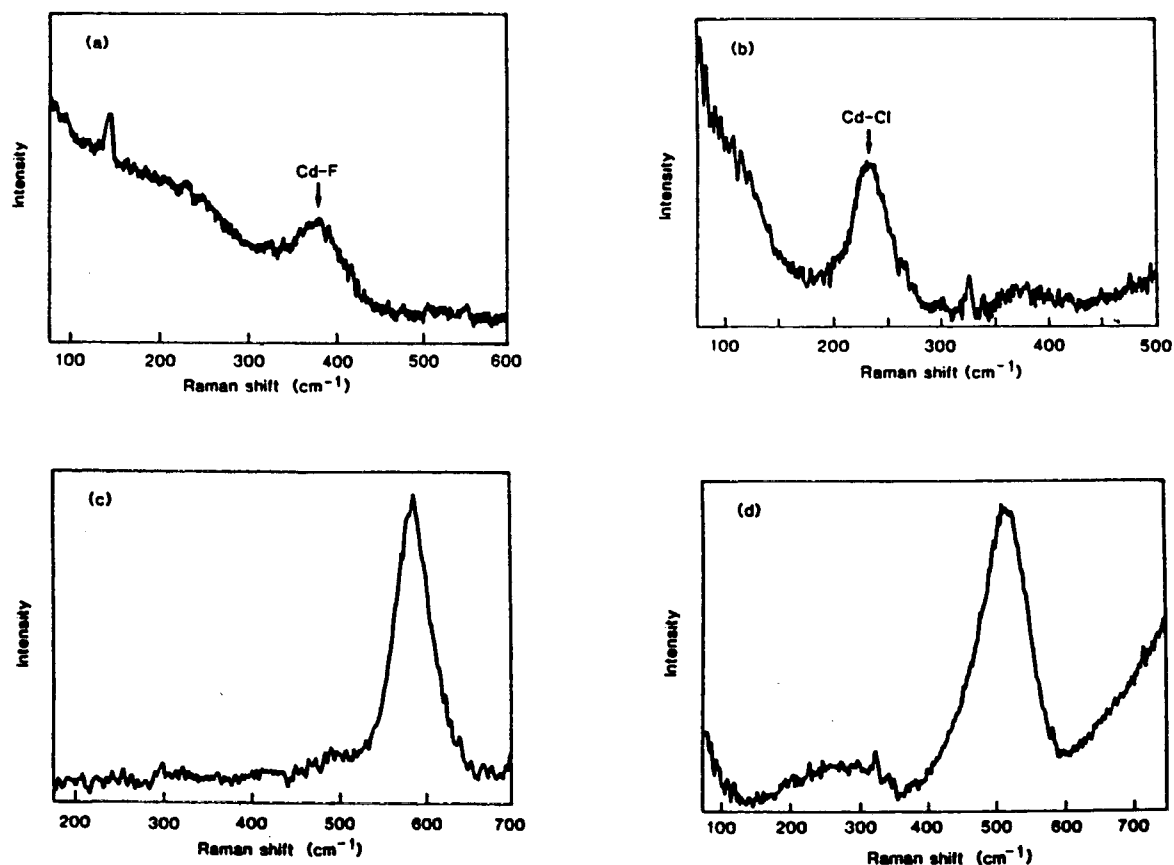


Figure 1 Raman spectrum for (a) Cd1, (b) Cd2, (c) Hf1 and (d) In1

The fluorohafnate and indium fluoride glasses are seen to have maximum phonon energy peaks centred at approximately  $580$  and  $515\text{cm}^{-1}$  respectively. Once again the multiphonon cut-off edge is seen to shift to a longer wavelength for the glass with the lower maximum phonon energy. However, it should be noted that the multiphonon cut-off edge is a convolution of all vibrational modes in a glass. Hence it is possible to achieve a shift in the multiphonon cut-off edge without altering the maximum phonon energy. The

energy barrier ( $\Delta\epsilon$ ) which is related to the rate of devitrification. For ease of fibre drawing a glass should exhibit large values of  $T_x - T_g$  and  $H$ , and a small value for  $T_m - T_x$ .

**Table 3 : Summary of the Thermal Properties of the New Fluoride Glasses**

Samples	$T_g$ (°C)	$T_x$ (°C)	$T_m$ (°C)	$T_x - T_g$ (°C)	$T_m - T_x$ (°C)	$H$	$\Delta\epsilon$ KJ/mole
Cd1	186	245	-	59	-	-	158
Cd2	132	217	305	85	88	0.97	-
Cd3	132	230	305	98	75	1.31	-
In1	306	426	-	120	-	-	-
Hf1	330	419	577	89	158	0.56	-
Hf3	330	430	520	100	90	1.11	-
ZBLAN	262	352	455	90	103	0.87	195

From Table 3 we see that the cadmium fluoride glass composition has undergone optimisation to exhibit a larger  $T_x - T_g$  gap and smaller  $T_m - T_x$  gap in comparison with ZBLAN, resulting in a significantly higher value of  $H$ , for Cd3 relative to ZBLAN. Following the same criteria, the fluorohafnate system is better than ZBLAN (compare Hf3 with ZBLAN) and as a consequence of its higher  $T_g$  is more thermally stable. With regard to the thermal stability of the cadmium fluorides it should be noted that while low phonon energies are associated with weak bond strengths, high values for  $T_g$  and  $T_m$  (which lead to enhanced thermal stability) generally require strong bonds between the network-forming structural units.

#### 4. CONCLUSIONS

Cadmium fluoride glasses with maximum phonon energies significantly lower than ZBLAN have been developed and a corresponding increase in the  ${}^1G_4$  lifetimes observed. These glasses have undergone optimisation to the point where they now compare favourably with ZBLAN in terms of  $H$ . Effort is currently being directed at improving the thermal stability of these glasses and reducing the level of impurities.

#### 5. ACKNOWLEDGEMENTS

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