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LONG LIFETIME SILICATE LASER GLASS COMPOSITIONS

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Final Report LLNL P.O. 4813705

Long Lifetime Silicate Laser Glass Compositions

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240

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Introduction:

This contract had as target the development of a silicate laser glass with the following properties:

1. Fluorescence lifetime greater than LG-660
2. Induced emission cross-section greater than $1.5 \times 10^{-20} \text{ cm}^2$
3. Tank meltability

In order to obtain such a glass, the compositional space between LG-660 and LG-650 was to be investigated.

The Nd^{3+} concentration for a megajoule laser glass will be between 5 and $8 \times 10^{20} \text{ ions/cm}^3$. Since concentration quenching is most severe at higher concentrations, we elected to test all glasses with a concentration of approximately $8 \times 10^{20} \text{ Nd}^{3+} \text{ ions/cm}^3$, with the exception of glass which is to be used to test tank meltability (refractory wear). In these glasses all Nd_2O_3 was replaced by La_2O_3 . Besides investigating the compositional space between LG-660 and LG-650, a few excursions were made testing some existing optical glasses for their suitability as a laser glass (melts LLS-4, 5, and 6).

The previous five Status Reports covered all compositions up to LLS-45. The sixth and final report discusses the findings on the remaining compositions (up to and including LLS-50) and also summarizes the complete development project.

Experimental:

All glasses were melted in 1000g batches in inductively heated platinum crucibles of $\frac{1}{2}$ liter volume. A light flow of nitrogen over the melt surface was employed in order to keep moisture out. Temperatures used had to be varied depending on the individual glass. All castings were annealed with 30°C/hr after a 3 hour soaking period at the appropriate annealing temperature, which also varies depending on composition. For the test of refractory wear,

two different approaches were taken: initially, a refractory sample 20 mm x 20 mm x 90 mm long was immersed about 50 mm deep into a glass melt of about 1300 g. It was then rotated with 20 RPM for 6 hours. Since all these glasses are relatively benign in respect to refractory attack, an extended time test was also made. A refractory sample of the same size as above was immersed to the same depth into about 2000 g. of glass for 3 days at a temperature corresponding to a viscosity of 100 poise. During this test, the sample was not rotated. After completion of the test, the refractory was inspected for edge-rounding, reduction in size, wear on glass-line, stones in the adhering glass and in the melt, and comparison of appearance of refractory above and below the glass level.

Experimental Results:

A total of 75 melts was made in this project. At this point it is felt that no further improvement can be achieved over the composition LLS-45, which fulfills the minimum requirement of the cross-section, σ , with the best possible fluorescence lifetime. Further, this glass is stable against devitrification and phase-separation, and its refractory wear characteristics are no worse than LG-660 (LLS-1), which is known to be easily tank-melted.

The attempts made in this last melting campaign to improve the laser properties beyond those of LLS-45 failed to better the previous results. Therefore, this project is considered to be completed.

The major findings during this development were:

1. The influences of the various alkali and alkaline-earth on laser properties confirmed previously published data (e.g., LLNL handbook on laser glasses) though to different degrees since the glass matrix utilized here was vastly different, and the Nd^{3+} concentration was much higher.
2. Other oxides not specifically investigated previously were tested during this development, such as PbO , Al_2O_3 , TiO_2 and many others.

In one case, P_2O_5 proved to be extremely beneficial (LLS-45).

3. The alkali-level in the present glasses is probably the maximum possible, since any further increase will lower the fluorescence lifetime, contrary to expectations.
4. Glass matrices have a very strong influence on the effect of specific compositional changes. Although the general effect, i.e., the direction of property changes, is predictable, its magnitude cannot be accurately predicted. This is the reason that the last melting campaign was unsuccessful, where it was attempted to apply previous results to different base compositions.
5. During this development, some glasses were modified in order to achieve NSP-treatability. However, glasses with compositions which lend themselves to NSP treatment have undesirable laser properties.

All the glass compositions and data are listed on the attached tables. Further, a table listing the changes made is supplied, and the data are graphically depicted on the attached diagrams.

Summary:

A silicate laser glass was developed according to the specifications given in LLNL P.O. 4813705. This glass, composition LLS-45, has an induced emission cross-section of $1.69 \times 10^{-20} \text{ cm}^2$ (SGT, LLNL est. $1.52 \times 10^{-20} \text{ cm}^2$) and a fluorescence lifetime of 306 μsec (1st e-folding time) at Nd^{3+} concentration of $7.18 \times 10^{20} \text{ ions/cm}^3$. The dependence of fluorescence on Nd-concentration (concentration quenching behavior) was established. The glass is stable against devitrification and phase-separation, and should be tank meltable without any problems.

The project investigated 50 compositions, a total of 75 melts was made. The properties of the above-mentioned glass could not be improved any further; therefore, the project is completed.

Melt No. Mole %	LLS-1	LLS-2	LLS-3	LLS-4	LLS-5
	Composition Proprietary	Composition Proprietary	Composition Proprietary	Composition Proprietary	Composition Proprietary
Nd ₂ O ₃ (wt. %)	0	8	8	8	8
<u>Properties</u>	-- Refractory Test --				
Nd ³⁺ (10 ²⁰ ions/cm ³)		7.82	7.56	7.42	8.08
1st e-folding time (μsec)		142	219	198	254
OH ⁻ abs. @ 3.0 μm (cm ⁻¹)		0.8	0.7	1.5	1.7
σ(10 ²⁰ cm ²)		1.85	1.73	1.60	1.36
n _d		1.54113	1.52938	1.52464	1.54080
V _d		56.35	57.75	58.93	58.71
n ₂ (calc.)		1.502	1.397	1.336	1.411
Density (g/cm ³)		2.73	2.64	2.59	2.92
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)		116	112	95	101
Tg (°C)		459	456	568	544

Melt No.	LLS-6	LLS-7	LLS-8	LLS-9	LLS-10
Mole %	LLS-5	LLS-3	LLS-7	LLS-8	LLS-9
Derived From:	LLS-5	LLS-3	LLS-7	LLS-8	LLS-9
SiO ₂	Composition Proprietary	71.73	71.73	73.73	71.73
AlPO ₄		--	--	--	1.0
Li ₂ O		6.92	4.92	4.92	4.92
Na ₂ O		6.91	6.91	6.91	6.91
K ₂ O		8.88	10.88	10.88	10.88
BaO		3.94	3.94	1.94	1.94
Sb ₂ O ₃		0.05	0.05	0.05	0.05
Nd ₂ O ₃		1.58	1.58	1.58	1.58
Nd ₂ O ₃ (wt. %)	8	7.68	7.53	7.73	7.73
Properties					
Nd ³⁺ (10^{20} ions/cm ³)	8.08	7.48	7.33	7.31	7.31
1st e-folding time (μ sec)	251	254	312	376	323
OH ⁻ abs. @3.0 μ m (cm ⁻¹)	1.0	0.7	0.8	0.7	0.6
α (10^{20} cm ²)	1.53	1.79	1.62	1.50	1.59
n_d	1.54187	1.53593	1.53430	1.52610	1.52564
V_d	57.62	58.06	57.72	58.51	58.66
n_2 (calc.)	1.456	1.414	1.419	1.356	1.349
Density (g/cm ³)	2.82	2.72	2.72	2.64	2.64
α_{20-300} (10^{-7}° C ⁻¹)	106	118	122	118	122
Tg (°C)	499	456	453	459	456

Melt No.	LLS-11	LLS-12	LLS-13	LLS-14	LLS-15
Mole %					
Derived From:	LLS-9	LLS-8	LLS-7	LLS-9	LLS-9
SiO ₂	67.73	71.73	71.73	71.73	71.73
Al ₂ O ₃	-	--	--	2.00	--
P ₂ O ₅	--	--	--	--	2.00
Li ₂ O	6.92	4.92	6.92	4.92	4.92
Na ₂ O	6.91	6.91	4.91	6.91	6.91
K ₂ O	14.88	10.88	10.88	10.88	10.88
BaO	1.94	--	3.94	1.94	1.94
PbO	--	3.94	--	--	--
Sb ₂ O ₃	0.05	0.05	0.05	0.05	0.05
Nd ₂ O ₃	1.58	1.58	1.58	1.58	1.58
Nd ₂ O ₃ (wt. %)	7.65	7.25	7.60	7.64	7.55
Properties					
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.31	7.32	7.40	7.22	7.11
1st e-folding time (μsec)	271	338	276	293	289
OH ⁻ abs. @3.0 μm (cm ⁻¹)	0.8	0.6	0.7	0.9	0.7
τ (10 ²⁰ cm ²)	1.60	1.57	1.69	1.58	1.76
n _d	1.53334	1.54699	1.53587	1.52704	1.52153
v _d	57.19	51.08	58.25	58.26	59.11
n ₂ (calc.)	1.435	1.769	1.407	1.369	1.317
Density (g/cm ³)	2.67	2.82	2.72	2.64	2.63
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	139	121	118	117	125
T _g (°C)	439	432	461	463	445

Melt No.	LLS-16	LLS-17	LLS-18	LLS-19	LLS-20
Mole %	LLS-9	LLS-9	LLS-17	LLS-9	LLS-9
Derived From:	LLS-9	LLS-9	LLS-17	LLS-9	LLS-9
SiO ₂	71.73	73.23	73.23	72.93	72.93
Al ₂ O ₃	--	0.50	0.50	--	--
P ₂ O ₅	--	--	--	0.80	0.80
Nb ₂ O ₅	2.00	--	--	--	--
Li ₂ O	4.92	4.92	0.92	4.92	--
Na ₂ O	6.91	6.91	10.91	6.91	11.83
K ₂ O	10.88	10.88	10.88	10.88	10.88
BaO	1.94	1.94	1.94	1.94	1.94
Sb ₂ O ₃	0.05	0.05	0.05	0.05	0.05
Nd ₂ O ₃	1.58	1.58	1.58	1.58	1.58
Nd ₂ O ₃ (wt. %)	7.30	7.71	7.57	7.66	7.49
Properties					
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.19	7.29	7.18	7.24	7.10
1st e-rolding time (μsec)	292	355	411	324	407
OH ⁻ abs. @3.0 μm (cm ⁻¹)	0.6	0.8	0.8	0.9	0.4
σ (10 ²⁰ cm ²)	1.62	1.46	1.38	1.66	1.53
n _d	1.55440	1.52979	1.52288	1.52458	1.52013
v _d	52.46	58.51	57.59	58.66	57.99
n ₂ (calc.)	1.739	1.372	1.375	1.345	1.349
Density (g/cm ³)	2.75	2.64	2.65	2.64	2.65
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	110	118	126	121	129
Tg (°C)	493	456	464	448	467
Softening pt. (°C)	---	---	---	---	654

Melt No.	LLS-21	LLS-22	LLS-23	LLS-24	LLS-25
Mole %	LLS-4	LLS-21	LLS-9	LLS-9	LLS-4
Derived From:	LLS-4	LLS-21	LLS-9	LLS-9	LLS-4
SiO ₂	76.23	76.23	71.73	71.73	75.83
Al ₂ O ₃	---	---	---	---	0.37
TiO ₂	---	---	2.00	---	---
ZrO ₂	---	---	---	2.00	---
Li ₂ O	---	---	4.92	4.92	---
Na ₂ O	7.81	7.81	6.91	6.91	7.81
K ₂ O	7.03	7.03	10.88	10.88	7.03
BaO	---	7.32	1.94	1.94	---
CaO	7.32	---	---	---	7.31
Sb ₂ O ₃	---	---	0.05	0.05	0.05
Nd ₂ O ₃	1.60	1.60	1.58	1.58	1.60
Nd ₂ O ₃ (wt. %)	8.06	7.29	7.69	7.59	8.03
<u>Properties</u>					
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.50	7.36	7.43	7.34	7.47
1st e-folding time (μsec)	242	362	313	297	233
OH ⁻ abs. @3.0 μm (cm ⁻¹)	0.9	0.6	0.7	0.7	0.9
δ (10 ²⁰ cm ²)	1.55	1.48	1.59	1.58	1.56
n _d	1.52467	1.53498	1.53864	1.53862	1.52502
v _d	59.08	58.30	55.26	56.93	59.07
n ₂ (calc.)	1.331	1.401	1.53	1.47	1.333
Density (g/cm ³)	2.60	2.82	2.70	2.70	2.60
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	---	103	118	115	97
T _g (°C)	---	512	467	477	558

Melt No. Mole %	LLS-26	LLS-27	LLS-28	LLS-29	LLS-30
Derived From:	LLS-25	LLS-26		LLS-20	LLS-20
SiO ₂	76.33	74.33	Deleted	72.13	70.43
Al ₂ O ₃	0.37	0.37		---	---
P ₂ O ₅	---	---		1.60	0.80
Na ₂ O	7.81	9.81		11.83	14.33
K ₂ O	7.03	7.03		10.88	10.88
BaO	---	---		1.94	1.94
CaO	6.81	6.81		---	---
Sb ₂ O ₃	0.05	0.05		0.05	0.05
Nd ₂ O ₃	1.60	1.60		1.58	1.58
Nd ₂ O ₃ (wt. %)	8.03	8.02		7.42	7.49
<u>Properties</u>					
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.46	7.49	Deleted	7.01	7.14
1st e-folding time (μsec)	236	229		353	335
OH ⁻ abs. @3.0 μm (cm ⁻¹)	1.0	0.9		0.7	0.8
τ (10 ²⁰ cm ²)	1.54	1.62		1.64	1.65
n _d	1.52354	1.52664		1.51824	1.52262
v _d	58.92	58.33		58.14	57.19
n ₂ (calc.)	1.331	1.365		1.336	1.388
Density (g/cm ³)	2.60	2.61		2.64	2.66
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	94	103		129	138
Tg (°C)	563	541		461	458

Melt No.	LLS-31	LLS-32	LLS-33	LLS-34	LLS-35
Mole %	LLS-30	LLS-20	LLS-15	LLS-20	LLS-9
Derived From:	LLS-30	LLS-20	LLS-15	LLS-20	LLS-9
SiO ₂	69.43	72.93	71.73	74.93	71.73
Al ₂ O ₃	1.00	---	---	---	---
P ₂ O ₅	0.80	0.80	2.00	0.80	---
Li ₂ O	---	---	1.92	---	4.92
Na ₂ O	14.33	14.83	9.91	11.83	6.91
K ₂ O	10.88	7.88	10.88	8.88	10.88
BaO	1.94	1.94	1.94	1.94	1.94
Y ₂ O ₃	---	---	---	---	2.00
Sb ₂ O ₃	0.05	0.05	0.05	0.05	0.05
Nd ₂ O ₃	1.58	1.58	1.58	1.58	1.58
Nd ₂ O ₃ (wt. %)	7.44	7.59	7.45	7.56	7.32
Properties					
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.09	7.19	7.03	7.08	7.20
1st e-folding time (μsec)	313	343	319	386	208
OH ⁻ abs. @3.0 μm (cm ⁻¹)	0.7	0.6	0.8	0.8	0.8
σ (10 ²⁰ cm ²)	1.67	1.64	1.74	1.51	1.68
n _d	1.52305	1.52018	1.51942	1.51797	1.54212
v _d	57.19	57.85	58.76	58.43	57.11
n ₂ (calc.)	1.390	1.354	1.320	1.325	1.477
Density (g/cm ³)	2.66	2.65	2.64	2.62	2.75
α ₂₅₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	139	125	131	121	115
T _g (°C)	458	467	444	472	493

Melt No.	LLS-36	LLS-37	LLS-38	LLS-39.1	LLS-40
Mole %	LLS-9	LLS-9	LLS-9	LLS-9	LLS-19
Derived From:	LLS-9	LLS-9	LLS-9	LLS-9	LLS-19
SiO ₂	71.73	71.73	73.73	72.73	72.73
P ₂ O ₅	---	---	---	---	1.00
Li ₂ O	4.92	4.92	4.92	4.92	4.92
Na ₂ O	6.91	6.91	6.91	6.91	6.91
K ₂ O	10.88	10.88	8.88	10.88	10.88
BaO	1.94	1.94	1.94	1.94	1.94
Sb ₂ O ₃	0.05	2.05	0.05	0.05	0.05
Ta ₂ O ₅	2.00	---	---	---	---
Rb ₂ O	---	---	2.00	---	---
WO ₃	---	---	---	1.00	---
Nd ₂ O ₃	1.58	1.58	1.58	1.58	1.58
Nd ₂ O ₃ (wt. %)	6.91	7.19	7.47	7.55	7.64
Properties					
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.11	7.13	7.21	7.20	7.20
1st e-folding time (μsec)	287	276	367	345	323
OH ⁻ abs. @3.0 μm (cm ⁻¹)	0.9	1.57	0.7	0.7	0.7
σ (10 ²⁰ cm ²)	1.62	1.64	1.55	1.57	1.67
n _d	1.55219	1.55035	1.52803	1.52908	1.52394
v _d	54.06	51.78	57.96	57.76	58.74
n ₂ (calc.)	1.652	1.751	1.384	1.395	1.339
Density (g/cm ³)	2.87	2.77	2.70	2.67	2.63
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	111	122	124	---	120
T _g (°C)	487	435	451	---	452

Melt No.	LLS-41	LLS-42	LLS-43	LLS-44	LLS-45
Mole %	LLS-9	LLS-9	LLS-9	LLS-7	LLS-40
Derived From:	LLS-9	LLS-9	LLS-9	LLS-7	LLS-40
SiO ₂	71.73	71.73	71.73	73.73	72.43
P ₂ O ₅	---	---	---	---	1.3
Li ₂ O	4.92	4.92	4.92	6.92	4.92
Na ₂ O	6.91	6.91	6.91	4.91	6.91
K ₂ O	10.88	10.88	10.88	8.88	10.88
BaO	1.94	1.94	1.94	3.94	1.94
Sb ₂ O ₃	0.05	0.05	0.05	0.05	0.05
GeO ₂	2.00	---	---	---	---
Ga ₂ O ₃	---	2.00	---	---	---
In ₂ O ₃	---	---	2.00	---	---
Nd ₂ O ₃	1.58	1.58	1.58	1.58	1.58
Nd ₂ O ₃ (wt. %)	7.64	7.46	7.27	7.67	7.62
<u>Properties</u>					
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.31	7.22	7.29	7.43	7.18
1st e-folding time (μsec)	352	304	223	260	306
OH ⁻ abs. @3.0 μm (cm ⁻¹)	0.6	0.9	1.0	1.0	0.7
b (10 ²⁰ cm ²)	1.56	1.56	1.66	1.72	1.69
n _d	1.52947	1.53180	1.54310	1.53360	1.52311
v _d	57.51	57.45	56.87	58.66	59.16
n ₂ (calc.)	1.406	1.418	1.490	1.382	1.322
Density (g/cm ³)	2.67	2.70	2.80	2.71	2.63
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	120	116	111	110	122
Tg (°C)	444	460	505	464	452
Softening Pt. (°C)	---	---	---	---	630

Melt No. Mole %	LLS-46	LLS-47	LLS-48	LLS-49	LLS-50
Derived From:	LLS-7	LLS-7	LLS-2	LLS-48	LLS-20
SiO ₂	71.73	73.36	66.88	70.86	70.23
P ₂ O ₅	---	---	---	---	0.80
Li ₂ O	3.92	6.92	6.86	6.86	---
Na ₂ O	9.91	6.91	7.22	7.22	11.83
K ₂ O	8.88	8.88	9.37	9.37	10.88
BaO	3.94	2.31	8.02	4.52	4.64
Sb ₂ O ₃	0.05	0.05	0.05	0.05	0.05
Nd ₂ O ₃	1.58	1.58	1.61	1.61	1.58
Nd ₂ O ₃ (wt. %)	7.56	7.84	7.38	7.72	7.23
<u>Properties</u>					
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.39	7.45	7.68	7.62	7.14
1st e-folding time (μsec)	280	273	169	220	326
OH ⁻ abs. @3.0 μm (cm ⁻¹)	1.2	0.9	0.7	0.7	0.8
κ (10 ²⁰ cm ²)	1.70	1.71	1.98	1.83	1.62
n _d	1.53413	1.52945	1.55410	1.53973	1.53073
v _d	57.48	58.47	56.51	57.50	57.10
n ₂ (calc.)	1.427	1.372	1.555	1.451	1.426
Density (g/cm ³)	2.73	2.65	2.91	2.76	2.76
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	123	116	124	121	132
T _g (°C)	448	449	450	450	464

Melt No. Mole %	LLS-9	LLS-9.2	LLS-9.3	LLS-9.4	LLS-9.5	LLS-9.6
SiO ₂	73.73	~	~	~	~	~
Li ₂ O	4.92	~	~	~	~	~
Na ₂ O	6.91	~	~	~	~	~
K ₂ O	10.88	~	~	~	~	~
BaO	1.94	~	~	~	~	~
Sb ₂ O ₃	.05	~	~	~	~	~
La ₂ O ₃ + Nd ₂ O ₃	1.58	~	~	~	~	~
La ₂ O ₃ (wt. %)	---	3.73		7.23	5.73	1.73
Nd ₂ O ₃ (wt. %)	7.73	4.00		0.50	2.00	6.00
<u>Properties</u>						
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.31	3.78		0.47	1.89	5.67
1st E-folding time(usec)	376	562		587	611	460
OH ⁻ Abs.@3.0μm(cm ⁻¹)	.7	.6		.5	.5	.6
σ(10 ²⁰ cm ²)	1.50	1.50		---	---	---
n _d	1.52610	1.52681		1.52753	1.52721	1.52690
V _d	58.51	58.29		58.45	58.29	58.30
n ₂ (calc.)	1.36	1.37		1.36	1.37	1.37
Density (g/cm ³)	2.64	2.64		2.64	2.64	2.64
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	118	121		---	---	---
Tg (°C)	459	458		---	---	---
Softening Point (°C)	627	---		---	---	---

Melt No. Mole %	LLS-20	LLS-20.2	LLS-20.3	LLS-20.4	LLS-20.5	LLS-20.6	LLS-20.7
SiO ₂	72.93	---	---	---	---	Deleted against number of melts required	---
P ₂ O ₅	0.8	---	---	---	---		---
Na ₂ O	11.83	---	---	---	---		---
K ₂ O	10.88	---	---	---	---		---
BaO	1.94	---	---	---	---		---
Sb ₂ O ₃	0.05	---	---	---	---		---
La ₂ O ₃ + Nd ₂ O ₃	1.58	---	---	---	---		---
La ₂ O ₃ (wt. %)	---	7.49	6.99	5.49	3.49		1.49
Nd ₂ O ₃ (wt. %)	7.49	---	0.5	2.00	4.00		6.00
<u>Properties</u>							
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.10	Refractory Test	0.47	1.89	3.78	5.69	
1st e-folding time (μsec)	407		591	618	550	462	
OH Abs @ 3.0μm (cm ⁻¹)	0.4		0.6	0.6	0.6	0.6	
σ (10 ⁻²⁰ cm ²)	1.53		---	---	1.50	---	
n _d	1.52013		1.52121	1.52103	1.52067	1.52032	
v _d	57.99		58.00	57.91	57.96	57.88	
n ₂ (calc.)	1.35		1.35	1.36	1.35	1.35	
Density (g/cm ³)	2.65		2.64	2.64	2.64	2.65	
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	129		129	128	128	127	
Tg (°C)	467		467	468	467	467	

Melt No. Mole %	LLS-45	LLS-45.2	LLS-45.3	LLS-45.4	LLS-45.5	LLS-45.6
SiO ₂	72.43	---	---	---	---	---
P ₂ O ₅	1.30	---	---	---	---	---
Li ₂ O	4.92	---	---	---	---	---
Na ₂ O	6.91	---	---	---	---	---
K ₂ O	10.88	---	---	---	---	---
BaO	1.94	---	---	---	---	---
Sb ₂ O ₃	0.05	---	---	---	---	---
La ₂ O ₃ + Nd ₂ O ₃	1.58	---	---	---	---	---
La ₂ O ₃ (wt. %)	---	7.62	7.12	5.62	3.62	1.62
Nd ₂ O ₃ (wt. %)	7.62	---	0.5	2.0	4.0	6.0
Properties						
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.18	-- Refractory Test --	0.47	1.88	3.77	5.65
1st e-folding time (μsec)	306		552	545	479	385
OH ⁻ abs. @ 3.0μm (cm ⁻¹)	0.7		0.9	0.8	0.8	0.9
σ (10 ²⁰ cm ²)	1.69		---	---	---	---
n _d	1.52311		1.52407	1.52388	1.52353	1.52332
V _d	59.16		59.02	59.02	59.04	58.80
n ₂ (calc.)	1.322		1.330	1.330	1.327	1.335
Density (g/cm ³)	2.63		2.63	2.63	2.63	2.63
α ₂₀₋₃₀₀ (10 ⁻⁷ °C ⁻¹)	122		---	---	122	---
T _g (°C)	452		---	---	451	---
Softening Pt. (°C)	630		---	---	---	---

LLS - Project
NSP-Treatability

Melt # Mole %	LLS-4	LLS-21	LLS-22	LLS-25	LLS-26	LLS-27	LLS-14	LLS-31	LLS-24
SiO ₂		76.23	76.23	75.83	76.23	74.33	71.73	69.43	71.73
Al ₂ O ₃		--	--	.37	.37	.37	2.00	1.00	---
P ₂ O ₅		--	--	--	--	--	--	.80	2.00(ZrO ₂)
Li ₂ O		--	--	--	--	--	4.92	--	4.92
Na ₂ O		7.81	7.81	7.81	7.81	9.81	6.91	14.33	6.91
K ₂ O		7.03	7.03	7.03	7.03	7.03	10.88	10.88	10.88
CaO		7.32	--	7.32	6.81	6.81	--	--	---
BaO		--	7.32	--	--	--	1.94	1.94	1.94
Sb ₂ O ₃		--	--	.05	.05	.05	.05	.05	.05
Nd ₂ O ₃		1.60	1.60	1.60	1.60	1.60	1.58	1.58	1.58
Nd ³⁺ (10 ²⁰ ions/cm ³)	7.42	7.50	7.36	7.47	7.46	7.49	7.22	7.09	7.34
τ ₁ (usec)	198	242	362	233	236	229	293	313	297
σ(10 ⁻²⁰ cm ²)									
S.G.T.	1.60	1.55	1.48	1.56	1.54	1.62	1.58	1.67	1.58
est. + LLNL	1.44	1.40	1.33	1.40	1.39	1.46	1.42	1.50	1.42
NSP-treatable:	Yes	No	No	No	No	No	"Yes"	No	No**

+ S.G.T. -10%

* AR-layer wipes off

** Does not leach at all

FROM	TO	OUT (MOLE %)	IN (MOLE %)
LLS-7	LLS-8	2 Li ₂ O	2 K ₂ O
LLS-8	LLS-9	2 BaO	2 SiO ₂
LLS-9	LLS-10	2 SiO ₂	1 AlPO ₄
LLS-9	LLS-11	6 SiO ₂	2 Li ₂ O + 4 K ₂ O
LLS-8	LLS-12	1 BaO	1 PbO
LLS-7	LLS-13	2 Na ₂ O	2 K ₂ O
LLS-9	LLS-14	2 SiO ₂	2 Al ₂ O ₃
LLS-9	LLS-15	2 SiO ₂	2 P ₂ O ₅
LLS-9	LLS-16	2 SiO ₂	2 Nb ₂ O ₅
LLS-9	LLS-17	0.5 SiO ₂	0.5 Al ₂ O ₃
LLS-17	LLS-18	4.0 Li ₂ O	4 Na ₂ O
LLS-9	LLS-19	0.8 SiO ₂	0.8 P ₂ O ₅
LLS-19	LLS-20	4.92 Li ₂ O	4.92 Na ₂ O
LLS-21	LLS-22	7.32 CaO	7.32 BaO
LLS-9	LLS-23	2 SiO ₂	2 TiO ₂
LLS-9	LLS-24	2 SiO ₂	2 ZrO ₂
LLS-25	LLS-26	0.5 CaO	.5 SiO ₂
LLS-26	LLS-27	2 SiO ₂	2 Na ₂ O
LLS-20	LLS-29	0.8 SiO ₂	0.8 P ₂ O ₅
LLS-20	LLS-30	2.5 SiO ₂	2.5 Na ₂ O
LLS-30	LLS-31	1 SiO ₂	1 Al ₂ O ₃
LLS-20	LLS-32	3 K ₂ O	3 Na ₂ O
LLS-15	LLS-33	3 Li ₂ O	3 Na ₂ O
LLS-20	LLS-34	2 K ₂ O	2 SiO ₂
LLS-9	LLS-35	2 SiO ₂	2 Y ₂ O ₃
LLS-9	LLS-36	2 SiO ₂	2 Ta ₂ O ₅
LLS-9	LLS-37	2 SiO ₂	2 Sb ₂ O ₃
LLS-9	LLS-38	2 K ₂ O	2 Rb ₂ O
LLS-9	LLS-39	1 SiO ₂	1 WO ₃
LLS-19	LLS-40	0.2 SiO ₂	0.2 P ₂ O ₅
LLS-9	LLS-41	2 SiO ₂	2 GeO ₂
LLS-9	LLS-42	2 SiO ₂	2 Ga ₂ O ₃
LLS-9	LLS-43	2 SiO ₂	2 In ₂ O ₃
LLS-7	LLS-44	2 Na ₂ O	2 SiO ₂
LLS-40	LLS-45	0.3 SiO ₂	0.3 P ₂ O ₅
LLS-7	LLS-46	3 Li ₂ O	3 Na ₂ O
LLS-7	LLS-47	1.63 BaO	1.63 SiO ₂
LLS-48	LLS-49	3.5 BaO	3.5 SiO ₂
LLS-20	LLS-50	2.7 SiO ₂	2.7 BaO

Figure 1

Figure 2

7th Status Report 8/16/84
 6th Status Report

Fluorescence lifetime (1st E-folding time), μsec
 Figure 3

LLS-Project

Figure 4