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Evaluation of alkali-rich glasses for poling

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Abstract: The dielectric strength is believed to limit the second-order nonlinearity induced by poling. We propose a simple method that allows the measurement of the dielectric strength of alkali-rich glasses in-situ.

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Introduction

It has been shown that the thermal poling of sodium-bearing glasses may yield regions of second-order nonlinearity, $\chi^{(2)}$, through a "frozen-in" space-charge field, E_{DC}, acting on the inherent third-order nonlinearity, $\chi^{(3)}$ according to [1,2]

$$\chi^{(2)} = 3E_{DC}\chi^{(3)} \qquad (1)$$

It has also been shown that is possible to pole silica glass waveguides[3]; however the value of 1pm/V currently obtained for $\chi^{(2)}$ in silica must be increased to at least 10pm/V for practical use in electro-optic devices. Soft glasses are suitable for this purpose since they can be engineered for high $\chi^{(3)}$ [4] and are versatile for waveguide fabrication. To produce high values of $\chi^{(2)}$ it is also necessary to maximize E_{DC}, which is limited by the dielectric strength of the glass[5]. We introduce a method to measure the dielectric strength of the glass while it is being poled, providing crucial information about the suitability of the glass for poling.

Method

Pyrex, soda lime (Fisher Premium), BK7, Crown, and SFL6 glasses were thermally poled in vacuum with evaporated aluminum electrodes 7mm in diameter in the parallel configuration shown in Figure 1. The external applied voltage was controlled in order to maintain a constant external current of 20 μA. After poling for 90 minutes (25 minutes for Pyrex), the samples were rapidly cooled in vacuum with the applied voltage maintained.

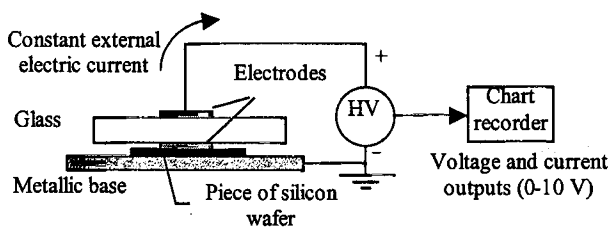

Figure 1. Poling and measurement apparatus

To maintain the current i constant, it can be shown that the applied voltage V should increase approximately linearly with time according to:

$$V = V_i + \frac{i}{eS}\frac{C_{Na}}{C_0^2}E_b t \qquad (2)$$

where V_i is the initial voltage, S is the anode area, C_0 is the total concentration of mobile ions, C_{Na} is the sodium concentration and E_b is the breakdown field or dielectric strength. V_i, the initial voltage, is given by:

$$V_i = iL/\mu e S C_{Na}\,, \qquad (3)$$

where μ is the sodium mobility and L is the glass thickness. The breakdown field and the sodium mobility may be determined from the temporal dependence of the voltage and from equations 2 and 3, respectively.

Results

Near-linear voltage versus time characteristics were observed for all samples, as shown in Fig. 2, in agreement with theory. The dielectric strengths and sodium mobilities calculated from the experimental data are given in Table 1, together with the relative optical damage thresholds estimated by surface damage observations using a mode-locked Q-switched Nd:YAG laser.

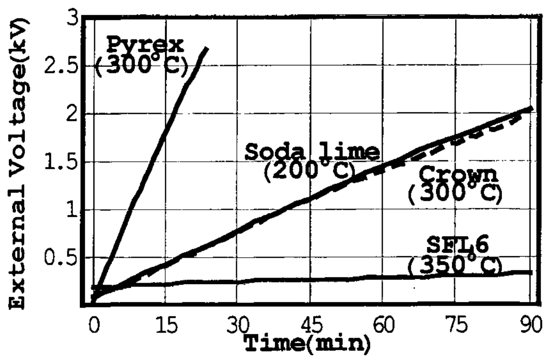

Figure 2. Voltage versus time characteristics

Table 1. Measured dielectric strength and sodium mobility

Glass	Ionic concentrations ($10^{27}m^{-3}$)				Poling temperature (^0C)	Dielectric strength (10^9Vm^{-1})	Na^+ mobility ($10^{-15}m^2s^{-1}V^{-1}$)	Relative optical damage threshold (300ps Nd:YAG)
	Na^+	K^+	Ca^{++}	Mg^{++}				
Pyrex	1.8	-	-	-	300	1.1	36	1
BK7	4.1	2.7	-	-	300	1.5	5.4	1
Soda Lime	7.2	0.2	1.7	0.45	200	1.5	5.3	1
Crown glass	5.0	1.6	2.1	-	300	1.4	8.6	1
SFL6	3.5	1.5	-	-	350	0.1	11	.06

Conclusion

A method to assess the dielectric strength and sodium ion mobility of alkali-rich glasses for thermal poling has been described. The dielectric strengths obtained for Pyrex, BK7, soda lime glass and crown glass are consistent with values from the literature, and the linearity of the voltage versus time characteristics is consistent with theory. The dielectric strength found for SFL6 is ten times lower than that of the other glasses, which is supported by measurement of its relative optical damage threshold. While SFL6 has a $\chi^{(3)}$ ten times higher than the other glasses, it may not produce higher $\chi^{(2)}$ since its dielectric strength is some ten times lower. Other high $\chi^{(3)}$ glasses will be poled for comparison of dielectric strength and the resultant $\chi^{(2)}$ will also be measured.

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