6.1 Introduction

Whether primary, secondary or hybrid, batteries are an important source of energy in many devices and equipments ranging from consumer durable devices to military purposes and can be found as an efficient, reliable and unmatched source of power in a variety of applications, spanning all walks of life. Super ion conducting glasses have gained popularity as solid electrolytes to replace the liquid or aqueous electrolytes in various electrochemical applications like “all solid state batteries”, super capacitors, etc. [1]. While Li^+ ion based solid state batteries are ideal for devices requiring high discharge currents, like different electronic gadgets including portable computers, communication devices and electrical vehicles; on the other hand Ag^+ ion batteries are suited for devices requiring low current drain, e. g. digital calculators and watches etc. Moreover, the Ag^+ conducting batteries are free from some of the potential hazards of Li^+ batteries, which occasionally burn or explode due to dendrite growth of lithium metal at metallic electrodes [2], while no such drawbacks are associated with silver ion based batteries. Over the years, a large number of α-AgI based glasses have been synthesized to achieve higher ionic conductivities, so as to come with better solid state batteries [3].

Since the discovery of the highly conducting α-AgI, it has attracted many a research groups to stabilize it at room temperature in crystalline hosts like $RbAg_4I_5$, and many noncrystalline hosts like, glasses. Following table shows some of noteworthy Ag^+ batteries prepared in past by various research groups across the globe.

Table 6.1: A list of some potential Ag^+ ion conductors based solid state batteries

Sr. No.	Electrolyte (glass composition)	Cell configuration Anode/SE/Cathode	Voltage	Capacity	Reference
1.	$50CuI-50Ag_3PO_4$	Ag / SE / Ph+I_2+CTC	639 mV	420 μ Ah	[4]
2.	60 AgI + 26.67 Ag_2O + 13.33 ($0.4SeO_2+0.6MoO_3$) (*all values in wt%*)	Ag / SE / C + I_2	686 mV	5.58 mAh	[5]
3.	60 wt.% AgI-24 wt.% Ag_2O-16 wt.% ($0.1MoO_3 + 0.9V_2O_5$)	Ag+SE / SE / I_2+C+SE	685 mV	6.3 mAh	[6]
4.	$30Cul-35Ag_2O-35MoO_3$	Ag / SE / I_2 + C.	687 mV	---	[7]
5.	$0.7[0.75AgI-0.25AgCl]-0.3[Ag_2O-WO_3]$	Ag / SE / C + I_2	681 mV	82.4 μA/cm^2 (at 100 k Ω)	[8]
6.	50 AgI-50[$0.5Ag_2O$+ $0.5CrO_3$]	Ag / SE / C + I_2	---	7.3 mA/cm^2	[9]
8.	$4AgI:1Ag_2WO_4$	Ag / SE / C + I_2	685 mV	---	[10]
9.	$7AgI-1Ag_2Se-2P_2Se_5$	Ag / SE / C + I_2	687 mV	---	[11]
10.	$70AgI-20Ag_20-l0V_2O_5$	Ag / SE / C + I_2 + SE	680 mV	5.4 mAh	[12]

SE = solid electrolyte, C = graphite, I_2 = Iodine

Basic constituents of a solid state battery

As we know, a battery consists of mainly three components, namely anode, cathode, electrolyte and a case to encapsulate all these constituents in a single unit. Fig. 6.1 depicts a typical dry cell battery.

1.) Anode: negative electrode, releases electrons into the circuit

2.) Cathode: positive electrode, accepts ions that come from through the electrolyte and electrons from the external circuit.

3.) Electrolyte: liquid or solid solvent for motion of ions.

4.) Case: to encapsulate all of above components in a single assembly.

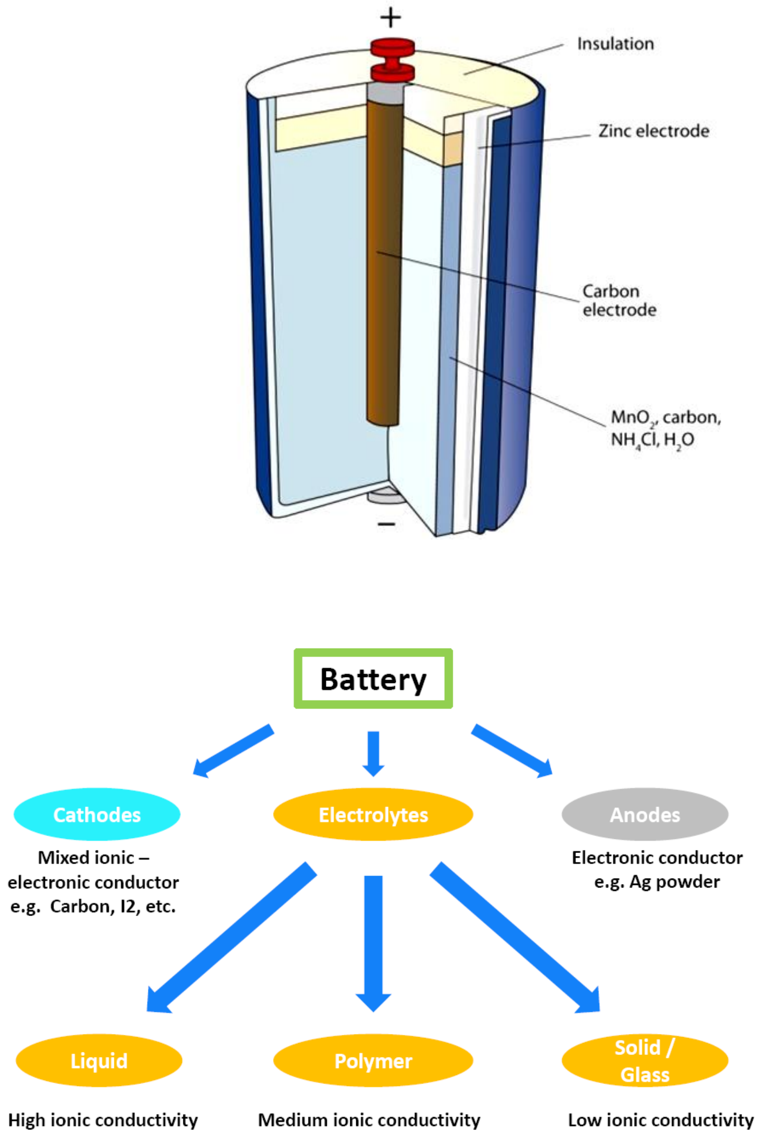


Fig. 6.1. Main Components of a Battery and chief classes of battery electrolytes

Classification of Batteries: Batteries can be classified in various ways on depending on the electrolyte material, their usage etc. Batteries are generally classified mainly as primary (non-rechargeable) and secondary (rechargeable). However, based on the type of the electrolyte material, further each of them may be classified into liquid electrolyte and solid electrolyte batteries.

The batteries having aqueous or **liquid electrolytes** e.g. Lead Acid Batteries, ordinary alkaline batteries etc. are called liquid electrolyte batteries. Such batteries have long been in service due to their excellent performance and cost effectiveness and still share a larger share in the global battery market. However due to their few drawbacks like leakage, corrosion of electrodes, variation in efficiency at very high or low temperatures, decomposition etc., which result due to liquid/aqueous electrolytes, limit their usage. On the other hand, if a liquid electrolyte is replaced by a solid electrolyte, in addition to getting rid from these drawbacks of liquid electrolytes; one may have following added advantages also, like

- ✓ Designing the battery in any shape is possible.
- ✓ Maximum miniaturization is possible.
- ✓ No leakage of electrolyte and hence no damage to the device is likely to occur.

Batteries that utilize a solid electrolyte are called '**All solid state battery**', in general, to distinguish them from others. The Solid electrolyte to be used in an 'all solid state battery' must have following characteristics to deliver expected/optimum performance.

(1). High ionic conductivity to reduce the resistance polarization effects in the battery. This is the most stringent requirement where high power levels or constant power levels are involved and the electrical efficiency is a key parameter.

(2). Transport number for ionic conduction should be as close as possible to unity because any significant electronic contribution to the total electrical conductivity of the electrolyte leads to self discharge of the battery leading to a limited life/shelf life.

(3). Needs to be thermodynamically stable and should perform well in a wide temperature range.

(4). Should be physically and chemically compatible with both anode and the cathode.

(5). Processability of the electrolyte is equally essential where miniaturization of the device requires thin film structures.

(6). Should have higher decomposition potential than the Gibbs free energy of the anode and the cathode that constitutes the open circuit potential.

In light of the facts mentioned above, the optimum conducting composition, one from each series of glass systems was chosen to use as a solid state electrolyte to prepare a solid state battery and various studies were carried out in an in-house setup. Various results including their conductivity, dielectric relaxation etc. on these systems have been already discussed in Chapters 4 and 5; now, studies on battery applications of the optimum conducting samples from each glass series are being presented here. Table 6.2, shows a summary of results and parameters obtained for the optimum conducting samples from each series. The following samples in each of the series were found to be the most conducting and were chosen for battery applications.

Table 6.2: Various Parameters of OCC from the presently studied glass series.

Solid Electrolyte (glass) Series	OCC*	Actual amount of constituents in each glass in mole%				σ_{DC} (30 ˚C) S/cm	t_{ion} (%)	T_g (˚C)
		PbI_2	Ag_2O	V_2O_5	B_2O_3			
Series (a) : $x\ PbI_2 - (100-x)$ $[Ag_2O - 2(V_2O_5 - B_2O_3)]$	$x = 25\%$	25	25	35	15	8.65×10^{-5}	99.98	77
Series (b) : $y\ (PbI_2 : 2Ag_2O) - (1-y)\ [0.7V_2O_5 - 0.3B_2O_3]$	$y = 55\%$	18.33	36.77	31.5	13.5	1.94×10^{-2}	99.98	96
Series (c) : $z\ (PbI_2 : Ag_2O) - (90-z)\ V_2O_5 - 10B_2O_3$	$z = 50\%$	25	25	40	10	1.02×10^{-5}	99.65	73

*** OCC = Optimum Conducting Composition**

As noted from Table 6.2, the optimum conducting compositions from each of the glass series are truly superionic in nature and hence they may be utilized as solid electrolyte for solid state battery applications. The glass transition temperature of the samples is well below 100 ˚C and hence the prepared batteries out of these may be used below their respective glass transition temperatures efficiently.

6.2 Experimental

This chapter presents the results of study on electrochemical behavior in terms of cell potential measurements of All-Solid-State cells fabricated using the newly synthesized Ag^+ ion conducting glass systems.

The procedure adopted for the fabrication of all-solid-state cell using these glass samples has been already discussed in Chapter 2 (Section 2. .). In order to test the performance of the cells, Open Circuit Voltage (OCV) values were measured and the cells were discharged through constant load resistances. The cell potential discharge profiles were recorded as a function of time. All the potential measurements were done using a high impedance electrometer (Keithley 6514 electrometer).

6.2.1 Cell Fabrication

The optimum conducting samples from each of the glass series were pulverized finely and were used as solid electrolyte in the following cell configuration.

Ag** (anode) // **Electrolyte** (powdered glass sample) // **Cathode

The fine pulverized glass sample was taken as the solid electrolyte (SE) electrolyte. Ag metal powder was taken as the anode. And following three different cathode combinations were tested.

Cathode 1. $C:I_2$ in different ratios viz. 5:5, 6:4, 7:3 and 8:2.

Cathode 2. $(C:I_2):SE = 7:3$ (here $C:I_2 = 7:3$)

Cathode 3. $(C:I_2): TBAI = 7: 3$ (here $C:I_2 = 7:3$)

where, C = graphite, I_2 = iodine, SE = Solid electrolyte (powdered glass sample) and TBAI = Tetra Butyl Ammonium Iodide. Cathode 1 consisted of different ratios of graphite and iodine. The cathode (with C:I_2 = 7:3 ratio) giving best results was chosen for further optimization as cathodes 2 and 3 by mixing the glass sample and TBAI respectively.

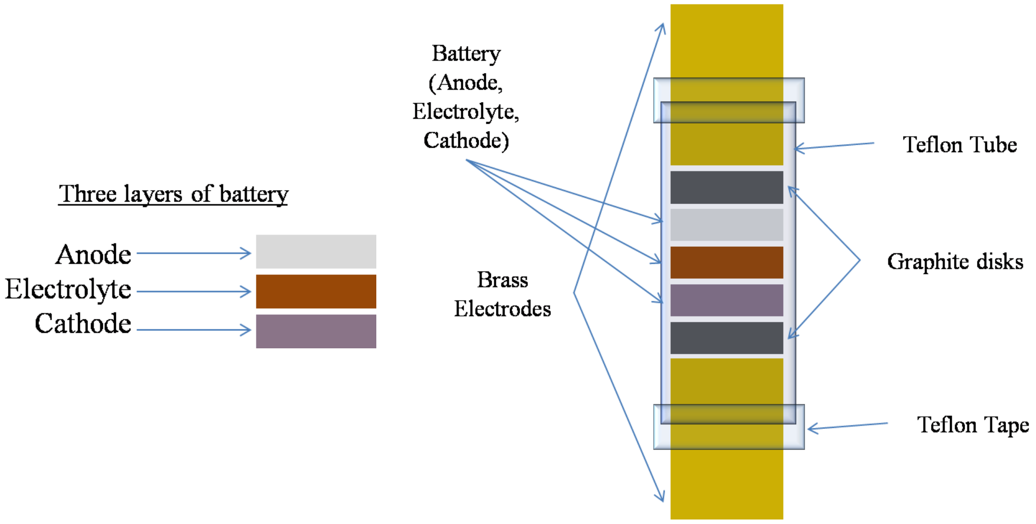


Fig. 6.2. Fabrication of the test cells

As shown in Fig. 6.2, all three layers namely anode, electrolyte (powdered glass sample) and cathode were taken in appropriate amounts/ratios and were sandwiched in an 8 mm die at a pelletizing pressure of 5000 kg/cm^2, altogether, so as to have a good interfacial contact between electrode and electrolyte layers and hence to have minimal contact/interfacial resistance/impedance between successive layers. The prepared cells were again sandwiched between graphite disks to make contacts with the external circuit via brass electrodes (here graphite layers were used only for contact purpose with external circuit) and the whole assembly was confined in a Teflon cylinder and then sealed using PTFE (Teflon) tapes, to isolate the whole assembly from environmental effects, as shown in the configuration in Fig. 6.2. The prepared cells were stored in a desiccator for further investigations.

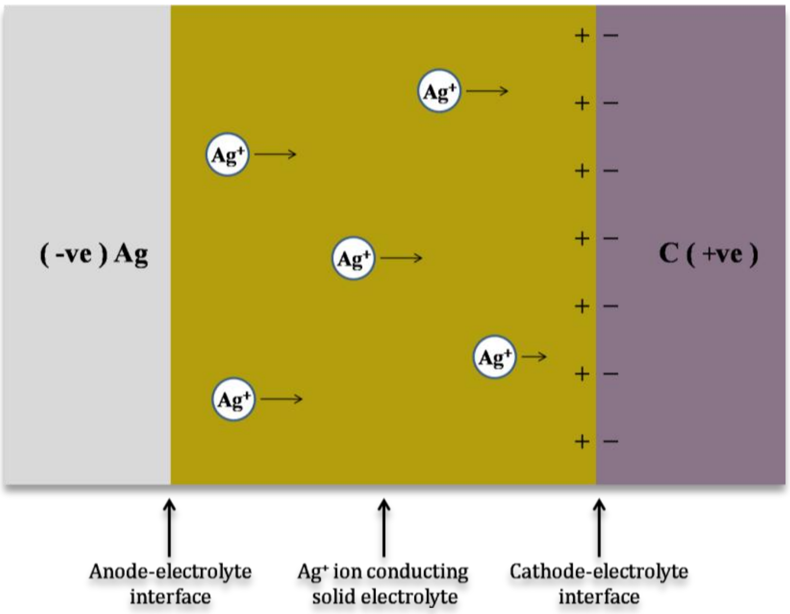


Figure 6.3. Discharge process in a "Ag//silver ion conducting solid electrolyte//cathode" cell.

The choice of the anode for a solid-state cell is dependent on the nature of the conducting ion in the electrolyte. In the present investigation, only silver could be used for the anode material. It was prepared by mixing the silver powder and finely ground powders of the electrolyte in a 2:1 ratio by weight. The solid electrolyte was added to silver powder to improve the interfacial contacts. Since silver is readily oxidized, the anode served as an electron reservoir and provides cations that migrate through the electrolyte to the cathode.

The cell reaction for the above constructed cell is as given in equation 6.1 and the standard e.m.f. for this half cell reaction is 0.687 V.

At anode: $\mathrm{Ag} \rightarrow \mathrm{Ag}^{+} + e^{-}$

At cathode: $\mathrm{I}_2 + 2\,e^{-}\ (\text{from external circuit}) \rightarrow 2\,\mathrm{I}^{-}$ …… (6.1)

&

$$2\,\mathrm{Ag}^{+}\ (\text{through electrolyte}) + 2\,\mathrm{I}^{-} \rightarrow 2\mathrm{AgI}$$

6.2.2 Cell characterization and other studies.

Following flow chart shows the standard procedure adopted to find out their various parameters like internal impedance (resistance), maximum current that can be drawn without destabilizing the cell, energy density, cell capacity etc.

a. **Open Circuit Voltage (OCV):** of the prepared cells was measured immediately after their preparation.

b. **Polarization studies:** Polarization measurements are done to find out stability of the cell to know that how much maxim mum current can be drained from the cell without reducing its operative voltage level.

c. **Discharge studies:** When the cell is discharging continuously, the amount of formed AgI at the cathode-electrolyte interface, progressively increases, and at the anode, silver is consumed continuously; resulting in the contact between silver and the electrolyte will decrease thereby increasing the internal resistance/impedance of the cell and causing a large internal voltage drop.

Rise in internal resistance of the cell with prolonged discharge can be explained on the basis of the direct cell reaction given in equation 6.1. The formed AgI layers having conductivity and act as an ion blocking layer or a barrier which obstructs the flow of ions to the cathode which ultimately results in reduction in performance of the cell.

From polarization studies it is found that, the overall internal resistance remains near about orders of 10 kΩ and hence to have the uniformity in the results, all prepared cells were discharged at room temperature at 100 kΩ resistance until the cell potential reached 0.2 V.

6.3 Results and Discussions

6.3.1 OCV

Open Circuit Voltage (OCV), measured for the Cells is listed in Table 6.3. To check the initial voltage (OCV) obtainable from the cell and to ensure proper electrode-electrolyte contacts, the voltage in open circuited condition has been measured over a period of few hours. As can be observed from the table 6.1, OCV of the prepared cells is found to be 0.687 V for all cells prepared with cathode 1 and 2. The cells having C-I_2-TBAI cathode show the lowest OCV amongst all prepared cells as mentioned in the Table 6.3. The reduction in OCV for TBAI containing cells might be due to reduced Iodine activity.

Table 6.3: OCV for all prepared cells.
(*For details, see text and forthcoming sections*)

Glass series	Cells	Cathode Composition	OCV (V)
Series (a)	A 1	I_2 - C	0.676
	A 2	I_2 - C - SE	0.683
	A 3	I_2 - C - TBAI	0.635
Series (b)	B 1	I_2 - C	0.675
	B 2	I_2 - C - SE	0.682
	B 3	I_2 - C - TBAI	0.678
Series (c)	C 1	I_2 - C	0.682
	C 2	I_2 - C - SE	0.685
	C 3	I_2 - C - TBAI	0.638

6.3.2 Polarization studies

Polarization studies are an important check to understand that how much maximum current can be drawn from a battery without significantly reducing its cell voltage (generally ≥ 80% of OCV). For this purpose, the cells were subjected to different load currents by applying different known resistance values using the circuit as shown in Fig. 6.7. In general, a polarization curve consists of following three regions,

1.) Initially, a rapid fall in cell voltage due to electrode polarization occurs.
2.) The second one as almost linear or plateau like region where internal resistance of the cell components causes a further voltage loss (the iR polarization).
3.) On increasing the current drain, the iR polarization gets combined with, further electrode polarization caused by depletion of electro active materials at the electrode surfaces and a drastic decay in cell potential is observed in the third region [13].

At first, the cells from glass series (b) (as this is the highest conducting composition amongst all) were prepared with cathodes containing graphite powder and iodine in different ratios of for C:I_2 = 5:5, 6:4, 7:3& 8:2. And the prepared cells were tested for their polarization behavior to judge the best cathode composition amongst them. The best C:I_2 composition was further tested with 7:3 ratio of SE and TBAI were added separately further to improvise the cell performance.

Fig. 6.5 shows the polarization curves for cells B-I to B-IV. The current density at 90 and 80% values of OCV are presented in Table 6.4. From these data, it is clear that the cell having cathode composition of C:I_2 = 7:3 is the best amongst them and can sustain drain currents as high as 0.0743 mA/cm^2 before reaching 90% value of OCV which is 50% more when compared to other cathode compositions. Thus, the cathode composition having C:I_2 =7:3 ratio was selected as the optimized cathode composition.

Table 6.4: current density values for cells B-I to B-IV

	Cell →	B-I	B-II	B-III	B-IV
Cathode →	**C:I_2 →**	**5:5**	**6:4**	**7:3**	**8:2**
Current density mA/cm^2	**(at 90% of OCV)**	0.0164	0.0306	0.0743	0.0368
Current density mA/cm^2	**(at 80% of OCV)**	0.0366	0.0460	0.1259	0.0722
Remark	**-**	lowest	low	Highest	moderate

Note: darker color means better response.

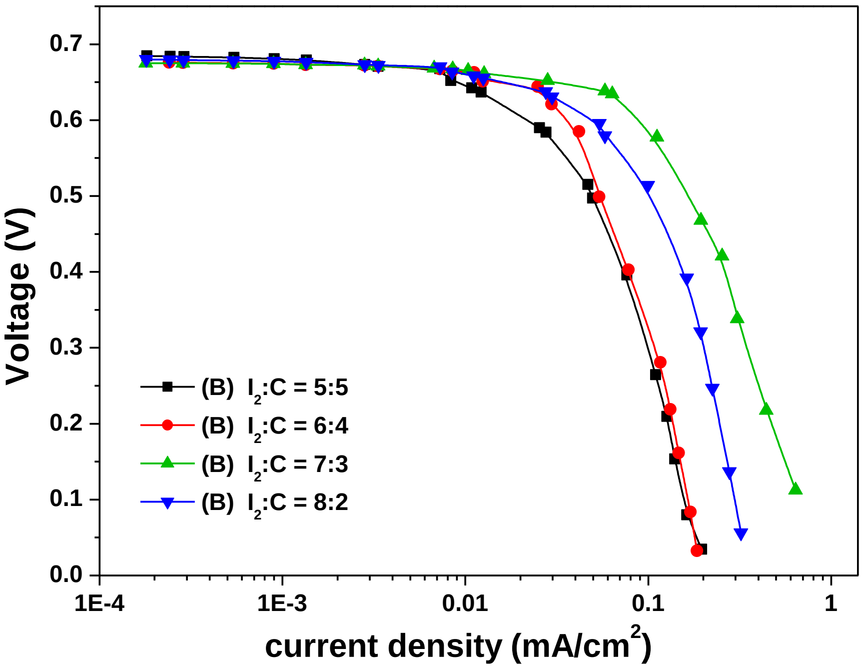


Fig. 6.4. Polarization curves for cells containing different ratios C:I_2 of cathode.

Now the optimized cathode composition C:I_2 = 7:3 is taken as the standard cathode and it is again modified in following way, and a total 3 different cathodes have been tested on all the three solid electrolytes as follows;

Cathode 1. C:I_2 = 7:3

Cathode 2. C:I_2:SE = 7:3 (here C:I_2 = 7:3)

Cathode 3. C:I_2: TBAI = 7: 3 (here C:I_2 = 7:3)

where, C = graphite, I_2 = iodine, SE = Solid electrolyte (glass sample) and TBAI = Tetra Butyl Ammonium Iodide.

Cathode compositions **2** (C-I_2-SE) and **3** (C-I_2-TBAI) have been selected to further improve the cathode 1, C:I_2. In cathode composition 2, the glass sample to be used as solid electrolyte (SE) in the respective battery was mixed in the cathode 1 in compositions given above to improve the electrode-electrolyte interface and hence improve the overall cell performance. In cathode composition 3: (C-I_2-TBAI), TBAI was mixed instead of SE. As reported by Venkateswarlu *et al.* [14] the TAAI (Tetra Alkyl Ammonium Iodide) compounds are known to reduce the Iodine activity and may lead to increased cell life and hence it has been used in many a battery systems to improve their performance [7, 15]. In total, nine (9) types of cells were fabricated as mentioned in the table below. Fig. 6.6 presents the polarization curves for all the above fabricated cells.

Table 6.5: Symbols / codes used for different cells

Solid electrolyte	**Cathode**		
	1 **C:I_2**	**2** **C:I_2:*SE***	**3** **C:I_2:*TBAI***
Glass series (a) : A	A 1	A 2	A 3
Glass series (b) : B	B 1	B 2	B 3
Glass series (c) : C	C 1	C 2	C 3

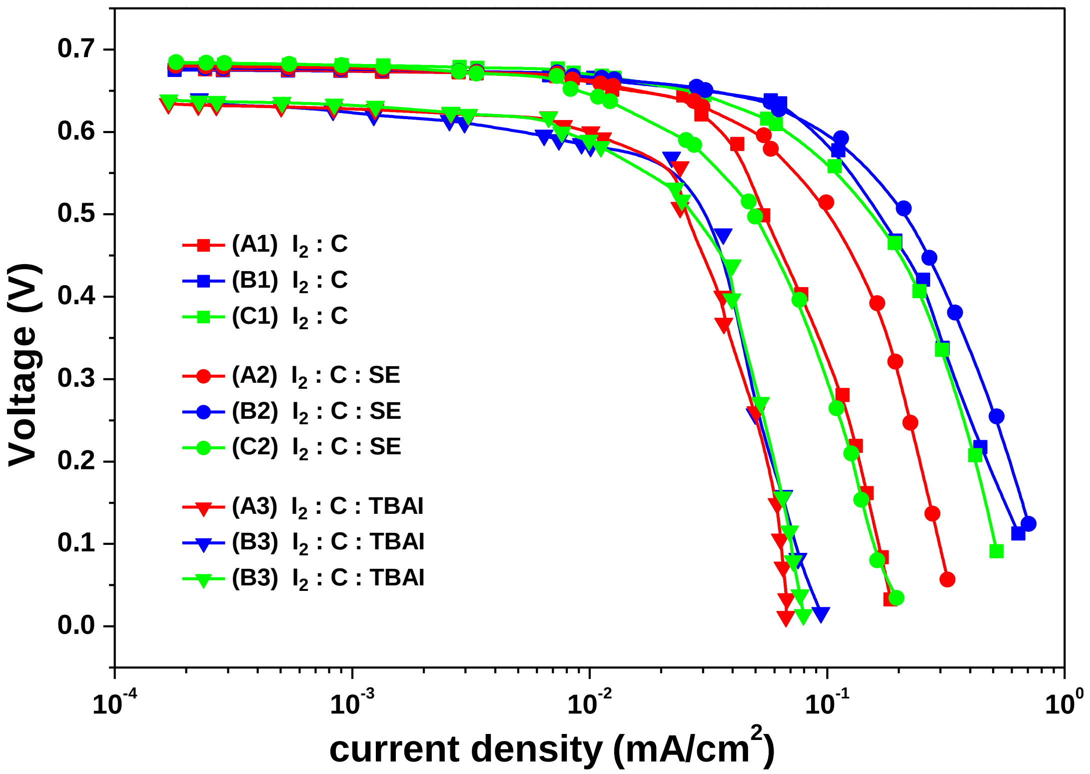


Fig. 6.5. Polarization curves for all the above fabricated cells.

A careful observation of the polarization curves reveals following points to one's notice

1.) Cells having cathode 3, C:I_2:*TBAI*, show least stability against higher current drain and their cell potential reduces drastically after 0.01 mA/cm^2 current drain.

2.) Cells having cathode 2, C:I_2:*SE*, show the longest operating plateau for each glass series.

3.) The B2 cell with C:I_2:*SE* cathode shows maximum stability amongst all of the nine cells and may be further utilized for practical applications.

4.) It should be noted that the response of cells B1 and B2 is not much different upto 90% of OCV, however as current drain increases, response of the B2 cell becomes better.

Addition of the solid electrolyte to the cathode reduces the iodine activity at cathode/electrolyte interface, which in turn is observed to improve performance of the cells having other cathodes. Following table presents the values of current density at 90% and 80% of OCV (= 0.687 V).

Table 6.6: Current density values at 90% and 80% of OCV for all cells

Glass system	Cell	Cathode	Current density (at 90% of OCV) mA/cm^2	Current density (at 80% of OCV) mA/cm^2
Series (a)	A 1	C:I_2	0.0306	0.0460
	A 2	C:I_2:SE	0.0364	0.0739
	A 3	C:I_2:TBAI	0.0048	0.0224
Series (b)	B 1	C:I_2	0.0727	0.1258
	B 2	C:I_2:SE	0.0738	0.1539
	B 3	C:I_2:TBAI	0.0015	0.0244
Series (c)	C 1	C:I_2	0.0522	0.1090
	C 2	C:I_2:SE	0.0160	0.0360
	C 3	C:I_2:TBAI	0.0047	0.0175

It is found that addition of TBAI to the cathode reduces the iodine activity at the electrode/electrolyte interface [14]. At the interface, the TAAI reduces the iodine activity by forming a strong complex $(CH_3)_4NI$, which avoids the tarnishing actions of molecular iodine with the electrolyte and hence increases the specific energy. Also, the iodine activity of the reaction product $[(CH_3)_4N]_2Ag_{13}I_{15}$ is highly conducting and offers good charge transfer continuity [15]. Hence, the improvement in polarization characteristics of these cells is attributed to reduced internal resistance (iR) drop compared with the cell of (I_2-C-SE) cathodes. This is due to the formation of a complex with higher conductivity than AgI [15].

6.3.3 Discharge studies

Discharge study of an electrochemical cells can be carried out in two ways, *one* by drawing a constant current from the cell till its potential drops to a predetermined value and *second* by discharging the cell through a known resistance (> Z_{in}) till its potential attains a predefined value.

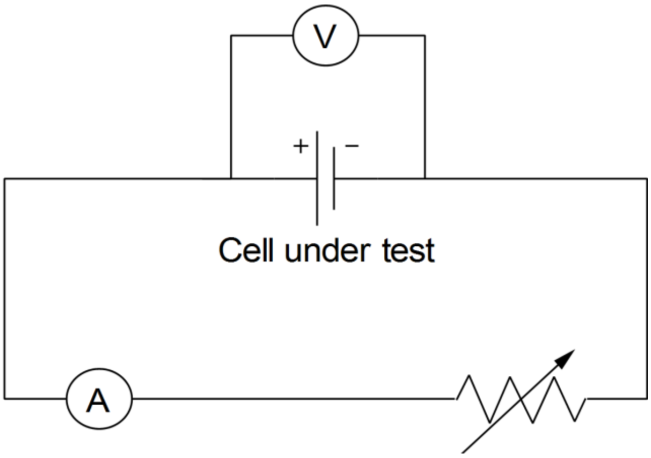
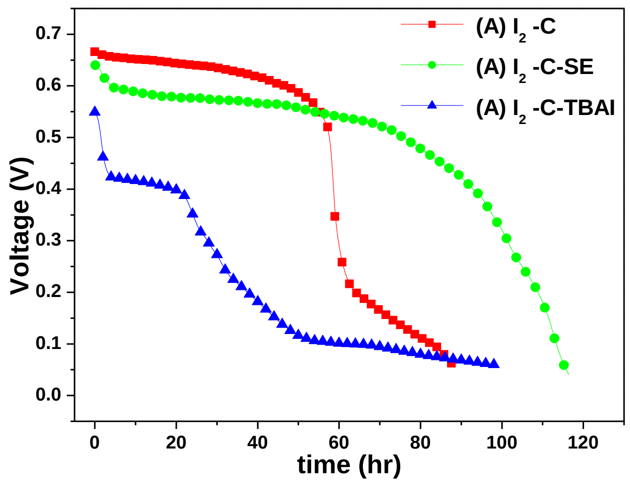
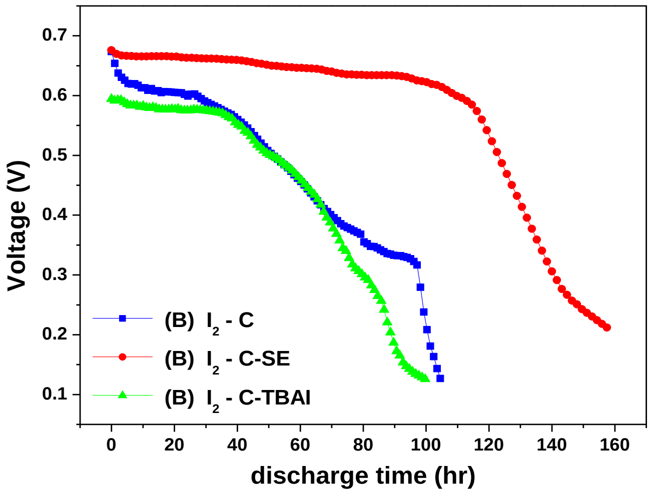


Fig. 6.6. Discharge circuit for testing a cell via a constant load.

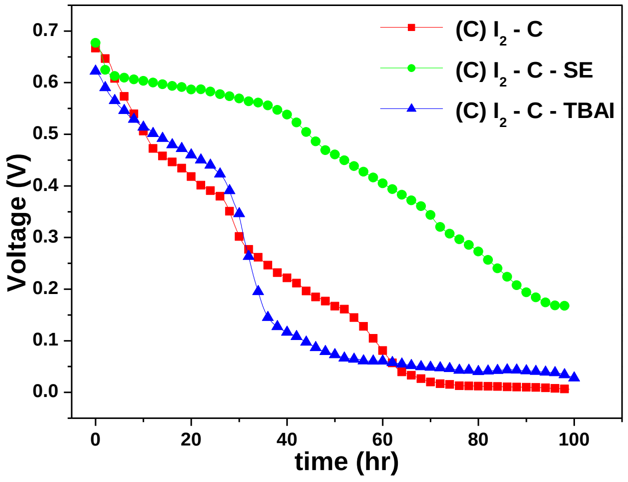
Both of these methods have their unique benefits, the first method gives a chance to test the cell in a reality like condition where normally any device requires to a draw a fixed current value, whereas in the later case a constant load may be tested, which also drains a constant current from the cell.



Series (a)

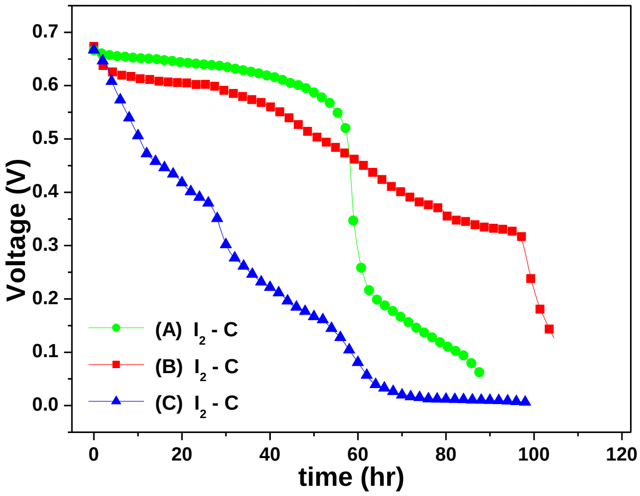


Series (b)

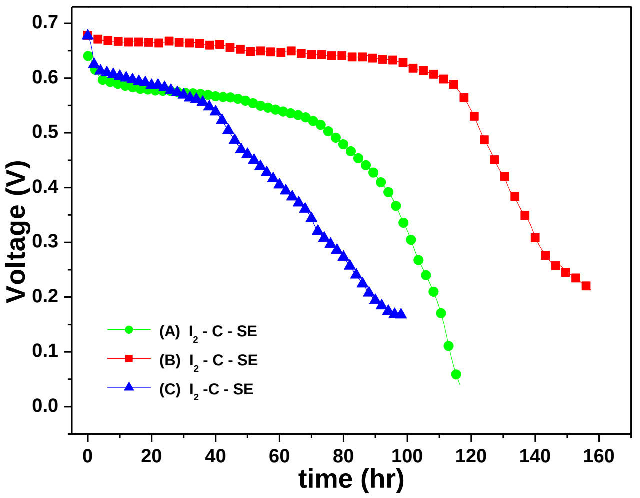


Series (c)

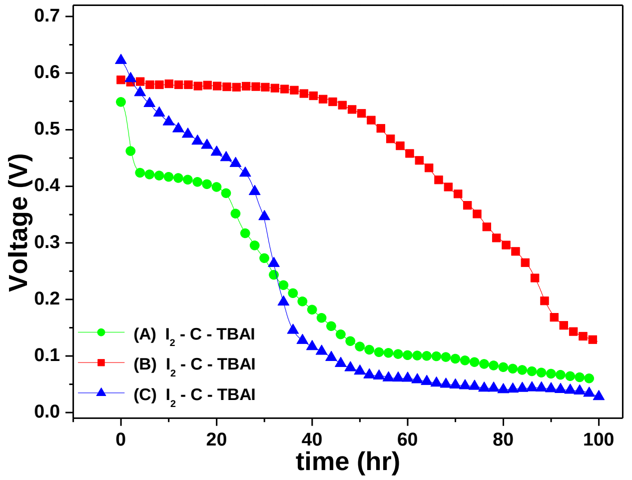
Fig. 6.7. Discharge profile for all cells at 100 kΩ resistance for different glass series. (for different glass series)



(a) I_2 – C



(b) I_2 – C – *SE*



(c) I_2 – C – *TBAI*

Fig. 6.8. Discharge profile for all cells at 100 kΩ resistance for different cathode compositions. (for different cathodes)

The prepared cells were discharged at 100 kΩ resistance using the following circuit and the cell potential was monitored as a function of time. Fig. 6.8 depicts the discharge curves for all cells made prepared. It is notable that for all discharge curves, there exists a small initial drop in voltage and then after the cell potential remains unaltered for 25 to 100 hrs for different cells and then after suddenly starts to decay as time passes.

Fig. 6.8 (a), (b) & (C) shows the discharge curve for all nine cells with each figure showing the discharge curve for a separate cathode. Table 6.7 presents various cell parameters calculated from the discharge curves of individual cells. Following points / conclusions can be made from these results.

[1]. Cells having cathode $C:I_2$:TBAI discharge fastest and hence may be utilized for very low current drain applications only.

[2]. Cells with cathode composition $C:I_2$:SE show the best discharge characteristics in all glass compositions and do discharge after a longer duration when compared to other cell types (having other cathodes).

[3]. Cell B2 lasts longest (approx. 110 hrs) before its potential starts to decrease from the constant value. The same sample has also shown the best results for polarization measurements.

[4]. Cells having the cathode $C:I_2 = 7:3$, show moderate operational life of 20 to 40 hrs.

[5]. Cells constituted from glass series (c) (solid electrolyte) fail to display any remarkable operating plateau except cathode 2 owing to its lowest conductivity.

[6]. Table shows different cell parameters, viz., discharge capacity, specific energy and energy density of the cells.

[7]. The data from table 6.7 show that the cell B2, having cathode C:I_2:SE, shows maximum discharge capacity, specific energy and energy density when compared to all other cells. And hence it can be utilized as a potential solid state battery with further optimization in potential low current drain devices.

Table 6.7: Summary of various parameters obtained for all prepared cells.

Solid electrolyte	**Cells**	**Cathode Composition**	**Cell weight**	**Cell Volume**	**O.C.V.**	**Discharge capacity**	**Electrical Energy**	**Specific Energy or Weight Capacity**	**Energy density Or Volume Capacity**
			gm	**cm^3**	**V**	**mA-h**	**mW-h**	**mW-h/gm**	**mW-h / cm^3**
Glass series (a)	**A 1**	I_2 : **C**	0.408	0.201	0.676	0.366	0.248	0.607	1.231
	A 2	I_2 : **C : SE**	0.300	0.226	0.683	0.506	0.345	1.151	1.526
	A 3	I_2 : **C : TBAI**	0.425	0.156	0.635	0.101	0.064	0.150	0.410
Glass series (b)	**B 1**	I_2 : **C**	0.368	0.176	0.675	0.388	0.262	0.713	1.489
	B 2	I_2 : **C : SE**	0.371	0.191	0.682	**0.819**	**0.558**	**1.507**	**2.924**
	B 3	I_2 : **C : TBAI**	0.408	0.186	0.678	0.365	0.247	0.606	1.330
Glass series (c)	**C 1**	I_2 : **C**	0.312	0.176	0.682	0.129	0.088	0.281	0.499
	C 2	I_2 : **C : SE**	0.314	0.186	0.685	0.271	0.185	0.590	0.997
	C 3	I_2 : **C : TBAI**	0.297	0.121	0.638	0.131	0.084	0.282	0.695

6.4 Conclusion

Open Circuit Voltage (OCV), for the prepared cells is near about 0.687, which is quite close to the standard e.m.f of the Ag/I_2 cell reaction. The cell having C+I_2+SE cathode show maximum stability against high discharge current, as well as they also show longest discharge times. The cells having C+I_2 and C+I_2+TBAI as cathode show moderate and lowest responses respectively. And do not seem to be suitable for any practical applications. While the cell having *y* = 55 mole% glass composition as electrolyte and C+I_2+SE as cathode shows maximum stability amongst all investigated cells and in addition to that it shows longest discharge time of more than 120 hr at a steady discharge current of 0.154 mA/cm^2 before reaching to 80% of OCV. And it possesses a discharge capacity of 0.819 mAh and its wattage is 0.559 mWh. Hence it be may conclude that this particular composition, i.e. the glass composition, **$55(PbI_2{:}2Ag_2O)\text{-}45(0.7V_2O_5\text{-}0.3B_2O_3)$** may be used as a suitable solid electrolyte for low and steady current requiring battery applications.

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