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"NOVEL CONCEPTS IN ELECTROCHEMICAL SOLAR CELLS"

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I. INTRODUCTION

In view of the large number of variables involved, it has become apparent in our search for viable combinations of semiconductor materials and suitable redox containing electrolytes that a more discriminating experimental approach was needed. To some extent, it can be argued that a problem exists because an emphasis has been placed on the properties and performance of the semiconductor materials with insufficient emphasis on the role of the electrolyte. Current research in many instances has merely achieved a demonstration of photoeffects with systems likely to have little or no ultimate practicality. In general, the ground work information for a wide range of semiconductor materials is available and, for example, the optimal bandgap required for a solar PEC is well known and understood. However, extremely few / PEC electrolytes would seem to have all of the properties needed for practical applications. Those electrolytes which have proven most effective for this task so far are the aqueous chalcogenide/polychalcogenide redox systems in strong base and the iodide ion/ iodine redox system. It can be noted that each of these systems permit high solubility ($>1M$) of components and good thermal and optical chemical stabilities. The development of suitable electrolytes for PEC's is most analogous to the development of electroplating systems where high concentrations and high current densities are needed, however, a far more complex array of solution properties are needed for PECs.

Table 1 has been compiled to list the properties required of an electrolyte for a straightforward semiconductor/electrolyte/counter

TABLE I: ELECTROLYTE PROPERTIES REQUISITE FOR PEC's

PROPERTY	ROLE
A. Reduction-oxidation potential	Model dependent - Redox reaction to be positioned <u>appropriate</u> to semiconductor band edges. Electrolyte decomposition limits suitable. Current theories appear to be primitive and unreliable.
B. Electron-transfer rates of Ox and Red	Ideally rapid (reversible) at both semiconductor and counter electrodes. Suitable mass transport conditions.
C. Photo-and thermal stabilities	Ox, red and solvent components to have photo- and thermal stabilities throughout usable solar spectrum and operational temperature range.
D. Substrate Compatibility	Non-corrosive to electrode and containment materials. Semiconductor corrosion inhibited if necessary and undesirable surface reactions absent.
E. Optical Transparency	Minimal absorption losses by solar energy spectrum
F. Fluidity	Liquidus range and viscosity to allow convective mixing within temperature extremes.
G. Solubility	Ox, red and supporting electrolyte concentrations in solvent or liquid matrix to be adequate.
H. Conductance	Increased ionic conductance of electrolyte reduces ohmic losses.
*I. Toxicity and reactivity to environment	Preferably low; also low flammability
*J. Cost	Material availability and cost preferably low

*I and J will depend on projected applications.

electrode PEC configuration to perform in sunlight under free (unforced) convection. The problem of electrolyte selection, therefore, is to find a satisfactory combination of these variables for a specific semiconductor substrate. A more detailed analysis of each requirement (to be presented later) verifies that although certain properties can be precisely defined other properties, such as the heterogeneous reaction rates of redox materials, are not predictable and do require empirical experimentation. Nevertheless, a set of guidelines for the optimization and selection of electrolyte compositions should be helpful to provide constraints on those systems with no possible practical utility.

The basic types of electrolyte that can be incorporated into PEC cells are summarized in Table II. Our present investigations are examining the advantages and limitations of type III electrolytes and, to a lesser extent, the possibilities of preparing type IV electrolytes. The reasons for this latter approach are given in section I.2.

TABLE II: ELECTROLYTE TYPES FOR PECS

CLASS	REDOX ADDITIVE	SUPPORTING ELECTROLYTE	MOLECULAR SOLVENT
I. Conventional Solutions	$\text{Red}^{(n-1)+}$ Ox^{n+}	M^+, A^-	Aqueous Inorganic Other Organic (mixed aqueous-organic, inorganic-organic, etc.)
II. Conventional Solutions	$\text{Red}^{(n-1)+}$ Ox^{n+} $\text{A}^-, \text{or } \text{M}^+$	None	Aqueous Inorganic Other Organic (mixed aqueous-organic inorganic-organic, etc.)
III. Indifferent Molten Salt	$\text{Red}^{(n-1)+}$ Ox^{n+}	M^+, A^- (multicomponent mixtures)	None
IV. Redox Molten Salt	$\text{Red}^{(n-1)+}$ Ox^{n+} $\text{A}^-, \text{or } \text{M}^+$	None	None

Notes (i) n commonly ranges ± 2

(ii) Cations and anions, M^+ and A^- , may be multi-charged

(iii) Only a one-electron charge transfer reaction is represented

II. RESULTS

II.1. Results with Type III Electrolytes

The primary thrust of our research activities in this area has been with the n-GaAs || AlCl₃: 1-butylpyridinium chloride; ferricenium cation/ferrocene || vitreous C cell. It is intended to discuss briefly our recent conclusions concerning this system in terms of the requirements outlined in Table I.

Figure 1 represents a normal pulse polarogram of ferrocene saturated in the 0.8:1 melt at a vitreous C electrode. It is evident from this figure that the oxidation wave becomes distorted at $\sim 200 \mu\text{A cm}^{-2}$ and the diffusion current at background (+0.7V vs. Al 2:1 ref) is $\sim 360 \mu\text{A cm}^{-2}$. It is not clear why the curve deviates from an ideal one, absorption of product or homogenous barriers to the reactant are the prime possibilities. Reduction of the 1-butylpyridinium cation in this melt (the concentration of which $\sim 4.4\text{M}$) showed that under unstirred conditions, the primary electron transfer process also was distorted at a current $\sim 7\text{mA cm}^{-2}$ [1]. Mass transfer of reactants to the semiconductor photo-electrode might be limiting at these low current densities because of the decreased mobility of reactants (viscous forces) and convective transport. Diffusion coefficients in the melts vary by two orders of magnitude lower from those in aqueous electrolytes. Confirmatory experiments are needed to determine the extent to which mass transport limitations affect the photoanodic current maxima. A second factor which will limit the flux of reactant to the electrode are the solubilities of ferrocene the redox components. Figure 2 illustrates the solubilities of ferrocene as a function of the composition of the molten salt mixture. The break in the curve at $\sim 1:1$ represents a break in the liquidus nature of the system at 30°C. Far higher mole fractions of the redox components in the molten salt would permit higher current densities from the photo-induced processes.

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Figure 1: Normal pulse polarogram of ferrocene (saturated) in 0.8:1 melt (room temperature) at vitreous C electrode (0.0855 cm^2); $V = 5 \text{ mV s}^{-1}$, 0.5s droptime.

Figure 2: Solubility of ferrocene at 30° as a function of the $AlCl_3$: 1-butylpyridinium chloride mole ratio.

Figure 3 shows current-voltage behavior of n-GaAs electrodes in the potentiostatic mode as a function of light intensity. The electrolyte in this case was 1:1 AlCl_3 -BPC containing 58 mM ferrocene and 6 mM ferricenium chloride. The dependence of the photocurrent saturation level on light intensity is characteristic of a process controlled by the availability of photogenerated minority carriers at the electrode/electrolyte interface (see above). The onset potential for photoanodic current flow is also seen to be a rather weak function of light intensity over the range of levels investigated in the present study. Figure 4 illustrates the current-voltage characteristics of a regenerative n-GaAs |1:1 AlCl_3 -BPC, $\text{Fe}(\text{Cp})_2^+/\text{Fe}(\text{Cp})_2$ |C cell, where $\text{Fe}(\text{Cp})_2^+/\text{Fe}(\text{Cp})_2$ represents the ferricenium/ferrocene redox couple. The current-voltage curves are shown for three light intensities. The output power typically peaks at 400 mV and the fill factors approach 45 percent for these cells. The optical to electrical conversion efficiency at the maximum power point is calculated to be ~ 0.6 percent at 100 mW/cm^2 . Best values for V_{oc} , J_{sc} and fill factor are shown in Table III for the molten salt electrolyte with and without added benzene. It is clear that reducing the viscosity of the electrolyte improves the mass transport of the ferrocene and the cell output.

Figure 3: Current voltage characteristics of n-GaAs in 1:1 AlCl_3 -BPC electrolyte containing 58 mM ferrocene and 6 mM ferricenium chloride at different light intensities. The carbon counter electrode was 0.24 V versus the reference electrode, curves were obtained under potentiostated condition. Scan rate: 2 mV/sec.

Figure 4: Current-voltage characteristics of n-GaAs (III) ($2.17 \times 10^{17} \text{ cm}^{-3}$) under illumination ()-100 mW/cm^2 , (Δ) 57 mW/cm^2 , (O) 40 mW/cm^2 in 1:1 AlCl_3 :1 BPC molten salt electrolyte containing ferrocene. Electrode area $\sim 20 \text{ mm}^2$.

TABLE III: CELL PERFORMANCE VALUES

n-GaAs	J_{sc} mA/cm ²	V_{oc} mV	FF	Maxpower output mW/cm ²	$\mu\%$
Without benzene: Singlextal	4.8	680	0.44	3.26	1.4
Polyxtal	3.8	580	0.33	2.20	0.7
With benzene: Singlextal	6.7	625	0.46	4.19	1.9
Polyxtal	4.9	610	0.38	2.99	1.1

Long-term irradiation (~ 80 hr.) of n-GaAs photoelectrodes was carried out with a view to test their stability. Typical results showing the variation of short-circuit current as a function of time is shown in Figure 5. The incident light intensity in these experiments was 57 mW/cm^2 . The electrolyte composition and redox concentration were the same as above. The constancy of the observed photocurrents indicates the good stability of n-GaAs electrodes in the 1:1 AlCl_3 -BPC electrolyte. The slight fluctuations that are observed in the short-circuit current presumably arise from electrolyte stirring effects and variations in the illumination intensity as a function of time.

Figure 5: A plot of photocurrent in the n-GaAs | 1:1 AlCl_3 -BPC, $\text{Fe}(\text{Cp})_2^+ / \text{Fe}(\text{Cp})_2$ | C cell under short circuit conditions as a function of time.

Figure 6 depicts the electrostatic aspects of the interface for n-GaAs in the dark in the 1:1 electrolyte. The maximum output potential that is attainable with a cell utilizing the $\text{Fe}(\text{Cp})_2^+/\text{Fe}(\text{Cp})_2$ couple in the 1:1 electrolyte is $(V_{\text{redox}} - V_{\text{fb}})$ or $E_G/e_0 - \phi_n$ (where ϕ_n = difference between the Fermi potential and the conduction band edge) whichever is smaller [2]. From Figure 6 this value is seen to be $\sim 1\text{V}$. The V_{OC} values that were routinely observed for n-GaAs 1:1 AlCl_3 -BPC, $\text{Fe}(\text{Cp})_2^+/\text{Fe}(\text{Cp})_2$ C cells in the present study are only 60 percent of the maximum output. This deterioration in the photovoltage and the low fill factors obtained can be ascribed to the influence of surface states and in this regard considerations essentially similar to those which have been outlined by Parkinson et al. [3] in their work on n-GaAs $|\text{K}_2\text{Se}-\text{K}_2\text{Se}_2$ KOH|C cells will apply. Appropriate surface pretreatment could lead to improvement in both V_{OC} and fill factor.

Figure 6: Interfacial energetics for n-GaAs in the 1:1 AlCl_3 -BPC electrolyte containing $\text{Fe}(\text{Cp})_2^+/\text{Fe}(\text{Cp})_2$ redox couple.

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Preliminary studies on the elucidation of the nature of electrolyte adsorption and chemical identification of adsorbed species giving rise to these effects have been carried out. The flat band potential shifts by about 160 mV per unit change in pCl (defined as $-\log[Cl^-]$) as shown in Figure 7.

An Auger analysis of GaAs electrodes which had been immersed in different compositions of $AlCl_3$:BPC was carried out. The electrodes were thoroughly washed with acetonitrile prior to analysis to remove any electrolyte from the electrode surface. The results are presented in Figure 8. As far as the identification of the adsorbed species is concerned the results were rather inconclusive. Further work in this direction is planned for the future.

Figure 7: Variation of flat band potential of n-GaAs with pCl of the electrolyte.

Figure 8: Auger analysis of n-GaAs immersed in (a) 0.8:1, (b) 1:1, (c) 2:1, AlCl_3 :BPC electrolyte.

The possibility of using Si as a photoelectrode in molten salt electrolytes was investigated. Si was studied in melts of varying composition. The flat band potentials obtained for the 1:1 and 0.8:1 AlCl_3 :BPC compositions were quite negative ($\sim -4.0\text{V}$ vs. Al/Al^{+3}). Therefore the band edges for Si in 1:1 and 0.8:1 AlCl_3 :BPC electrolytes lie beyond the melt stability range and no photoeffects were observed. This behavior is consistent with that expected from theory [4]. The flat band potential for Si in the 2:1 AlCl_3 :BPC melt lies very close to the stability range of this melt. Typical results are shown in Figure 9.

Figure 9: Schottky-Mott plots for n-Si in 2:1 AlCl_3 :BPC melt (•) 5 KHZ, (○) 1 KHZ.

The stability range of 2:1 AlCl_3 :BPC melt on Si in the dark as obtained by cyclic voltammetry is shown in Figure 10.

Figure 10: Voltammetric behavior of n-Si in dark in 2:1 AlCl_3 :BPC electrolyte.

The close proximity of the electrolyte decomposition potential to the flat band potential can lead to a suppression of photoeffect. No photoeffect was observed in this case. The behavior of Si in 2:1 melt containing (a) ferrocene and (b) anthracene under dark and illumination was almost "metallic" as shown in Figure 11.

Figure 11: Cyclic voltammetric behavior of Si in (---) dark and under illumination (—) in 2:1 AlCl_3 :1BPC electrolyte containing (a) ferrocene (b) anthracene.

II.2 Screening Redox Materials

The chemistry of the metallocenes is under review from the viewpoint of their usefulness as redox components in PECs. Electrochemical investigations have been made of ferrocene, 1-butylferrocene, decamethylferrocene, 1-ferrocenylmethyl-dimethyl benzylammonium chloride, 1-ferrocenylmethyldimethyl butylammonium bromide, nickelocene, dicyclopentadienyl titanium dichloride and dicyclopentadienyl hafnium dichloride in the room temperature molten salts as a function of the melt acidity e.g. Figures 12-14. The quaternized ferrocene derivatives are far more soluble in polar solvents than ferrocene, Table IV and may be valuable candidates for type II electrolytes. The figures in Table IV may be lower in practical electrolytes because of the need for supporting electrolyte and the corresponding redox component. Butylferrocene is a liquid at room temperatures and may be highly miscible with organic solvents such as CH_3CN .

II.3. Redox Molten Salt Electrolyte

In an earlier progress report, it was noted that an approximately 1:1 molar ratio FeCl_3 : 1-BPC mixture formed a room temperature orange liquid. Further experiments have been made of this system to determine its suitability as a PEC electrolyte. The liquidus range at ambient temperatures seems to be 2:1 to 1:1 FeCl_3 : 1-BPC, respectively, and a Fe wire quasi-reference in the 1-5:1 melt has a potential +1.612V vs. Al 2:1 AlCl_3 : 1-BPC (including liquid junction potential). Figure 15

TABLE IV. COMPARISON OF SOLUBILITIES

Compound	Solvent	Solubility
Cp_2Fe	H_2O	$1.7 \times 10^{-5} \text{ M}$ [5]
	CH_3CN	0.18 M (30°)
	AlCl_3 :1-BPC	$\sim 0.25\text{--}0.6 \text{ M}$ (30°)
$\text{Cp}_2\text{FeCH}_2\text{N}(\text{CH}_3)_2\text{BuBr}$	H_2O	> 2.4M
	CH_3CN	0.35M (30°)

Figure 12:

Top: 21 mM nickelocene in 1:1 melt (40°); $V = 50 \text{ mV s}^{-1}$

Middle: 10 mM nickelocene in 0.8:1 melt (30°); $V = 200 \text{ mV s}^{-1}$

Lower: 19 mM nickelocene in 1.2:1 melt (40°); $V = 50 \text{ mV s}^{-1}$

Cyclic voltammograms of Nickelocene as a function of the melt acidity a vitreous C electrodes (area 0.0573 cm^2); reference Al 2:1 melt.

Figure 13: Cyclic voltammogram of 124mM butylferrocene in 0.8:1 melt (35°C); $v = 20, 100, 200$ mV s with iR correction.

Figure 14: Cyclic voltammograms of quarternized ferrocene compound ($\text{Cp}_2\text{FeCH}_2\text{N}(\text{CH}_3)_2\text{BuBr}$) at vitreous C electrodes.

Upper: 6.6mM in 1:1 melt (40°); 100mV s^{-1} , area of C electrode 0.0573 cm^2 , ref. Al 2:1 melt.

Lower: 4.8mM in 0.8:1 melt (40°); 200mVs^{-1} , area of C electrode 0.0573 cm^2 , ref. Al 2:1 melt.

Figure 15: Cyclic voltammetry of a 1.5:1 mole ratio FeCl_3 : l-butylpyridinium chloride melt (40°) at a vitreous carbon electrode, $V = 50\text{mV s}^{-1}$, area of C electrode 0.0855 cm^2 .

illustrates a cyclic voltammogram recorded at a vitreous C electrode. The positive solvent limit appears to be $\sim +1.0V$ vs. Fe 1.5:1 reference and a reduction wave occurs in the negative scan direction at $\sim -0.8V$. This appears to represent the formation of an insoluble film ($FeCl_2?$) which can be stripped off at $\sim +0.8V$. An attempt to titrate potentiometrically between 2:1 and 1:1 mole ratios with an Fe wire indicator electrode gave an emf curve of about $-400mV$ from the 1.5:1 to the 1:1 compositions. Although we have not yet established the limitations of the Fe (111)/Fe(0) indicator electrode, it is possible that the $Fe(111)$ complex ion species may be changing over this range e.g. $[Fe_2 Cl_8]^{2-}$, $[FeCl_4]^-$ and $FeCl_3$ species. The stability limits of this electrolyte would seem to be too positive for the n-GaAs electrode but the electrolyte might be useful for other semiconductor materials (e.g. Si) or as a battery electrolyte.

A second approach to the problem of preparing type IV electrolytes has been tested, but so far was unsuccessful. This involves attaching a quaternary alkyl ammonium derivative to a metallocene unit to form a possible cationic species for a room temperature molten salt of the type $AlCl_3: MCl$. Our first attempt to obtain a liquid, by mixing 1-ferrocenylmethyl-dimethyl benzylammonium chloride with $AlCl_3$ revealed that the mixture did not form a low melting salt. Other modifications are in progress to examine the feasibility of preparing organometallic molten liquids of type IV.

II.4. Studies on MoSe₂, Iodine/Iodine, H₂O, Pt System

At the inception of this program the only source of large crystals of MoSe₂ was Professor A. Levy's laboratory in Lausanne. Accordingly, we sought to develop the expertise essential to growing high quality MoSe₂ and WSe₂ crystals. Over the course of several months, we have gotten our experimental techniques to the point where we can grow quality crystals consistently. To this time, we have been using MoSe₂ crystals grown by bromine vapor transport in 20 cm quartz tubes at two different temperatures and temperature gradients as shown in Table V.

TABLE V

	Type	High T(°C)	Low T(°C)	^p (ohm cm)	Form
Growth conditions and characteristics of Br ₂ vapor transported MoSe ₂ .	i	917	851	.02	thick single xtals
	ii	845	753	.2	thin single xtals & multi xtals

In order to determine the optimum concentration of iodine to use, a crystal of type i was incorporated into a PEC in 5.2 M KI and titrated with I₃⁻ solution. These results are shown in Figure 16.

The product of I_{sc} and V_{oc} peaked near I = 5 x 10⁻³ M and remained essentially constant to higher concentrations. The output of this cell vs light intensity is shown in Figure 17 and can be seen to be linear up to 150 mW/cm² for the dilute I₃⁻ case. Power curves obtained for cells fabricated with two different I₃⁻ concentrations are shown in Figure 18. Although increasing the iodine concentration reduces the short circuit current, it is seen that the open circuit potential and fill factor increase, yielding a higher overall power efficiency.

Figure 16: Iodine Titration of Type (i) n-MoSe₂ PEC

Figure 17: Limiting Power Output of a type (i) n-MoSe₂ PEC

Cells fabricated from the type ii crystals typically exhibited higher values of I_{sc} (up to 19 ma/cm^2 at 100 mW/cm^2 illumination, increasing nearly linearly to 75 ma/cm^2 at 450 mW/cm^2 illumination) similar V_{oc} but lower fill factors, to yield power conversion efficiencies of 2.5-3.0%. The larger type ii crystals (up to 2 cm^2) were clearly multicrystalline. A cell fabricated from a multicrystalline MoSe_2 sample yielded photocurrents of only $10\text{-}11 \text{ ma/cm}^2$ under illumination of 100 mW/cm^2 .

We have demonstrated short circuit currents superior to any reported in the literature for MoSe_2 . Expected improvements in fill factor and V_{oc} should ultimately lead to cells with 6.5% power conversion efficiencies.

Figure 18: Power curves for type (i) n-MoSe_2 in two different iodine concentrations.

II.5. MoSe₂ Formation by Anodization

In a recent series of experiments, we have found the molybdenum foils, anodized in a solution of sodium selenide show photo currents. It appears that anodization in a 0.2M Na₂Se/0.1M NaOH solution at low currents (5-10mA) for about 10-20 mts. facilitates the formation of a layer of MoSe₂ on the metal foil. These foils, when kept in the same electrolyte with Mo counter electrode show photo currents. To understand whether the conditions could be optimized for higher currents, the anodization time and currents were varied and it has been found that the photo current increases with increasing time of anodization Table VI. Now attempts are being made to increase the efficiency of the anodized foils. Further experiments are in progress with I/I₂ systems also. During our preliminary experiments, we have observed that the deposited MoSe₂ is not bound to the metal surface strongly and so efforts will be made to see if surface pre-treatment improves the adhesion. Additionally, the cell currents consisted of a faradaic (non-photo) as well as a photo-current. This process might be useful for the complete anodization of thin metallic films on inert substrate electrodes to produce photoactive films. Process control is facile and the film composition might be doped if the electrolyte were to contain appropriate amounts of a suitable additive.

TABLE VI

PHOTOELECTRIC EFFECT SHOWN BY ANODIZED Mo METAL

ELECTROLYTE USED $\text{Na}_2\text{Se}/0.2\text{M NaOH } 0.1\text{M}$

Current & Time of Anodization		Photocurrent mA	Voltage mV
Current	Time		
2 mA	5 mts	0.001	1.0
2 mA	10 mts	0.003	1.0
2 mA	20 mts	0.004	3.0
6 mA	5 mts	0.002	3.0
6 mA	10 mts	0.004	3.0
6 mA	20 mts	0.005	3.0
10 mA	5 mts	0.002	4.0
10 mA	10 mts	0.002	3.0
10 mA	20 mts	0.004	3.0
20 mA	5 mts	0.002	4.0
20 mA	10 mts	0.002	5.0
20 mA	20 mts	0.007	7.0
20 mA	60 mts	0.014	14.0

III. SUMMARY OF PROGRESS

Our efforts have been primarily directed toward evaluation of the room temperature molten salt electrolyte in terms of its overall performance for photovoltaic cells. Mass transport processes may prove to be the rate-limiting factor for such electrolytes, unless the concentration of the photo-active redox component can be increased and the solvent viscosity reduced. Acid-base surface chemistry of n-GaAs as occurs in aqueous systems, has been found present and its consequences will be further explored. The selection and optimization of PEC electrolytes is a complex task and we believe that a systems approach would facilitate in identifying the basic electrolyte properties needed. A preliminary analysis reveals that although some of the criteria for an electrolyte are definable precisely, others do require empirical experimentation. It can be concluded that relatively few electrolytes in current use are adequate and it would appear that greater efforts to develop electrolytes would be advantageous. The various types of electrolytes that could be used for PEC's have been identified.

Good quality MoSe_2 single crystals can be grown and short circuit currents greater than previously reported have been achieved in an $\text{I}_2/\text{I}^-/\text{Pt}$ cell. A novel technique to produce photo-active films by anodization is being investigated, initially for the formation of polycrystalline MoSe_2 layers. Work on the economic and theoretical modeling has commenced and will be reported later.

Objective I: Obtain and characterize semiconductor electrodes including MoSe_2 , CuInS_2 and CuInSe_2 .

Report on properties and quality of electrodes.

Experiments with commercially available CuInSe_2 discouraging and halted. Good quality MoSe_2 xtals have been prepared and cell performance studies underway.

Objective II: Fabricate and evaluate Si in $\text{BuPyCl}/\text{AlCl}_3$ molten salts.

Fabrication, analysis and stability data on devices.

Poor photo-effects found with ferrocene redox system. Other redox systems to be tested.

Objective III: Fabricate and evaluate n-GaAs in $\text{BuPyCl}/\text{AlCl}_3$ molten salts

Fabrication, analysis and stability data on devices.

Extensive tests have been on this system which may be mass transport limited. Further experiments in hand.

Objective IV: Fabricate and analyze MoSe_2 in aqueous electrolytes

Fabrication, analysis and stability data on devices.

Fabrication method satisfactory and good cell performances observed with I_2/I^- redox system.

Objective V: Fabricate and analyze thin film CuInS_2 and CuInSe_2

Fabrication, analysis and stability data on devices.

No significant photoeffects observed in sulfide/polysulfide electrolytes. Selenide/polyselenide untested as yet.

Objective VI and VII:

Report evaluating applicability of SIS Model and a report on the costs of manufacturing various types of PEC cells.

Theoretical modeling has been incorporated into planning experiments. Analysis of electrolyte requirements commenced for systems approach. Economic modeling study commenced.

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