a thin film of metal such as silver or aluminum as the cathode layer on top of a previous layer such as an active layer.

FIG. 6 shows the prior-art thermal-evaporation device 80 widely used for small-scale fabrication of electronic devices. As shown, the prior-art thermal-evaporation device 80 comprises a vacuum chamber 82 receiving a heater 84 in a lower portion thereof and a sample holder 86 in an upper portion thereof. The sample holder 86 comprises a window 88.

A substrate 90 is placed on the sample holder 86 exposing to the window 88. The heater 84 heats a pure metal 92 thereon to evaporate the metal 92 into a gas phase which flows upwardly as indicated by the arrow 94 through the window 88 of the sample holder 86 and deposits onto the substrate 90 to form a metallic cathode layer. The prior-art thermal-evaporation device 80 may also comprise a vacuum gauge 96 for monitoring the level of vacuum in the vacuum chamber 82, and a gas inlet 98 for introducing an ambient gas (not shown) such as O_2, N_2, or the like for promoting surface reactions or maintaining film stoichiometry.

Conventional deposition methods generally require a high level of vacuum which may cause significant burden to large-scale fabrication of electronic devices. Moreover, above-listed conventional deposition methods also have other disadvantages such as:

(1) long operation-time,

(2) causing damages to previous layers due to the bombardment of metal particles during deposition of the current layer, and

(3) expensive procedure.

Due to above-described disadvantages, the conventional deposition methods may not provide an optimal solution for large-scale fabrication of electronic devices. Therefore, there is a desire for solution processing techniques with improved performance.

SUMMARY

Embodiments of this disclosure relate to a hybrid-energy apparatus or module that integrates solar cells, battery cells, and in some embodiments electronic circuits in an efficient and reliable manner, resulting in a reliable energy apparatus or module with high efficiency.

Disclosed herein is a multi-layer apparatus has a transparent or semi-transparent substrate, a solar-cell layer coupled to the substrate, an energy-storage layer coupled to the solar-cell layer, and a converter layer coupled to the energy-storage layer. The solar-cell layer has a plurality of solar cells for receiving light through the substrate and converting energy of the received light to a first electrical energy, the energy-storage layer has one or more energy-storage units for storing a second electrical energy, and the converter layer has one or more power converters electrically connected to the solar-cell layer and the energy-storage layer for receiving the first electrical

energy and the second electrical energy therefrom and outputting a third electrical energy through an output thereof.

In some embodiments, the substrate may comprise a layer of glass.

In some embodiments, the substrate may comprise a flexible, transparent, or semi-transparent material such as a transparent or semi-transparent plastic material such as polyethylene terephthalate (PET, also denoted as poly(ethylene terephthalate)), poly(ether sulfones) (PES), polyethylene naphthalene (PEN), polyimide (PI), and/or the like.

In some embodiments, the solar-cell layer may be an inverted organic photovoltaic (OPV) structure, comprising a plurality of sublayers such as, named starting from the substrate, a sublayer of Indium Tin Oxide (ITO) deposited or otherwise coupled to the substrate and acting as an anode, a sublayer of Zinc Oxide (ZnO), a sublayer of poly(ethylenimine) and poly(ethylenimine) ethoxylated (i.e., PEIE), a sublayer of organic bulk heterojunctions (BHJs) (i.e. a blend of p-type and n-type conjugated polymers), a sublayer of Molybdenum trioxide (MoO_3), and a sublayer of silver (Ag) or Aluminum (Al) as the cathode.

In some embodiments, the energy-storage layer comprises one or more semiconductor capacitors.

In some embodiments, each semiconductor capacitor comprise a plurality of Gallium Arsenide (GaAs)/Aluminum Gallium Arsenide (AlGaAs) sublayers, such as n AlGaAs layers ($n>0$ is an integer) and (n+1) GaAs layers with each AlGaAs layer sandwiched between two neighboring GaAs layers.

In some embodiments, the converter layer comprises a multi-input electronic power converter having a solar-input converter, a battery-input converter, and an output converter.

In some embodiments, any of the solar-input converter, battery-input converter, and output converter may comprise coils winding about a ferromagnetic or ferrimagnetic core.

In some embodiments, any of the solar-input converter, battery-input converter, and output converter may have a structure of at least three layers including a core layer made of a ferrite material and sandwiched between two wiring layers. Each wiring layer comprises electrically conductive wirings on a base and the wirings of the two wiring layers are interconnected through vias or holes thereon to form the coils winding about the ferrite core.

Disclosed herein is a hybrid power system comprising: a solar module having a plurality of solar cells, the solar module electrically coupled to a first circuitry having one or more first semiconductors for converting the output of the solar module to a first Alternating-Current (AC) current; an energy-storage module coupled to a second circuitry having one or more second semiconductors for converting the output of the energy-storage module to a second AC current; an output module coupled to a third circuitry having one or more third semiconductors for

outputting an electrical power; a transformer coupling the first and second circuitries to the third circuitry; and a control module for optimizing the output electrical power by adjusting signals applied to gate terminals of the first, second, and third semiconductors based on at least an output voltage of the solar module, an output voltage of the energy-storage module, an output current of the first circuitry, an output current of the second circuitry, an input current of the third circuitry, and an output voltage of the output electrical power.

According to a first aspect of this disclosure, there is provided a power circuitry comprising: a first input circuit for coupling to a photovoltaic (PV) source; a second input circuit for coupling to an energy-storage source; a third circuit coupled to the first and second input circuits for processing and outputting electrical energy received from at least one of the first and second circuits; and a control circuit coupled to the first, second, and third circuits for optimizing the output of the third circuit by controlling power flow therebetween based on output voltages of the PV and energy-storage sources, outputs of the first and second input circuits coupling to the third circuits, and an output voltage of the third circuit.

In some embodiments, the third circuit is coupled to the first and second input circuits via a transformer with the first and second input circuits on an input side of the transformer and the third circuit on an output side of the transformer.

In some embodiments, each of the first, second, and third circuits comprises one or more semiconductors for power conversion.

In some embodiments, the control circuit is configured for optimizing the output of the third circuit by adjusting gate signals applied to gate terminals of the semiconductors of the first, second, and third circuits based on the output voltages of the PV and energy-storage sources, the outputs of the first and second input circuits coupling to the third circuits, and the output voltage of the third circuit.

In some embodiments, the outputs of the first and second input circuits are output currents of the first and second input circuits; and the power circuitry further comprises one or more current sensors for sensing the output currents of the first and second input circuits.

In some embodiments, the control circuit is configured for optimizing the output of the third circuit further based on at least one of output currents of the PV and energy-storage sources, and an input current of the third circuit.

In some embodiments, the output of the third circuit is a direct-current (DC) output; the power circuitry further comprises a DC-to-AC inverter circuit coupled to the third circuit for converting the DC output of the third circuit to an alternate-current (AC) output; and the control circuit is configured for optimizing the output of the DC-to-AC inverter circuit based on the output voltages of the PV and energy-storage sources, the output currents of the first and second input

circuits coupling to the third circuits, the output voltage of the third circuit, an output voltage of the DC-to-AC inverter circuit, and an output current of the DC-to-AC inverter circuit.

In some embodiments, the outputs of the first and second input circuits are output voltages of the first and second input circuits; and the power circuitry further comprises one or more current estimators for estimating the output currents of the first and second input circuits based on the output voltages of the PV source, the energy-storage source, and the third circuit, and the gate signals of the semiconductors of the first, second, and third circuits.

In some embodiments, the one or more semiconductors of at least one of the first, second, and third circuits are gallium nitride (GaN) gates; and the power circuitry further comprises a GaN gate-driver circuit for preventing the GaN gates from shoot-through, the GaN gate-driver circuit comprising a level-shifter circuit.

In some embodiments, the level-shifter circuit comprises a Zener diode and a capacitor coupled in parallel and connected to a resistor in series.

In some embodiments, the third circuit comprises a parallel inductor on the output side of the transformer for compensating for parasitic capacitances.

According to a second aspect of this disclosure, there is provided an energy apparatus comprising: a transparent or semi-transparent substrate; a solar-cell layer coupled to the substrate, the solar-cell layer comprising a plurality of solar cells for receiving light through the substrate and converting energy of the received light to a first electrical energy; an energy-storage layer coupled to the solar-cell layer, the energy-storage layer comprising one or more energy-storage units for storing a second electrical energy; and a converter layer coupled to the solar-cell layer and the energy-storage layer for receiving and processing electrical energy therefrom and outputting the processed energy via an output; the converter layer comprises the above-described power circuitry and using the solar-cell and energy-storage layers as the PV and energy-storage sources, respectively.

Disclosed herein is a thermoelectric recycling structure comprising: a heat-conductive first component for engaging a heat source for receiving heat generated therefrom; a second component spaced from the first component; and a heat-nonconductive and electrons-and-holes-transportive thermoelectric layer sandwiched between the first and second components for receiving the heat from the first component and converting the received heat to electrical power.

In some embodiments, the thermoelectric recycling structure further comprises: a light-harvesting layer coupled to the first component one an opposite side of the thermoelectric layer for engaging the first component with the heat source therethrough, the light-harvesting layer comprising: a metasurface for harvesting light; and a nano-wire layer coupled to the metasurface

for converting the harvested lighted to converted heat and transferring the converted heat to the thermoelectric layer.

In some embodiments, the thermoelectric layer comprises one or more thermoelectric components made of one or more two-dimensional (2D) materials.

In some embodiments, the one or more 2D materials comprises 2D perovskite.

In some embodiments, the one or more thermoelectric components comprise a continuous thermoelectric sheet made of the one or more 2D materials.

In some embodiments, the thermoelectric layer comprises a plurality of the thermoelectric components separated from each other.

In some embodiments, the thermoelectric layer comprises a plurality of electrically conductive nano-channels having one or more subwavelength dimensions thereof.

In some embodiments, the thermoelectric layer has a thickness of about 10 nanometers (nm).

Disclosed herein is an energy apparatus comprising: a transparent or semi-transparent substrate; a solar-cell layer coupled to the substrate, the solar-cell layer comprising a plurality of solar cells for receiving light through the substrate and converting energy of the received light to a first electrical energy; an energy-storage layer coupled to the solar-cell layer, the energy-storage layer comprising one or more energy-storage units for storing a second electrical energy; a converter layer coupled to the solar-cell layer and the energy-storage layer for receiving and processing electrical energy therefrom and outputting the processed energy via an output; and at least one of the thermoelectric recycling structure as described above, coupled to at least one of the solar-cell layer and the converter layer for receiving the heat generated therefrom.

Disclosed herein is a supercapacitor comprising: one or more capacitor layers; and a first and a second electrical terminals; each capacitor layer comprises: a pair of electrically conductive thin-film sublayers sandwiching electrically insulating membrane sublayer, a conductive medium between the each of the thin-film sublayers and the membrane sublayer, and a first and a second conductor sublayers sandwiching the pair of thin-film sublayers and the membrane sublayer, the first conductor sublayer coupled to the first electrical terminal and the second conductor sublayer coupled to the second electrical terminal.

In some embodiments, the thin-film sublayers comprise at least one of activated carbon, graphene, and graphite.

In some embodiments, the conductive medium comprises at least one of ionic liquid, conductive ink, and current collector.

In some embodiments, the conductive medium is coated onto the membrane sublayer.