Exercise 9.1 solution.

a) The bandgap of amorphous Ge can be extracted by fitting the linear portion of the spectrum and extrapolating the value on the x-axis and is equal to 0.88 eV at 300°K.

b) The absorption in the low energy part of the spectrum corresponds to the Urbach tail. The absorption coefficient dependence on the energy is given by:

$$\propto(\omega)_{Urbach} = \propto_0 \exp\left(\frac{\hbar\omega}{E_e}\right)$$

Where E_e is a measure for the width of the distribution of localized states in the tail (also called Urbach energy). The Urbach energy gives an indication on the energetic disorder in amorphous or disordered semiconductors.
It can also apply for crystalline materials, especially when those are highly dopped or when studied at high temperature.

Exercise 9.2 solution.

a) In conventional solar cells, light absorption and charge transport both occur in the same material. Charge separation is made through the potential barrier at the p-n or through the p-i-n junction. Most of the time, photoexcited charge carriers are generated in the p-side and separated at the junction (or the n-side, called the getter). First generation solar cells need for a thick absorption layer (hundreds of μm) to compensate for low absorption. Second-generation solar cells (thin films) have a higher absorption coefficient than first-generation solar cells but charge transport is less efficient due to lower purity/multi grain structure. These can be called homojunction devices (the junction is made of the same material).

Dye-sensitized solar cells (DSCs) are low-cost photoelectrochemical solar cells that operate by separating light absorption and charge transport. In a DSC, a photoexcited dye with a high extinction coefficient injects an electron into the conduction band of a transparent semiconductor metal oxide, such as TiO_2, or ZnO. Because the semiconductor cannot absorb visible light, it needs to be “sensitized” with a dye absorbing visible light to maximize solar light absorption. This approach ensures that light absorption and charge transport are processes happening in separated materials, therefore decreasing the rate for charge recombination and ensuring a higher probability of collecting the separated charges at the respective electrodes. After being injected in the semiconductor, the electron travels to an external electrical circuit, while the dye ground state is regenerated through the oxidation of a redox mediator (liquid, solid, or gel electrolyte). This process is also known as hole injection/hole transfer. Reduction of the oxidized redox mediator at the counter-electrode closes the electric circuit. The performance of these cells is dictated by the competition between charge separation and charge recombination at the heterojunction.

For perovskites, the same principle applies: The perovskite layer can be used as a “sensitizer” and absorbs visible light. The charges are then separated at two different interfaces: The electron can be extracted in a film of TiO2, while the hole is extracted through a hole-transport material such as spiro-OMeTAD. The particularity of the perovskite cell is that it can work in a variety of configurations (i.e. also as a classic p-i-n junction). However, having separate interfaces such as TiO2 and spiro-OMeTAD to separate the charges can greatly prevent charge recombination and help to efficiently extract the charges.

b) Solar cells and photodetectors are essentially doing the same process: separating the photogenerated charges. However, the technical requirements can be very different. Solar cells need to operate outside with long lifetimes, and are optimized for the spectrum of the sun. Photodetectors are usually very efficient and optimized for a given wavelength depending on the application.
The device is anti-reflection coated, and we therefore assume that no optical power is lost at the front surface. A well-designed photodiode will have negligible absorption in the top contact and quantum efficiency $\eta \approx 1$ at the operating wavelength. We therefore obtain:

Responsivity = $\frac{e\eta}{\hbar\omega}(1 - e^{-\propto l}) = \frac{e}{\hbar\omega}(1 - e^{-0.1\times 10})$ = 0.41 A/W

c) The photocurrent is given by the product of the responsivity and the optical power. The photocurrent will therefore be 0.41 mA.

Exercise 9.3 solution.

This band diagram refers to a LED. One can see that without any potential applied the potential barrier at the junction is quite steep. Therefore, no electron can flow from the n-side to the p-side and conversely no hole can flow from the p-side to the n-side. By applying a positive bias (= forward bias) one can reduce the steepness of the potential barrier at the junction. Additionally, the bias is driving a current through the device, and electrons and hole are injected in the circuit. By reducing the steepness of the potential barrier, one creates a region where it will be easier for the injected electrons and holes to “meet and recombine” to generate light.