Supplementary Information

Absorption and transmission of light in III-V nanowire arrays
for tandem solar cell applications

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Figure S1. Absorptance $A$ (solid blue line) compared to $1 - R - T$ (dashed blue line), with $R$ the reflectance and $T$ the transmittance, for the GaInP nanowire array embedded in the First Contact™ polymer membrane after removal of Au particles. As described in the methods section, some of the scattered light is collected in neither transmission nor reflection measurements, which can lead to $1 - R - T > A$ in these measurements. Also, the absorptance of a First Contact™ membrane without nanowires is shown (solid black line). The absorptance of the membrane appears on the 1-2% range, which is at the level of the calibration of our absorption measurements.

Figure S2. Photoluminescence (PL) spectrum of GaInP nanowires in a polymer membrane. We assign the peak at $\lambda \approx 640$ nm, that is, at approximately 1.95 eV in photon energy, to bandgap luminescence of the GaInP nanowires. We assign the peak at $\lambda \approx 860$ nm to the approximately 100 nm long remaining InP stub part of the nanowires after breaking them off the substrate. Note that this InP peak is blue-shifted from the $\lambda \approx 925$ nm expected for bulk InP. We speculate that such a shift could originate for example from a possible mixed wurtzite/zincblende crystal phase in the stub and/or quantization effects if some of the nanowires break off with a much shorter stub than the approximated 100 nm length.
Figure S3. Schematics of a sample inserted into an integrated sphere. In (a), we measure the reference counts $C_{\text{ref.abs}}(\lambda)$ on the detector when the incident light passes by the sample onto the inner wall of the integrating sphere. In (b), the light is directly incident on the sample, and we measure the counts $C_{\text{sample.abs}}(\lambda)$ on the detector. From these measurements, we extract the absorptance as $A(\lambda) = 1 - \frac{[C_{\text{sample.abs}}(\lambda) - C_{\text{dark.abs}}(\lambda)]/[C_{\text{ref.abs}}(\lambda) - C_{\text{dark.abs}}(\lambda)]}{C_{\text{dark.abs}}(\lambda)}$ with $C_{\text{dark.abs}}(\lambda)$ being the dark counts when light was not incident into the sphere. In the measurements of $C_{\text{sample.abs}}(\lambda)$, the incidence angle toward the sample was approximately $10^\circ$.

Figure S4. (a) Reference counts $C_{\text{ref.abs}}(\lambda)$ for varying size of an approximately 300 μm thick single-side polished square-shaped planar Si sample with side length given in the legend (see Figure S3a for a schematic of the measurement; note that to be able to insert the largest samples, which were larger than the openings into the sphere, we opened the casing of the sphere, detached the two halves that the sphere consisted of, mounted the sample, and reassembled the sphere). Note that these reference counts depend on the sample size. That is, the samples absorb some of the light that scatters diffusively inside the integrating sphere, and a larger sample absorbs more of this light. However, as seen in (b), the calibration of the measurements is independent of sample size at least up to a sample size of 15 mm × 15 mm (in these measurements, light was incident on the polished side of the Si sample). For comparison, we also show 1 - $R_{\text{Si}}(\lambda)$ with $R_{\text{Si}}(\lambda) = |1 - n_{\text{Si}}(\lambda)|^2 / |1 + n_{\text{Si}}(\lambda)|^2$ the reflectance of a planar Si/air interface at normal incidence (note that the polarization averaged reflectance of a planar Si interface at the approximately $10^\circ$ incidence used in the measurements is very close to that at $0^\circ$). Tabulated values\(^1\) were used for $n_{\text{Si}}(\lambda)$, the refractive index of Si. We find good agreement between the measured absorptance and 1-$R_{\text{Si}}(\lambda)$ for $\lambda < 900$ nm, where the absorption in the 300 μm thick Si samples is limited by reflection. Note that with increasing wavelength beyond 900 nm, the Si samples become more and more transparent due to the decreasing absorption coefficient of Si, and consecutively $A(\lambda) < 1 - R_{\text{Si}}(\lambda)$ there.
**Figure S5.** Absorptance of InP nanowires in polymer membrane with (red line) and without (blue line) the Au particle present on the nanowires. The InP nanowires were fabricated similarly as the GaInP nanowires, as described in the main text.

**Figure S6.** Modeled reflection for varying array pitch $P$ as a function of wavelength. The gray line for each $P$ shows results from modeling with 1 nm step in wavelength, and the red line shows results after averaging over 50 nm in wavelength. We consider a hexagonal array of nanowires, without the Au particle, embedded in a polymer matrix (see the schematic in Figure 2). The light is incident at normal angle from the top air side, and we average the results over both polarizations of the incident light. Here, the nanowires are 180 nm in diameter and 2000 nm in length. For simplicity, we use a fixed refractive index of $n = 1.5$ for the membrane and $n = 3.5$ for the nanowires. Thus, with this choice of a real-valued $n$, that is, with $\text{Im}(n)=0$, for the nanowires, we consider non-absorbing nanowires in order to concentrate on the light scattering and possible enhanced reflection from the nanowires. In this modeling, we assumed the membrane to be infinitely thick in the downward direction, and the transmission occurs to the membrane. Therefore, the reflection occurs due to interaction of the incident light with the nanowire array, and the large reflectance values are due to resonant scattering from the nanowire array. The light scattering is solved based on the Maxwell’s equations.\textsuperscript{2-3} Note that the experiments in the main text are performed with $P = 500$ nm.
References

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