Supplementary Materials

1. SAMPLE GROWTH
Samples were grown in two connected Varian Gen. II solid source molecular beam epitaxy systems, “Echo” and “Bravo”. The n++ InAs backplane was grown on Echo and the device structures, for the control and n++, were grown on Bravo. Both systems are equipped with valved-crackers for arsenic and SUMO effusion sources for gallium and indium. To grow the n++ backplane, Echo is equipped with a SUSI silicon sublimation source which allows for doping \(\sim 1.2 \times 10^{20} \text{cm}^{-3}\). After the growth of the n++ InAs backplane an arsenic cap was deposited for in situ transfer and the sample is transferred into Bravo. For device growth, Bravo is equipped with an additional valved-cracker for antimony, a SUMO effusion cell for aluminum and individual dopant sources for silicon and beryllium. All device growth temperatures were measured by blackbody thermometry with a kSA BandiT system.

2. SAMPLE CHARACTERIZATION
Photoluminescence of the sample was optically characterized by Fourier transform infrared (FTIR) amplitude modulation step scan PL spectroscopy, using a 980 nm pump laser modulated at 10 kHz. Electroluminescence (EL) was also characterized using FTIR amplitude modulation step scan with the sample modulation provided by an Agilent 8114a pulsed current source. In both cases, the resulting detector signal was demodulated by a lock-in amplifier synchronized to the pump source modulation frequency. For temperature-dependent EL measurements, the sample was pulsed at 400 mA in “quasi-CW” mode (a duty cycle of 50%) with a repetition rate of 10 kHz. For power measurements, light from the devices, modulated at 1 kHz and 50% duty cycle, was collected by a ZnSe lens and then focused onto a calibrated HgCdTe detector using a second ZnSe lens. Both ZnSe lenses were 1-inch diameter and had a 2-inch focal length. A lock-in amplifier was used to demodulate the collected HgCdTe signal.

Reflection spectra were collected from the samples using a Bruker Vertex 80v Fourier transform infrared (FTIR) spectrometer with an attached Bruker Hyperion infrared microscope. Reflection measurements were normalized to the reflection of a gold mirror. The optical properties of the n++ substrate, including the plasma wavelength, were calculated by fitting the measured reflection of the n++ sample to a transfer matrix model of the sample. Knowing the thickness of each layer allows for the fitting of the experimental data with only two parameters, plasma wavelength and scattering rate of the sample.

TEM samples were prepared using Scios 2 FIB and imaged in a JEOL 2010F microscope equipped with LaB6 filament using g = 004 and 220 two-beam conditions.

3. THEORETICAL CALCULATIONS
We modeled our system using a Dyadic Green’s function formalism, incorporated into a transfer matrix method solver [1–3], positioning our emitter at the five QD layer positions. These calculations provide us with the position- and wavelength-dependent Purcell enhancement \((P(\lambda))\), as well as the Purcell-corrected Poynting flux representing the total energy emitted by the point dipole to the far field \((S_z(\lambda))\), shown in Fig. S1(a). Note the anti-correlation between the strongest Purcell enhancement (at the surface plasmon wavelength) and our \(S_z(\lambda)\), a result of the bound nature of the surface plasmon modes at the n++/undoped InAs interface which dominate the strong Purcell enhancement.

While Purcell enhancement modifies the quantum efficiency of our QD emitters (the fraction of recombination events in a QD resulting in emitted photons), \(\tilde{q}_i = P_{q_i}/[(P - 1)q_i + 1]\) with \(\tilde{q}_i\) being the quantum efficiency of an isolated QD, only a fraction of emitted photons escape the leaky LED cavity and the detector in the far field. Therefore, the total measured emission enhancement can be estimated by comparing the product \(\tilde{q}_i(\lambda) \cdot S_z(\lambda)\) in the plasmonic structure to its counterpart in the control structure. The overall enhancement of QD emission results from the interplay of the short wavelength tail of the Purcell enhancement (which peaks at the wavelength of the surface plasmon wavelength of the n++/undoped InAs interface) and the cavity formed by the layered system.
Fig. S1. Spontaneous emission enhancement from In(Ga)Sb for a series of five In(Ga)Sb emitters 100 nm above the n$^{++}$/undoped interface. From this we extracted (a) the Purcell enhancement factor as a function of wavelength (red) as well as the z-component of the Poynting vector, in black, as a function of dipole emitter wavelength. (b) Control EL emission (dashed) for three possible intrinsic quantum efficiencies, (green) $q_i = 1\%$, (blue) $q_i = 5\%$, (red) $q_i = 25\%$, and modeled overall far field emission of the highly-doped device (solid).

Fig. S1(b) illustrates the evolution of the emission spectra of the plasmonic and control devices for the range of intrinsic quantum efficiencies from 1% to 25%. For each quantum efficiency, the spectrum of the plasmonic device is formed from the product of total emission enhancement (defined above) and the spectrum of the control counterpart. The experimental and predicted emission is shown in Fig. 3(c) (for $q_i = 5\%$). The calculations that predict the observed EL enhancement of the emission are quite accurate when compared to experimental results.

REFERENCES

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