

Supplementary Information for

**Efficient power extraction in surface-emitting semiconductor lasers
using graded photonic heterostructures**

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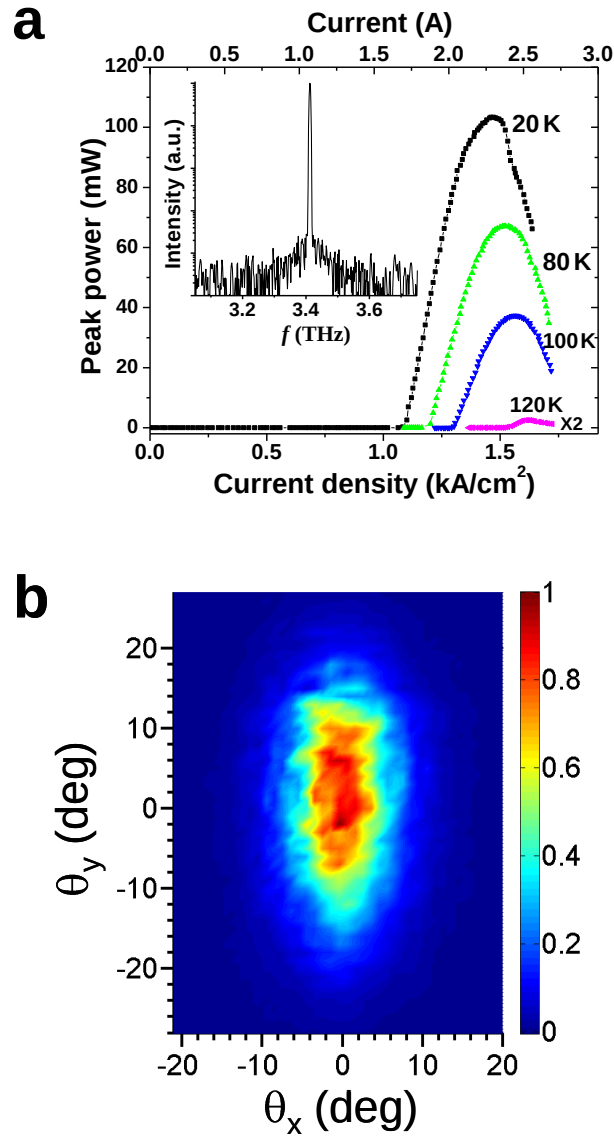
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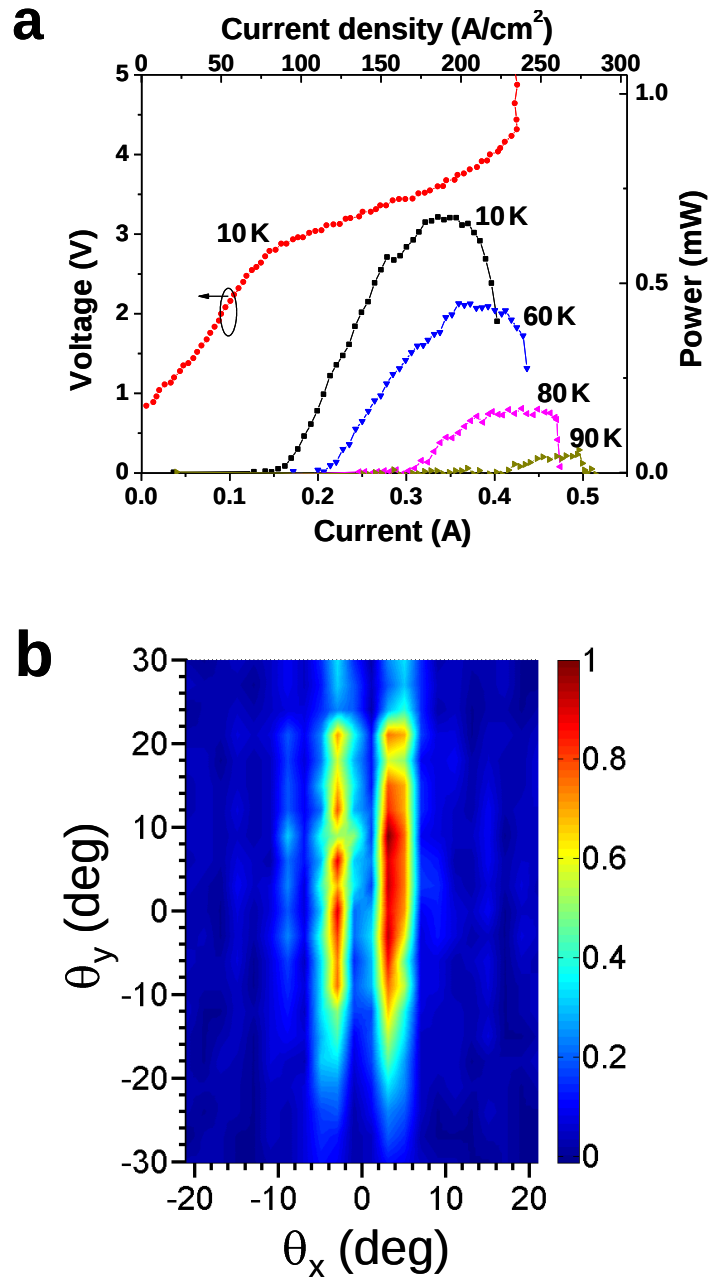
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Supplementary Figures S1 to S2



Supplementary Figure S1. **Improvement of power output and far-field pattern in a wide ridge graded photonic heterostructure laser.** The ridge width is $214\ \mu\text{m}$, and a_0 is $27.4\ \mu\text{m}$. (a) Light-current curves at different operation temperatures. The inset of (a) is the emission spectrum measured at 20 K. (b) The far-field pattern measured at 78 K.



Supplementary Figure S2. **Continuous wave operation of standard second-order distributed feedback lasers.** (a) Light-current-voltage (L-I-V) curves of a typical second-order distributed feedback (DFB) laser at different heat-sink temperatures. The ridge width is $127\ \mu m$, the ridge length is $1.42\ mm$, and the single-mode emission frequency is $2.70\ THz$. The DFB laser operates in CW up to $90\ K$, with a maximum output power of $0.65\ mW$, and a wall-plug efficiency of 0.05% at $10\ K$. (b) Far-field pattern of the same device measured at $78\ K$.