[0009] CLAIMS

I. Device / Apparatus Claims

1. A semiconductor photonic device comprising:

    1.1 a planar photonic-crystal slab of direct-gap semiconductor material that defines a symmetry-protected bound state in the continuum (BiC) of optical radiation having an unloaded quality factor $Q \geq 10^5$;

    1.2 a plurality of quantum wells disposed in said slab and coupled to the BiC field so as to form exciton–polaritons; and

    1.3 means for providing a driven-dissipative gain to the quantum wells;

wherein, when a mean polariton density exceeds a first threshold $P(c1)$, a phase-coherent condensate is established and, when the density exceeds a second threshold $P(c2)$, intrinsic χ^3 interactions populate ±k side-modes that phase-lock to a $k \approx 0$ mode, thereby spontaneously producing a spatially periodic density modulation while retaining global phase coherence, such that the condensate simultaneously breaks continuous and discrete translational symmetry and therefore constitutes a supersolid.

2. The device of claim 1, wherein the BiC possesses a non-zero topological charge that imparts tolerance to lattice-parameter disorder.

3. The device of claim 1 or 2, wherein the photonic crystal comprises a square or triangular lattice of apertures having period a = 240–380 nm, radius r = 0.25–0.40 a and slab thickness t = 0.70–0.85 a.

4. The device of any preceding claim, wherein a pumping rate Γ_pump exceeds a total polariton loss rate Γ_loss so that the device operates in a non-equilibrium steady state.

5. The device of any preceding claim, wherein the quantum wells are GaAs/AlGaAs or $In_xGa_{1-x}As$ $(0 < x \le 0.15)$ and provide a Rabi splitting ≥ 8 meV at 300 K.

6. The device of any preceding claim, further comprising a p-i-n current-injection ridge or nanoridge that supplies carriers to said quantum wells so that the gain is provided electrically.

7. The device of any preceding claim, further comprising a suspended phononic waveguide, resonator or ring patterned adjacent to the photonic crystal and evanescently or piezo-electrically coupled to acoustic-like Goldstone modes of the supersolid.

8. The device of claim 7, wherein the phononic structure exhibits a mechanical quality factor $> 10^4$ at room temperature and supports delay-line or band-pass filter operation with fractional bandwidth ≤ 1 %.

9. The device of any preceding claim, further comprising a bonded control layer of $LiNbO_3$, AlN or SiN for electro-optic or piezo-electric tuning of a lattice vector k or a modulation depth m of the supersolid.

10. The device of any preceding claim, further comprising (a) an inverse-taper edge coupler designed for numerical aperture 0.14–0.16 with ≤ 1.5 dB insertion loss, or (b) an apodised surface-grating coupler having ≤ 3 dB insertion loss and ± 2 µm 1-dB alignment tolerance.

11. An array comprising N ≥ 2 devices according to any of claims 1–10 disposed on a common substrate and having tunable nearest-neighbour couplings Jij set by local pump intensities or bias currents, thereby implementing a programmable Ising or Bose–Hubbard Hamiltonian for quantum simulation.

II. System Claims

12. A room-temperature microwave oscillator comprising (a) the device of claim 7 and (b) an optical or electrical read-out circuit coupled to the phononic waveguide to generate an RF signal, the phase noise of which at 10 kHz offset is ≤ -110 dBc Hz^{-1}.

13. A radio-frequency filter front-end comprising the device of claim 7 cascaded with a transceiver integrated circuit, wherein the phononic element supplies a pass-band of < 0.5 % full width with insertion loss ≤ 2.5 dB in the 3–10 GHz range.

14. A quantum-annealing processor comprising the array of claim 11 together with a control computer programmed to vary Jij(t) and onsite detunings µi(t) so as to perform an adiabatic

optimisation protocol.

III. Method Claims

15. A method of generating a supersolid exciton–polariton condensate, comprising:

    a) providing the device of claim 1;

    b) injecting carriers or optically pumping the slab at a power $P \geq P(c1)$ to form a uniform condensate; and

    c) increasing the injected power to $P \geq P(c2)$ so that χ^3 scattering populates ±k side-modes that phase-lock to the zero-momentum mode, thereby establishing a periodic density grating of period $\Lambda = \pi/k$ while maintaining global phase coherence.

16. The method of claim 15, wherein the condensate is seeded by spectrally resonant picosecond pulses shaped by a spatial-light modulator to select a lattice vector k'.

17. The method of claim 15 or 16, wherein the pumping is supplied electrically through a ridge-waveguide aperture and the drive current is modulated to dynamically tune a modulation depth m of the supersolid.

18. The method of claim 15, further comprising evanescently coupling Goldstone-mode oscillations of the supersolid into the suspended phononic waveguide of the device of claim 7 and detecting a resulting acoustic signal.

19. A method of sensing a physical perturbation comprising:

    i) operating the device of claim 7 in a supersolid state;

    ii) exposing the phononic waveguide or the photonic lattice to an analyte or mechanical load; and

    iii) measuring a shift in a Goldstone-mode resonance frequency Ωph, wherein a magnitude of said frequency shift is mapped to mass loading, refractive-index change or strain.

20. A method of fabricating the device of claim 1, comprising:

    a) epitaxially growing, on a substrate, a sacrificial layer and an active slab containing multiple quantum wells;

    b) depositing a hard mask and lithographically patterning a two-dimensional lattice of apertures;

c) etching the apertures by inductively coupled plasma to define a BiC cavity;

d) selectively removing the sacrificial layer to form a suspended membrane;

e) depositing a conformal passivation layer;

f) bonding a wafer-level glass or silicon lid under vacuum to form a hermetic cavity that maintains $\leq 10^{-4}$ mbar for $> 1\,000$ h at 85 °C in accordance with Telcordia GR-468-CORE; and

g) dicing the wafer and attaching each die onto a thermally conductive interposer, followed by electrical/optical interconnection and final over-moulding or metal-lid sealing.

IV. Computer-Implemented Claim

21. A non-transitory computer-readable medium storing instructions that, when executed by a controller coupled to pump lasers or drive circuits of a plurality of devices according to claim 11, dynamically adjust individual pump powers to realise time-dependent coupling graphs Jij(t) implementing a prescribed optimisation or quantum-simulation algorithm.

V. Use Claim

22. Use of the device of claim 1 as a room-temperature source of coherent phonons for on-chip Brillouin memory, acousto-optic modulation or frequency-comb generation.