Novel Microwave Resonance around Integer Landau Level Fillings in Unidirectional Lateral Superlattices

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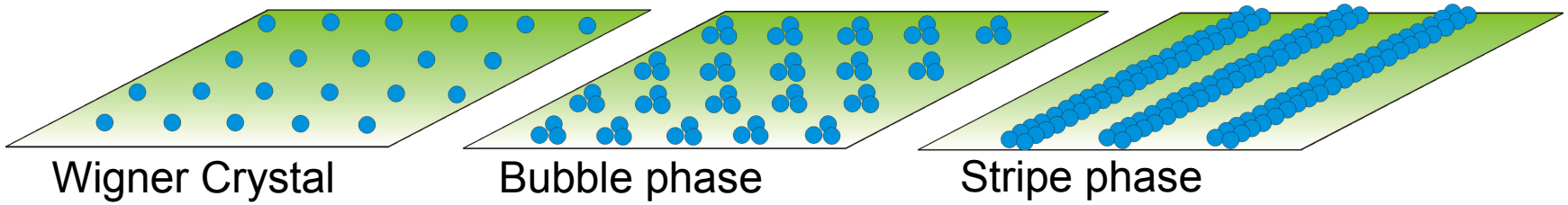
1. Motivation

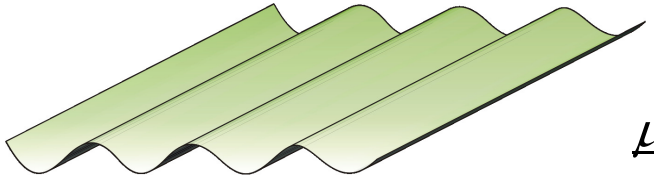
Electron-Crystal-like states in Quantum Hall Systems



→ fragile

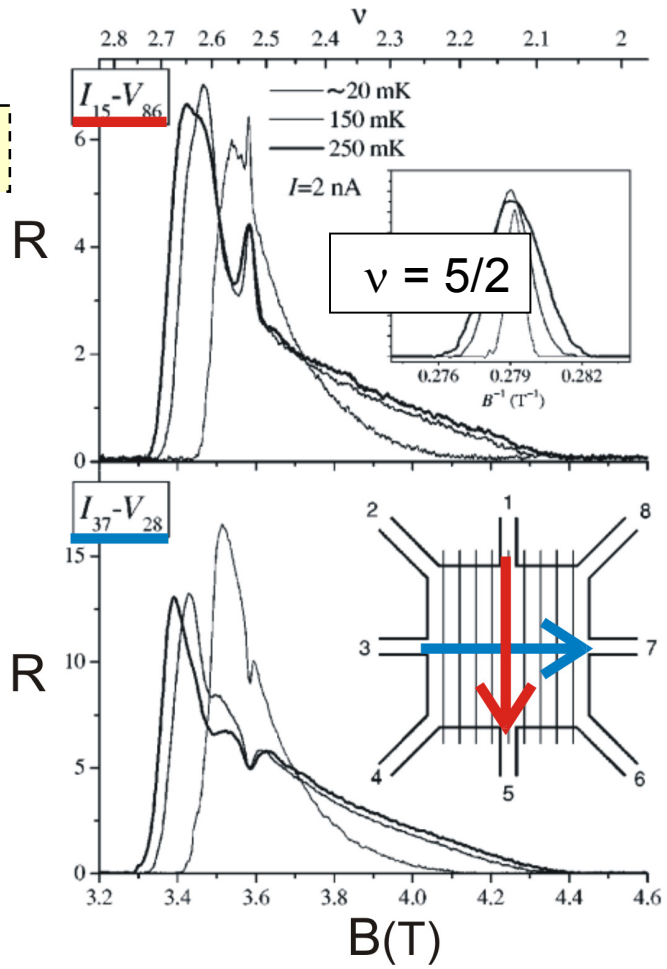
→ultrahigh-mobility 2DES (μ >1000 $m^2V^{-1}s^{-1}$)

Unidirectional lateral superlattice :ULSL



μ ~100 $m^2V^{-1}s^{-1}$

Anisotropic DC resistance



→ formation of the stripe phase

[A. Endo *et al*, PRB **66**, 075333 (2003)]

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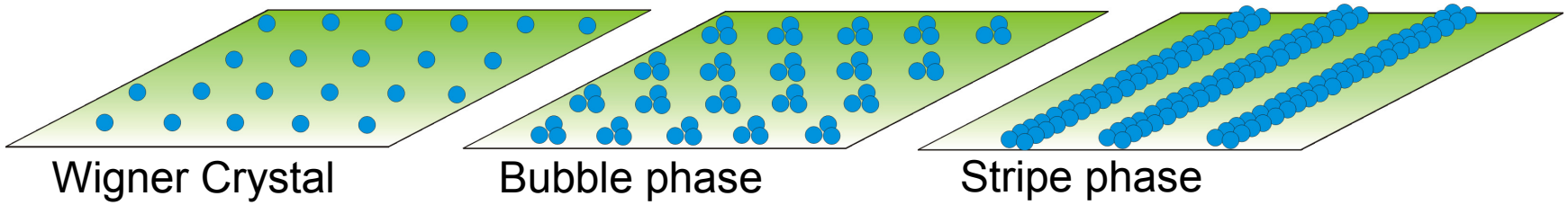

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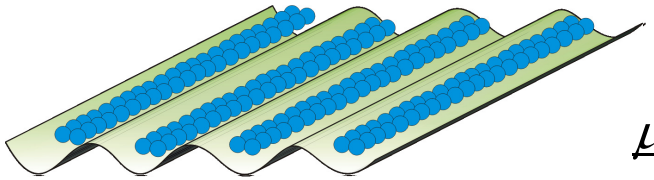

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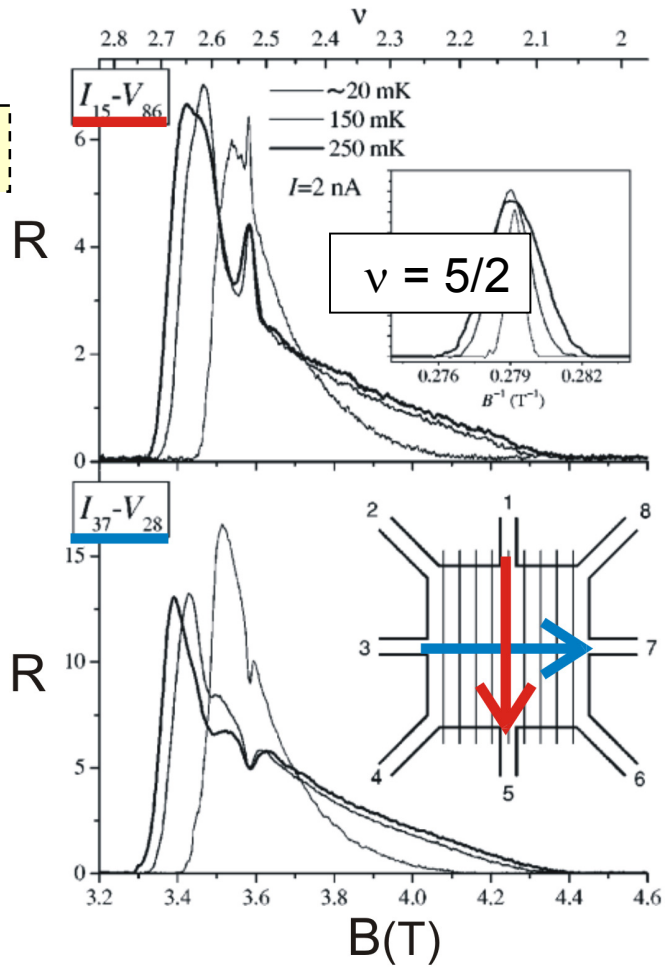

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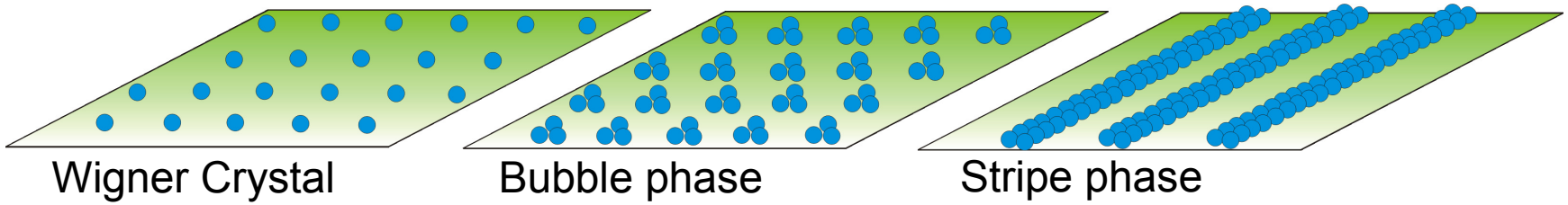

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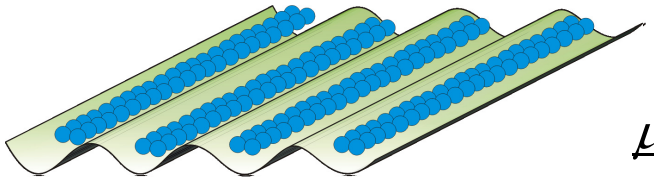

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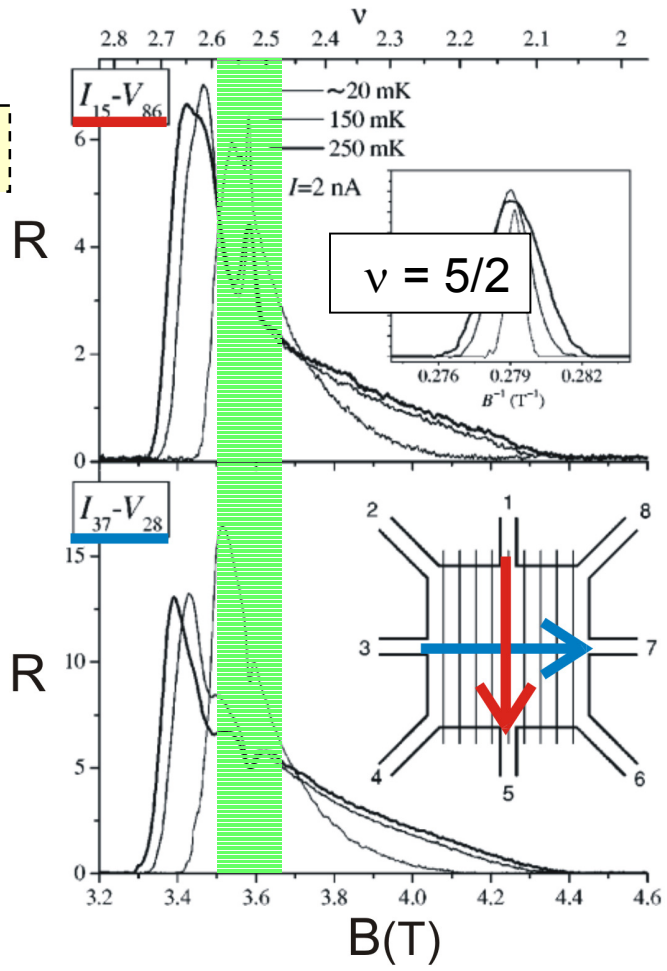

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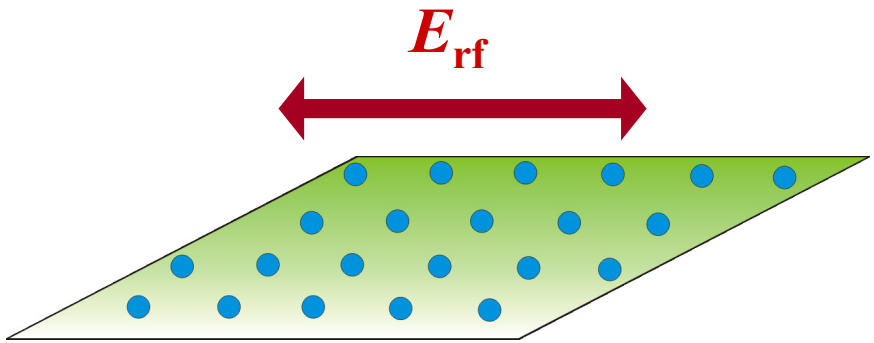
Pinning mode resonance

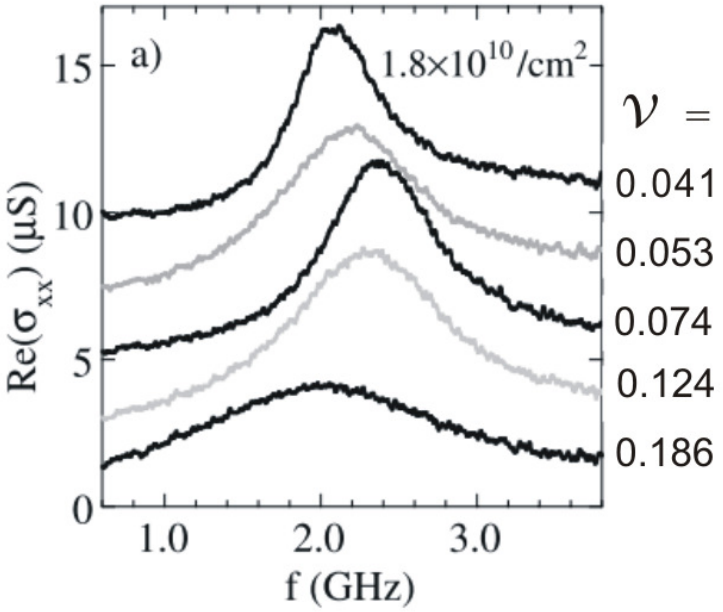
Electron-Crystal-like states

→ Pinned by disorder

→ Microwave resonance

Peak in Re{σ_{xx}} vs. frequency





Pinning mode resonance of Wigner Crystal at high *B*

[P. D. Ye *et al*, PRL **89**, 176802 (2002)]

Microwave conductivity of the ULSL has not investigated yet .
Will there be any resonance?

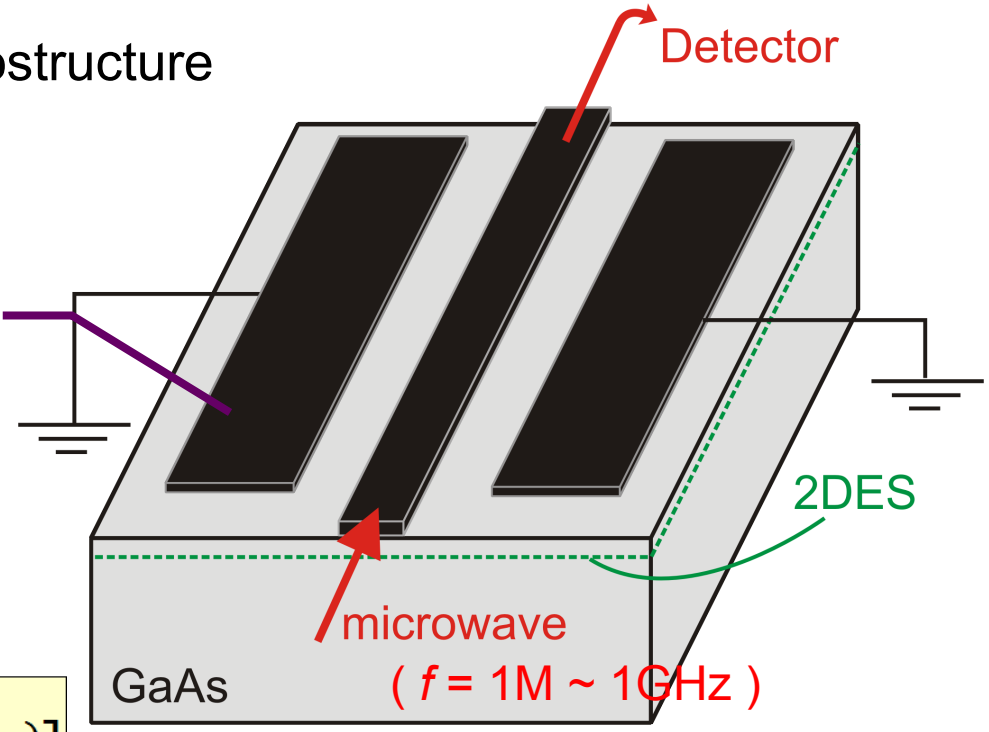
2. Experimental

Measurement of microwave conductivity

2DES in a GaAs-AlGaAs heterostructure

μ = 102 $m^2V^{-1}s^{-1}$

Coplanar Waveguide (CPW) :
coupled capacitively to the 2DES



Power Transmission:

$$P = \frac{P_{out}}{P_{in}} = \exp\left[-(2lZ_0 / w)\,\mathrm{Re}\{\sigma_{xx}\}\right]$$

$$\Rightarrow \quad \mathrm{Re}\{\sigma_{xx}\} = -\frac{w}{2lZ_0}\ln|P|$$

[Engel *et al*, PRL **71**, 2638 (1993)]

line length: l = 1.6 mm

slot width: w = 28 μm

characteristic impedance Z_0 = 50 Ω

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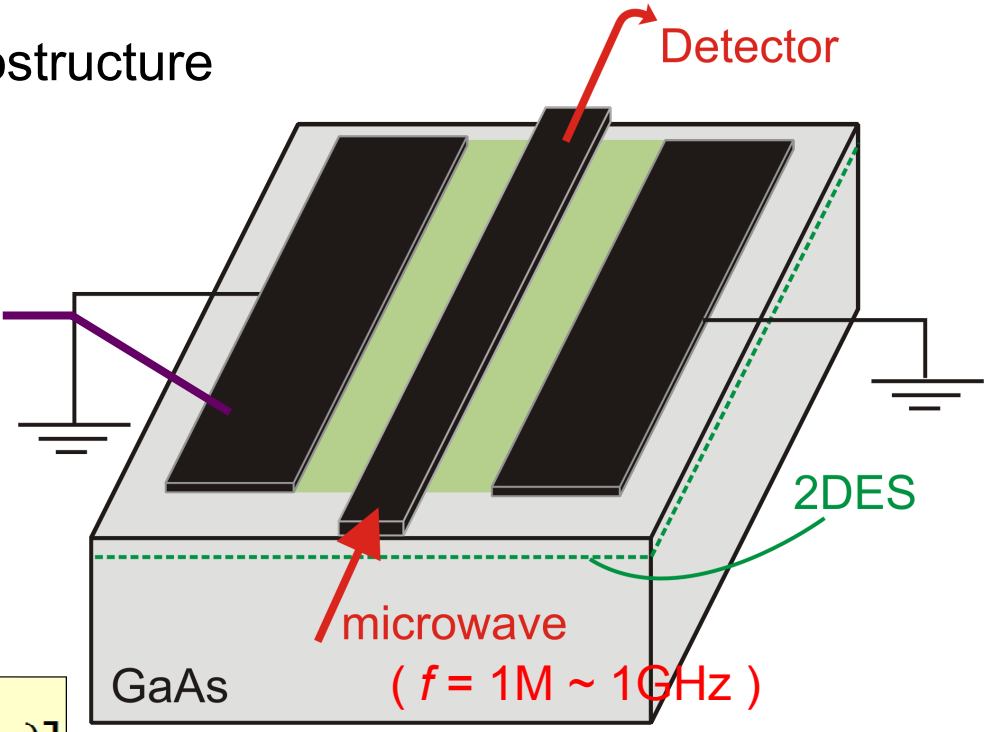

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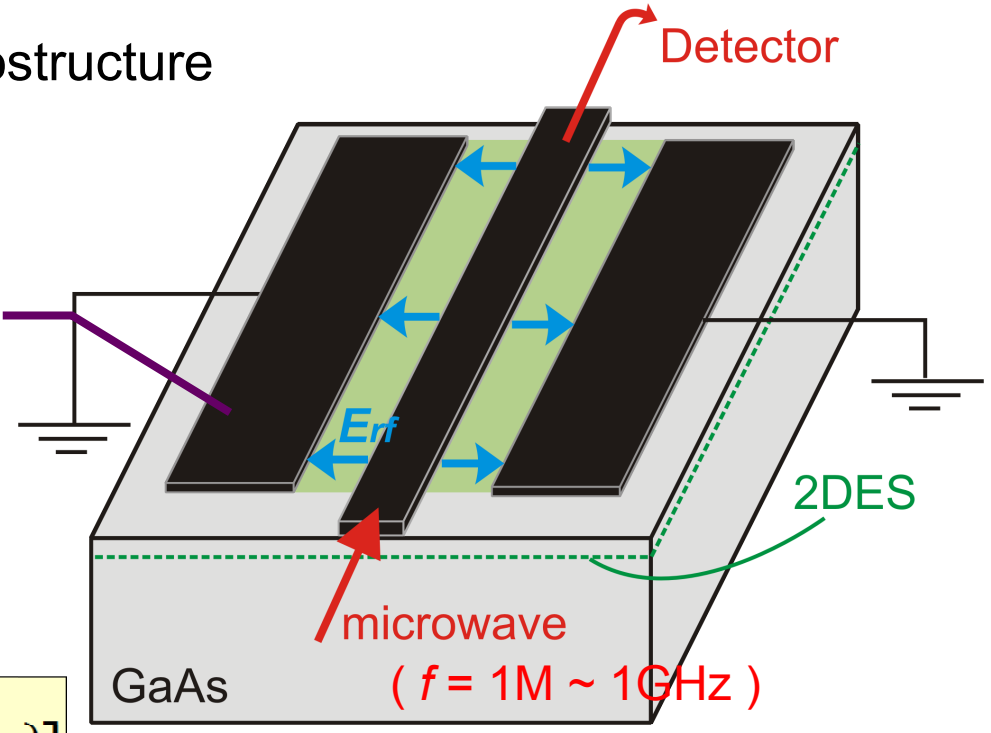

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characteristic impedance Z_0 = 50 Ω

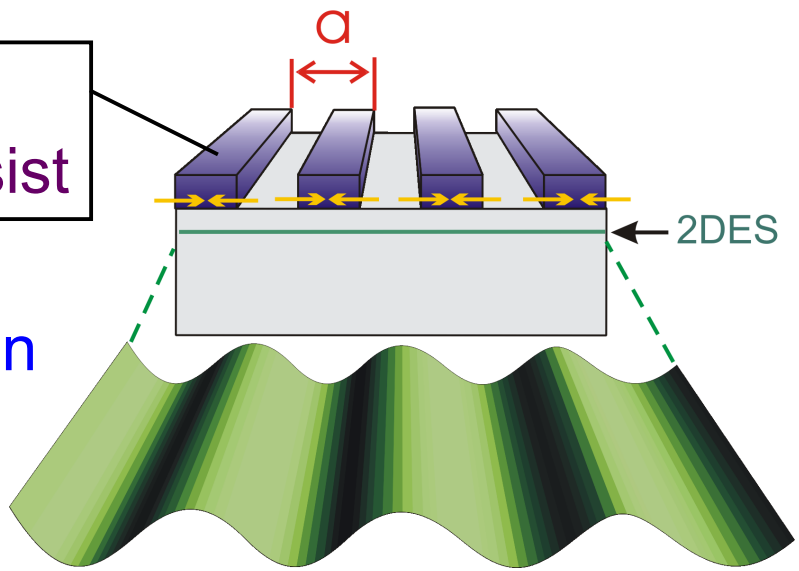
1D periodic modulation

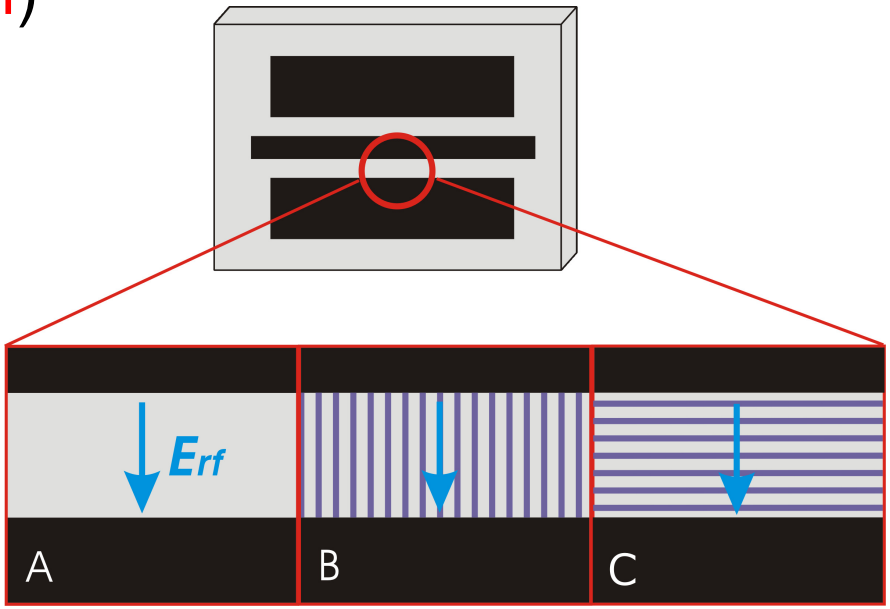
Grating fabricated
with the negative electron-beam resist

piezoelectric effect induced by strain

1D periodic modulation
(period a = 200 nm)

[A. Endo *et al*, PRB **63**, 113310 (2000)]





3-type Samples

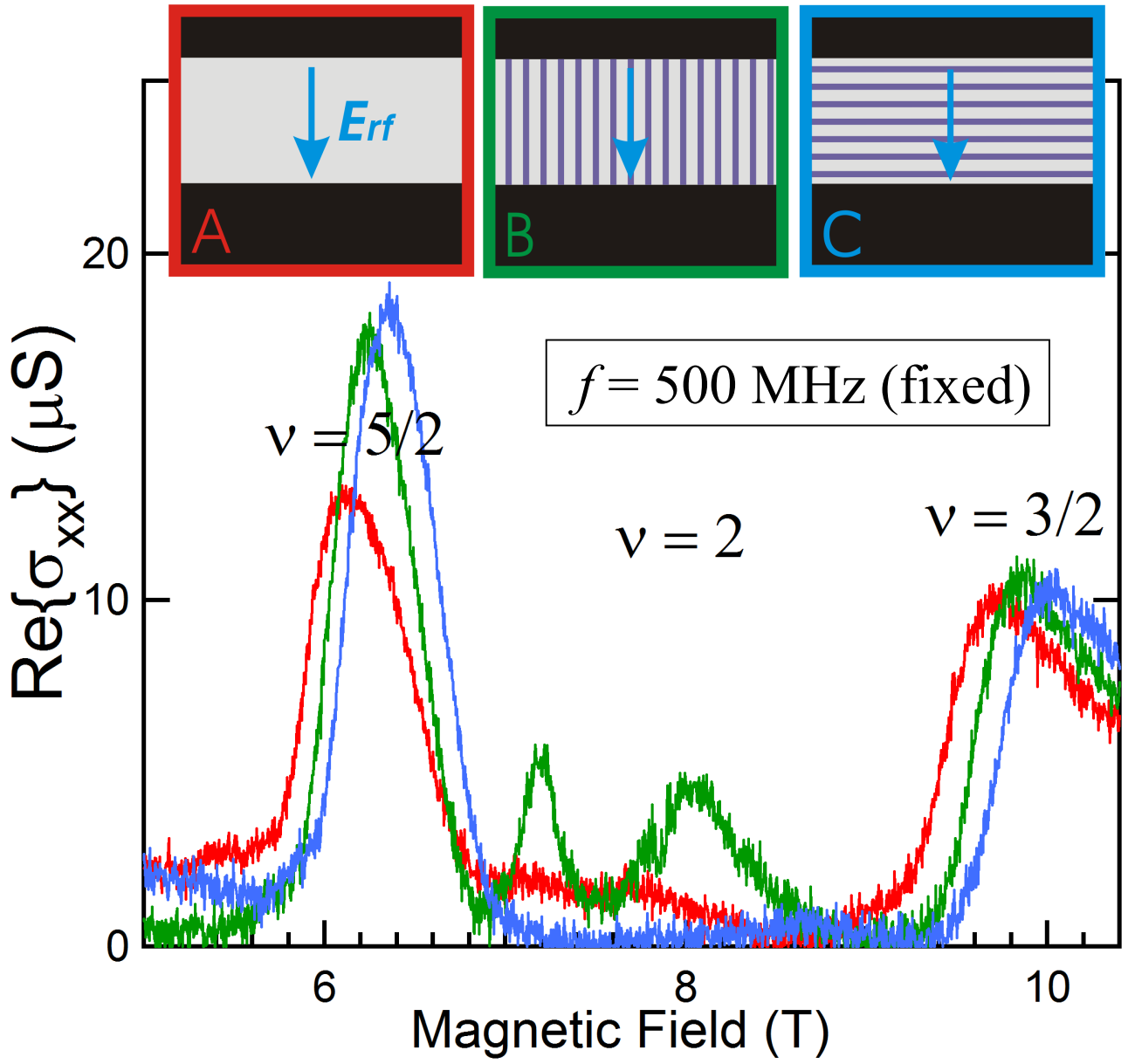
A: w/o modulation

B: modulation // E_{rf}

C: modulation ⊥ E_{rf}

3. Results

Re{σ_{xx}} vs. *B*



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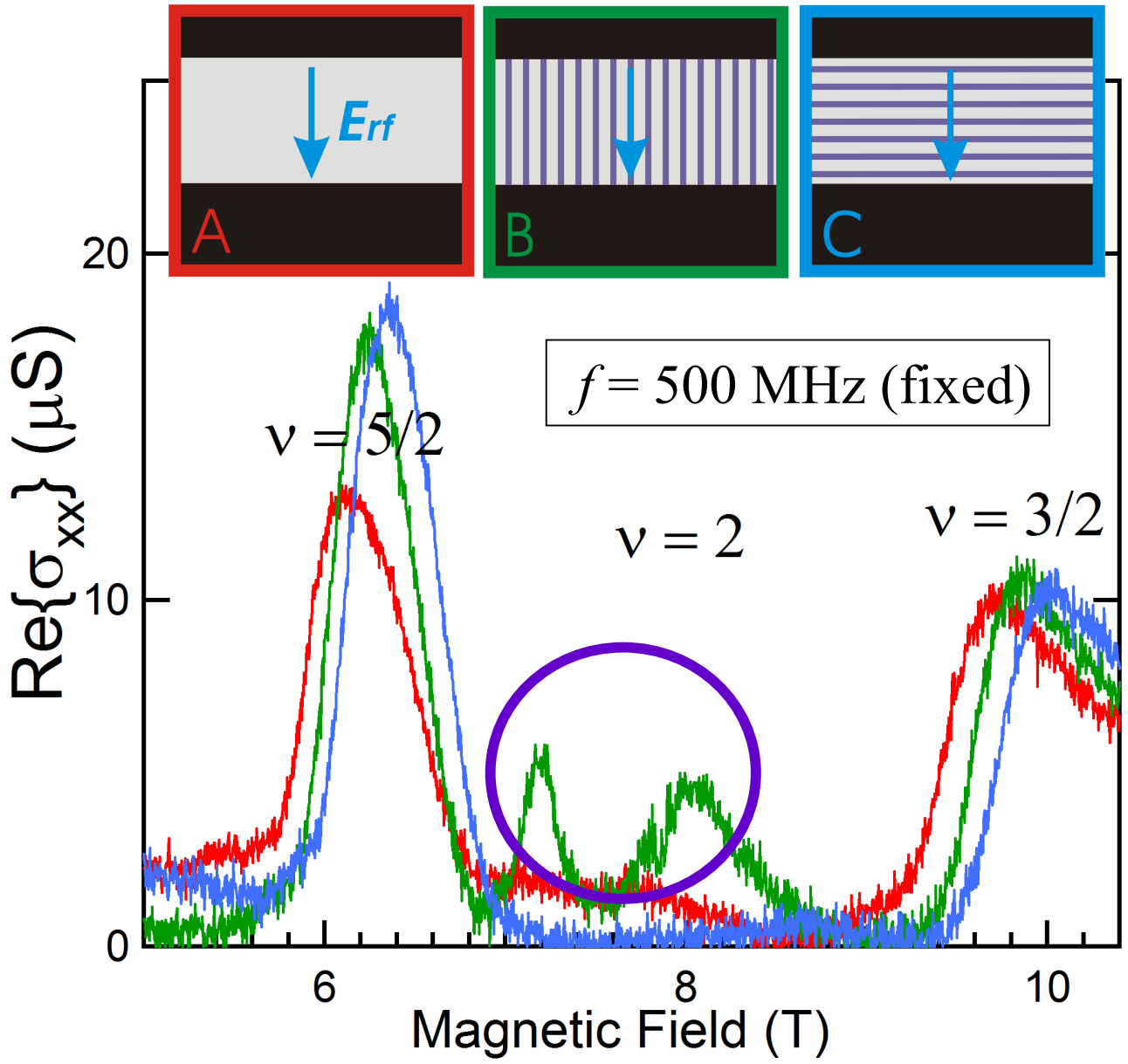
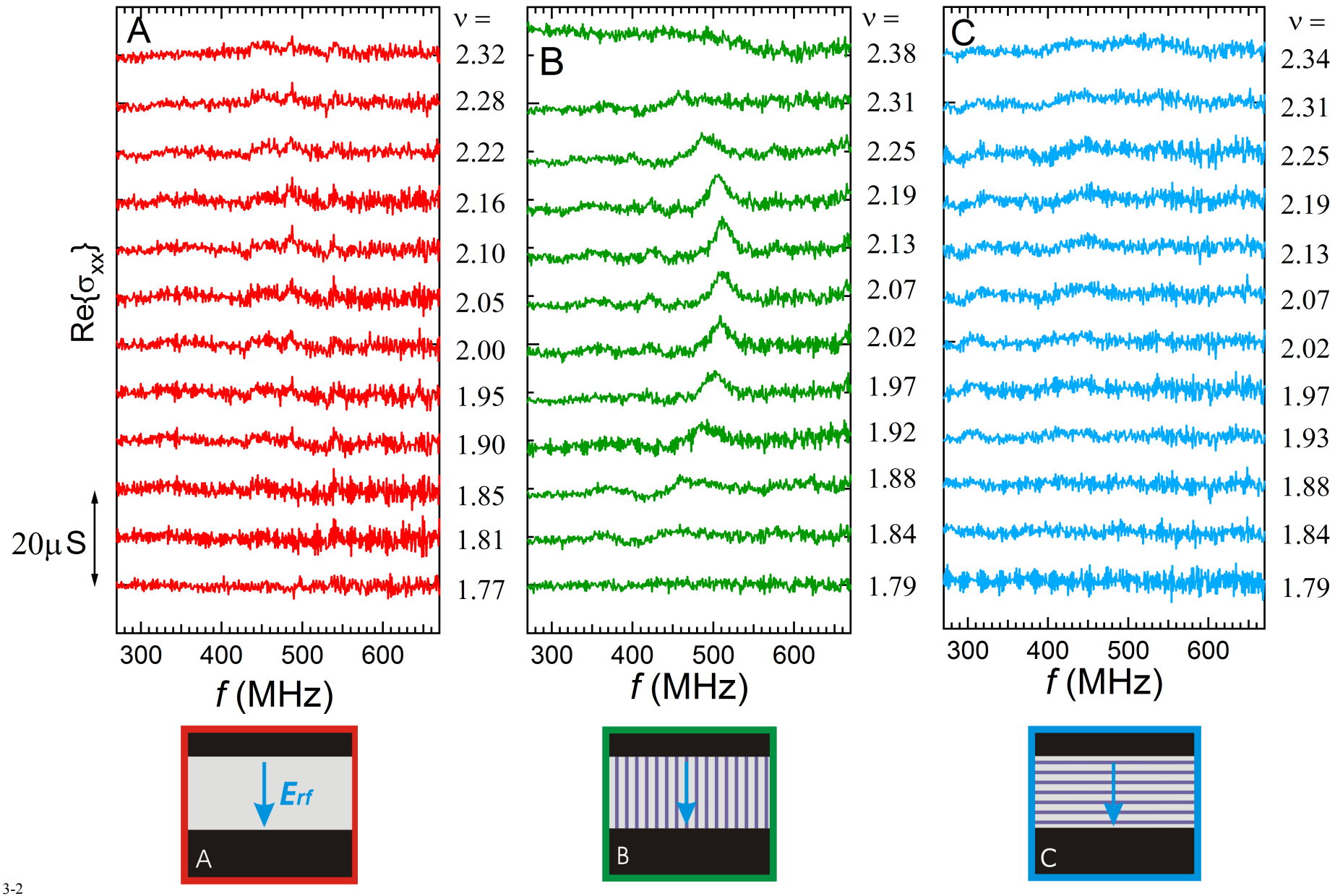


Re{σ_{xx}} vs. *f*



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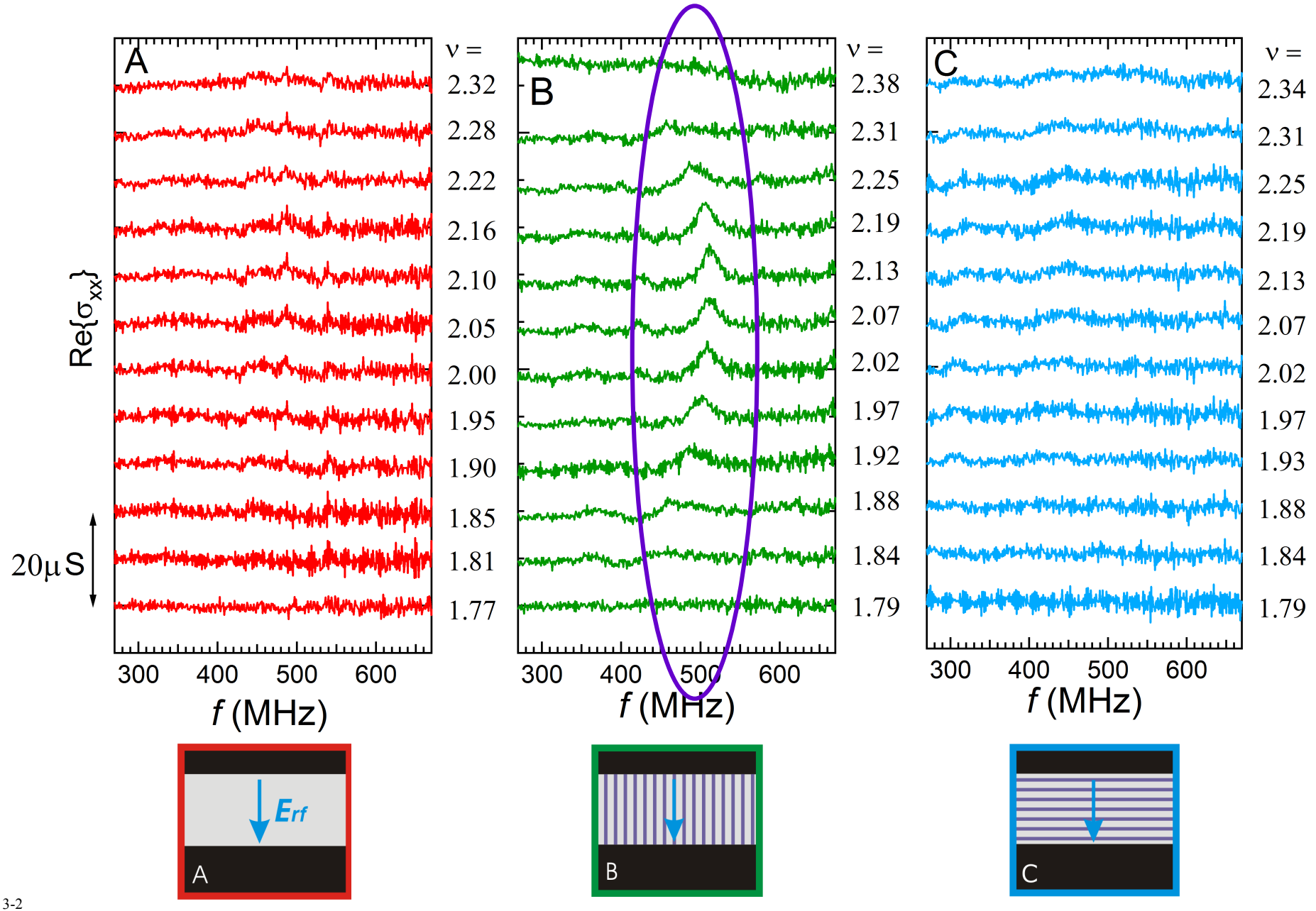

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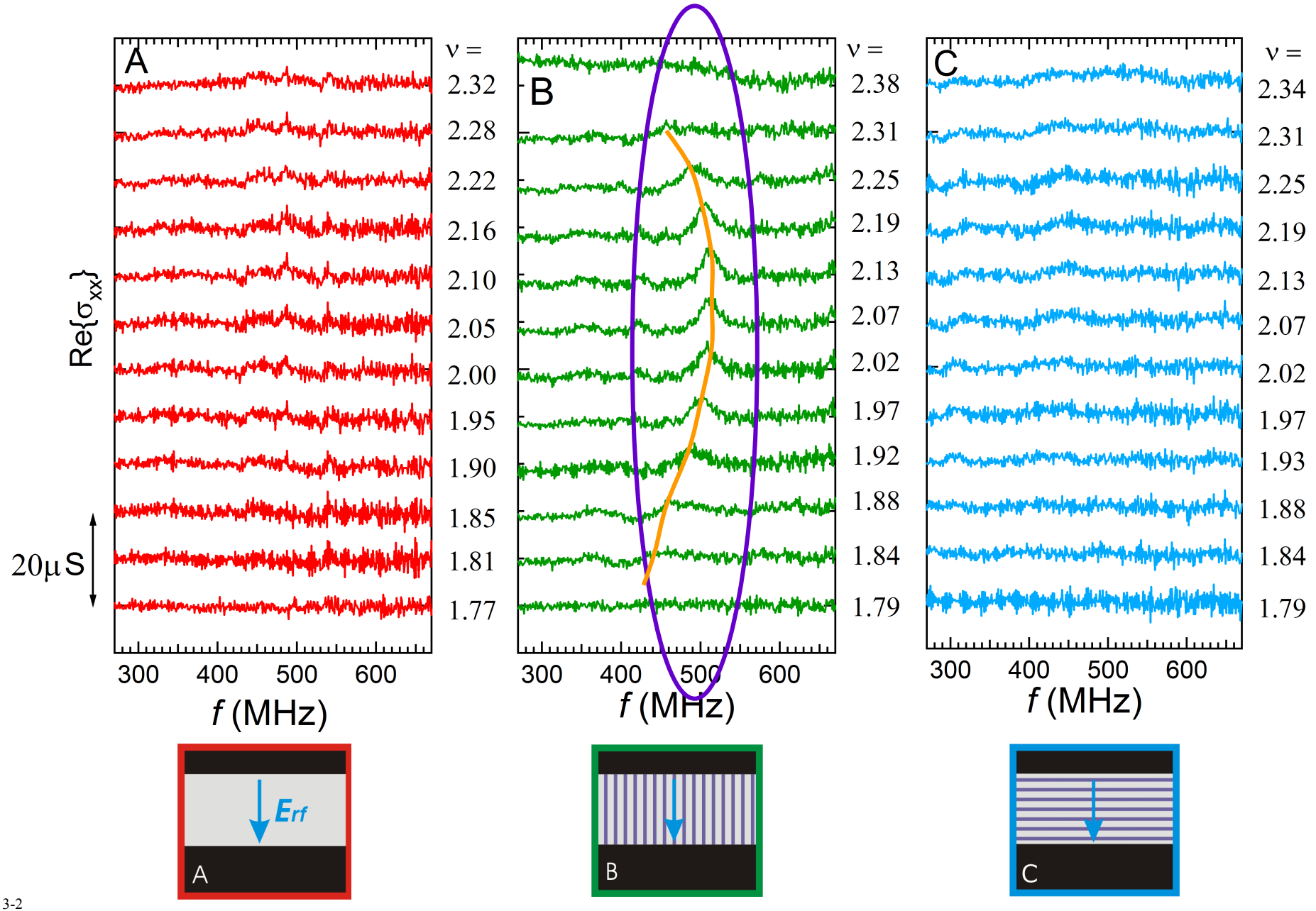


4. Discussion

What is the origin of the resonance ?

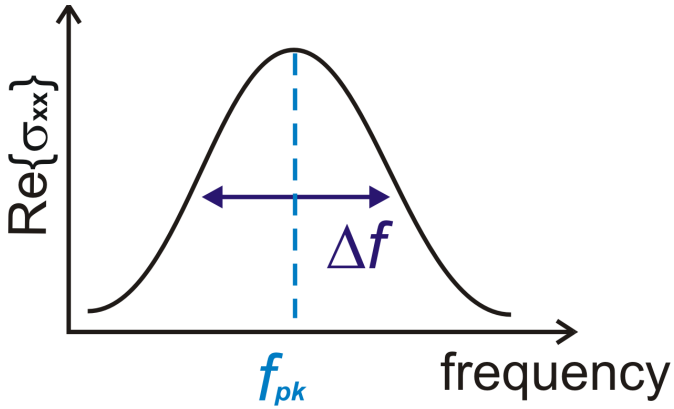
→ Pinning Mode resonance of a Crystal-like state

Crystal-like state is corroborated
by 1D periodic modulation.

Quality factor: $Q = f_{pk}/\Delta f \sim 25$

cf.

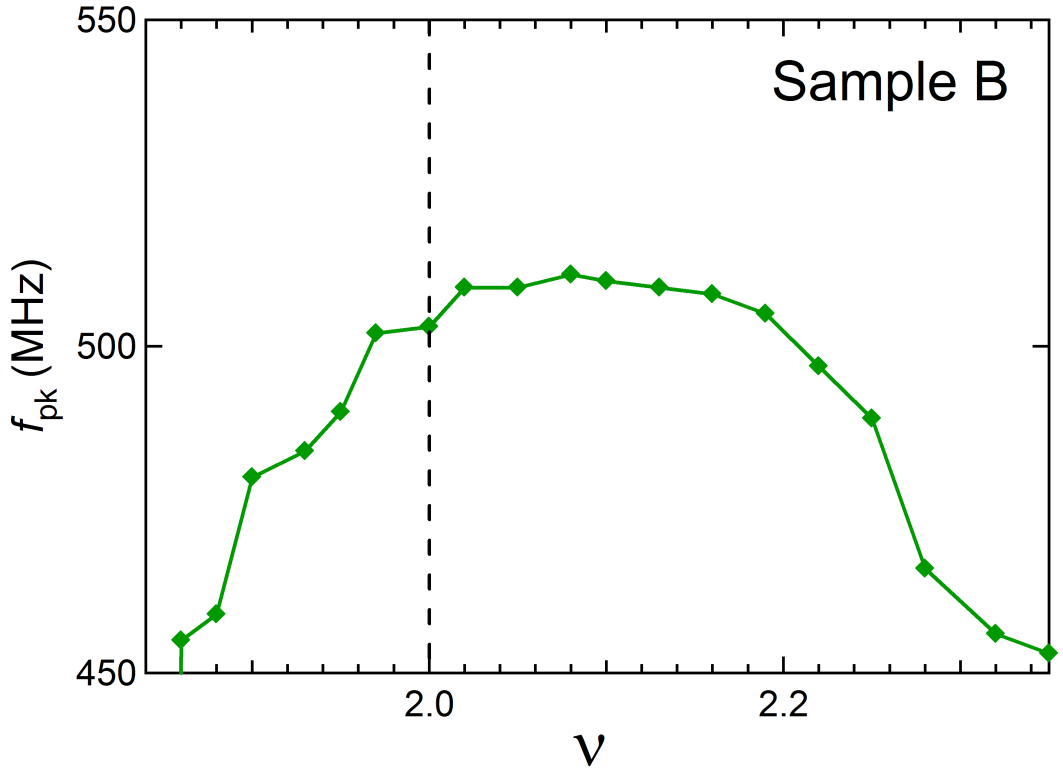
$Q \sim 10$: Wigner Crystal at high B
[C. C. Li *et al*, PRL **79**, 1353 (1997)]



→ electrons in large regions oscillate coherently (in phase)

[M. M. Fogler and D. A. Huse, PRB **62**, 7553 (2000)]

Peak frequency vs. filling factor



Weak pinning: [H. Fukuyama and P. A. Lee, PRB **18**, 6245 (1978)]

reducing effective carrier density in topmost LL ($\nu \rightarrow 2$)

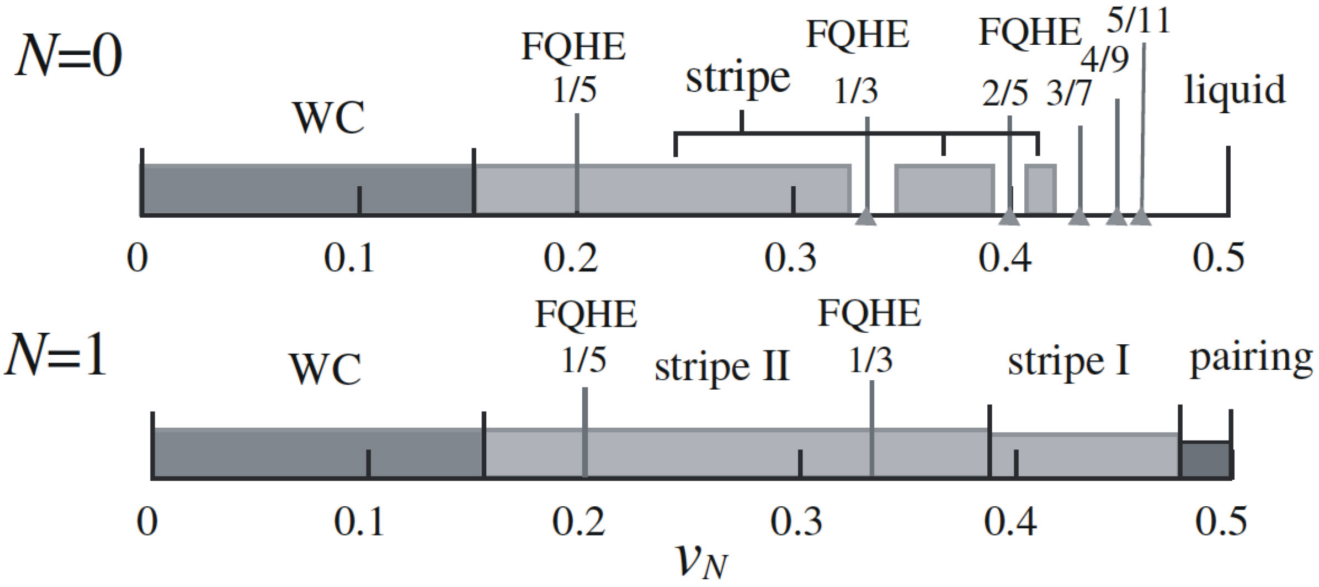
⇒ weaker e-e interaction (more easily-deformable)

⇒ electrons fall deeper into disorder potential (more pinned)

⇒ f_{pk} increases

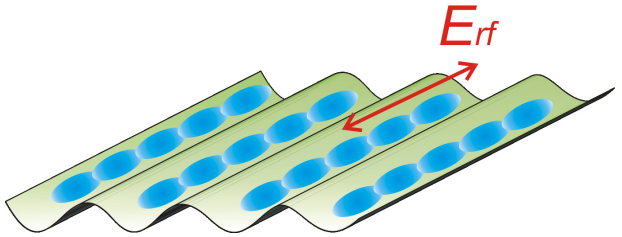
Candidates for the origin of the resonance

Ground state phase diagram calculated by DMRG method
(for plain 2DES) [N. Shibata and D. Yoshioka, JPSJ **72**, 664 (2003)]



Stripe II (predicted in theory):
Wigner Crystal melt by quantum fluctuations anisotropically

It is possible that Stripe II is corroborated by artificial modulation.



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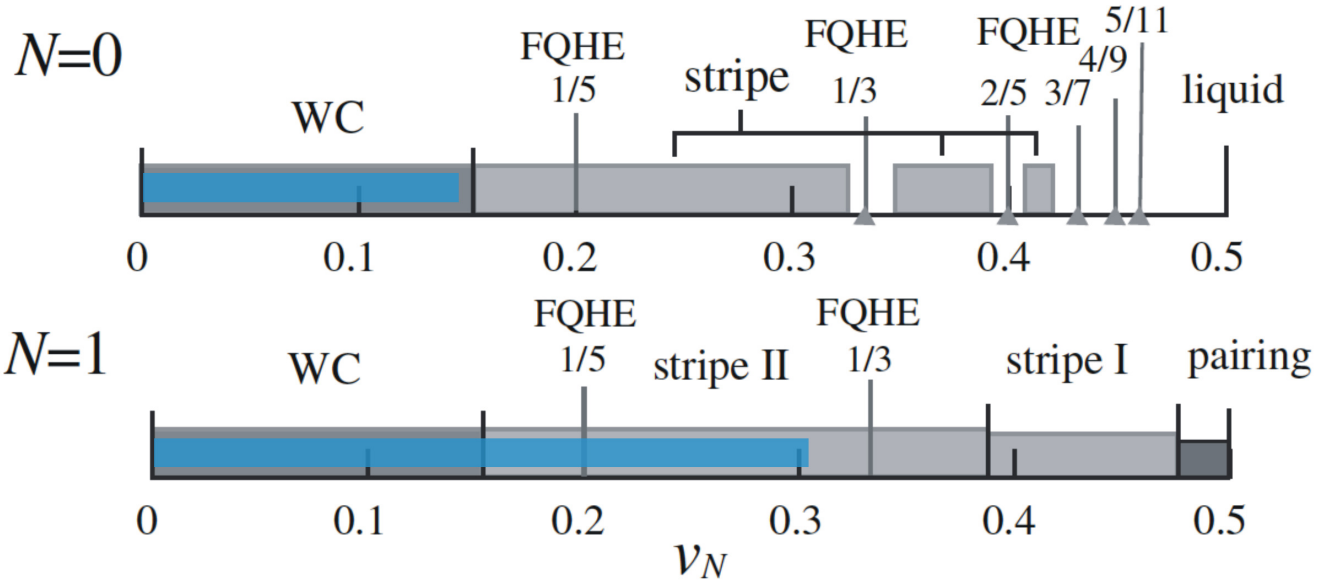

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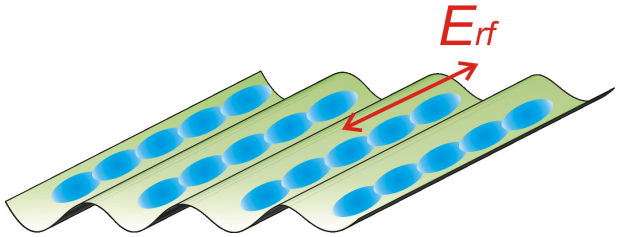

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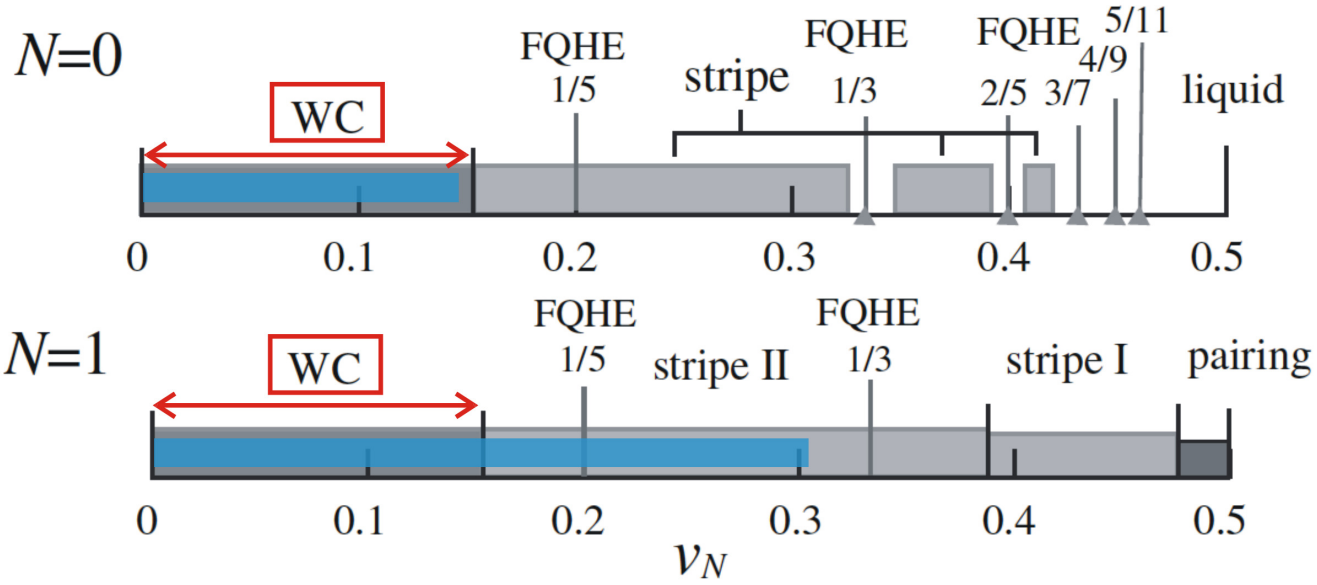

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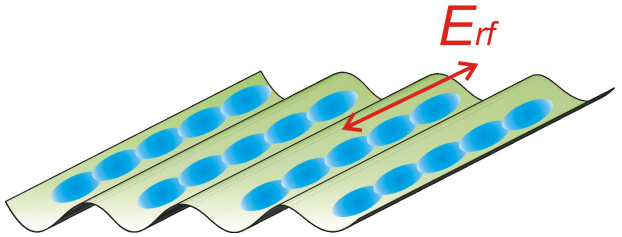

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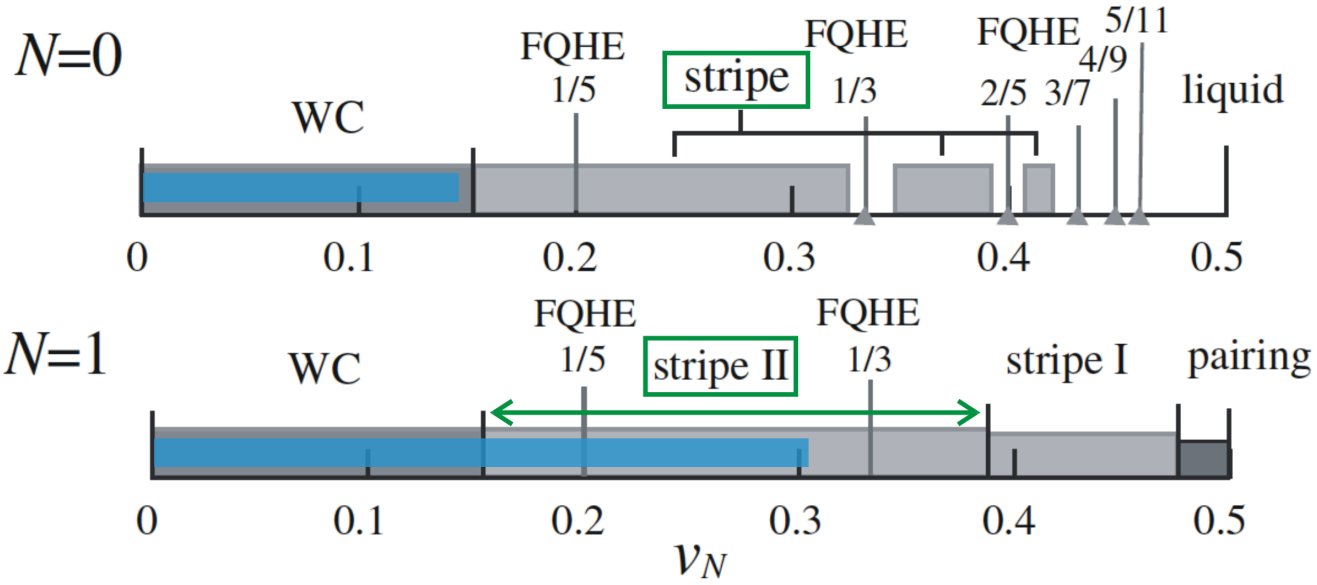

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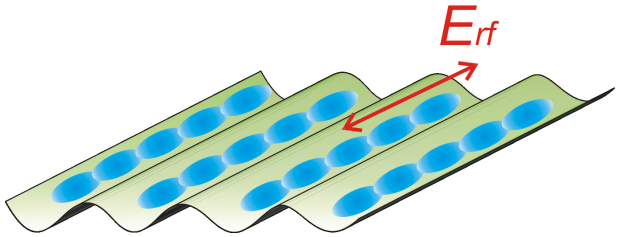

5. Summary

We investigated microwave conductivity Re{σ_{xx}} of ULSLs.

In the vicinity of $\nu = 2$, the resonant peak is …

{ ① absent / ② observed / ③ absent } when the modulation is { ① not introduced. / ② along the rf electric field. / ③ across the rf electric field. }

The resonance is reminiscent of the pinning mode resonance of crystal-like states.

Stripe II phase predicted in theory may be related to the observed resonance. However, further studies are required to clarify the origin of the resonance.