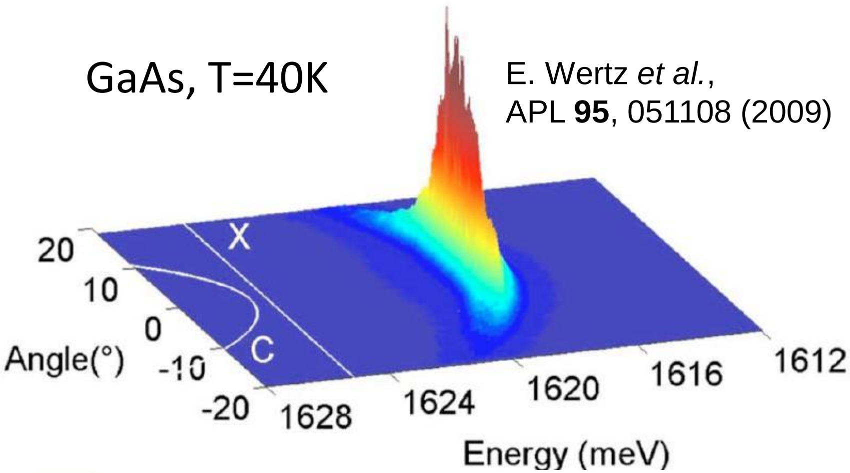
University
of Southampton

Vertical Cavity Surface Emitting Terahertz Lasers

Alexey Kavokin (SOLAB, St-Petersburg)
Ivan Shelykh (University of Iceland)
Tomas Taylor (University of Southampton)
Mikhail Glazov (Ioffe Physico-Technical Institute)

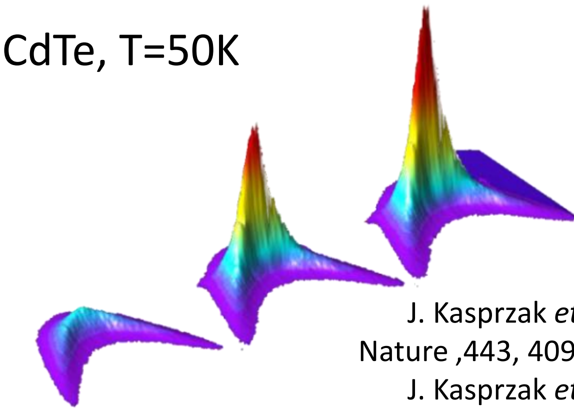
Polariton Lasers

GaAs, T=40K



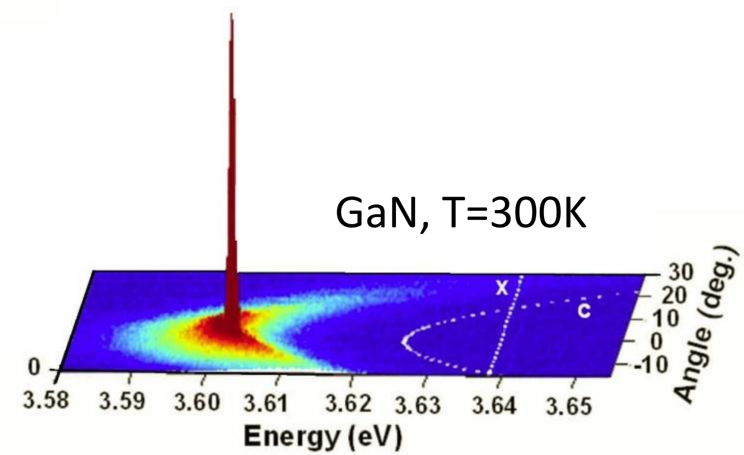
E. Wertz *et al.*,
APL **95**, 051108 (2009)

CdTe, T=50K



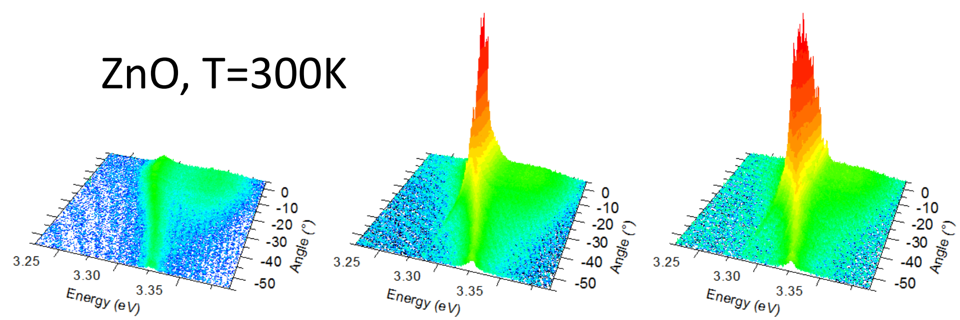
J. Kasprzak *et al.*
Nature ,443, 409 (2006)
J. Kasprzak *et al.*
PRL ,101, 146404 (2008)

GaN, T=300K



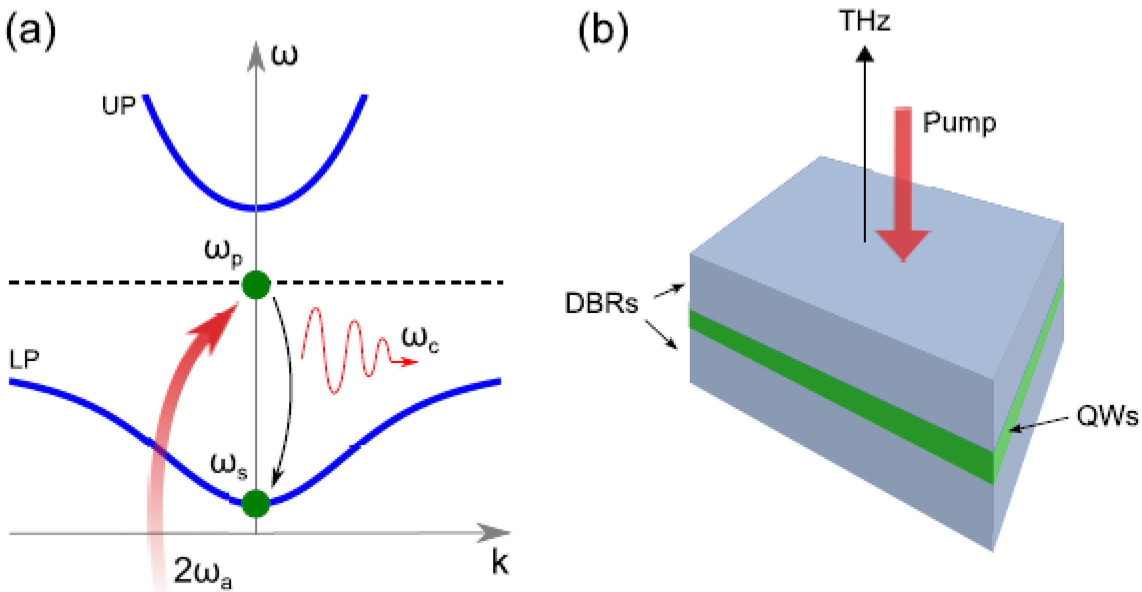
G. Christmann *et al.*,
APL **93**, 051102 (2008)

ZnO, T=300K



Thierry Guillet, this conference

Vertical Cavity Surface Emitting Terahertz Lasers based on Polariton Lasers



- Excitation of a 2p exciton state by a two-photon absorption
- 1s polariton state populated due to the THz transition from 2p state
- Polariton population of 1s state stimulates the THz transition
- Per each visible photon the device emits a THz photon
- Vertical geometry! No terahertz cavity needed!

2p-exciton state

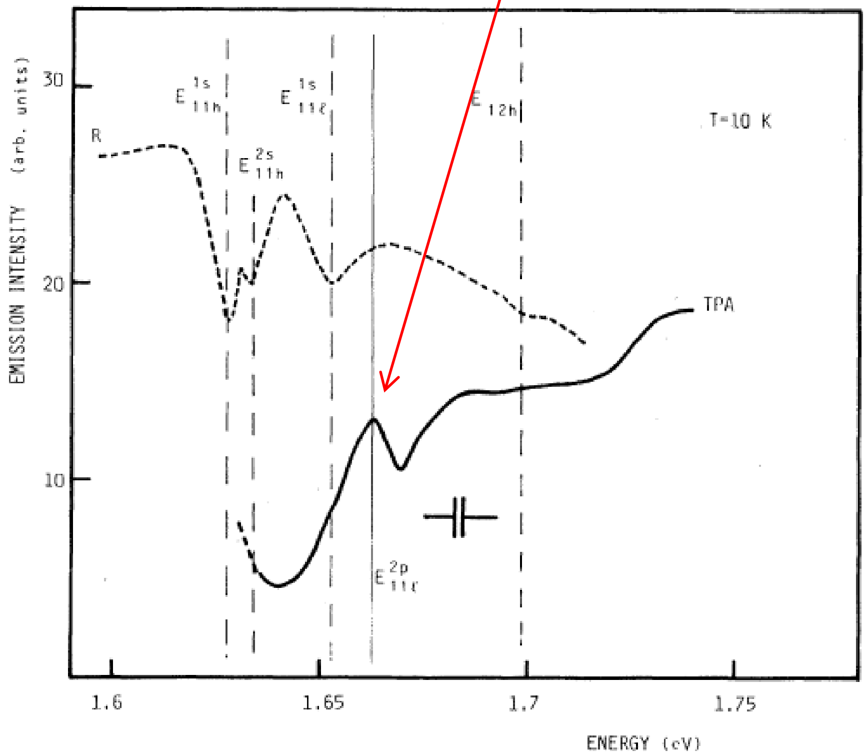


FIG. 1. Two-photon absorption luminescence excitation spectrum of sample *A* vs $2\hbar\omega$ at 10 K (TPA curve).

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Two-photon spectroscopy in GaAs/Al_xGa_{1-x}As multiple quantum wells

I. M. Catalano, A. Cingolani, R. Cingolani, and M. Lepore

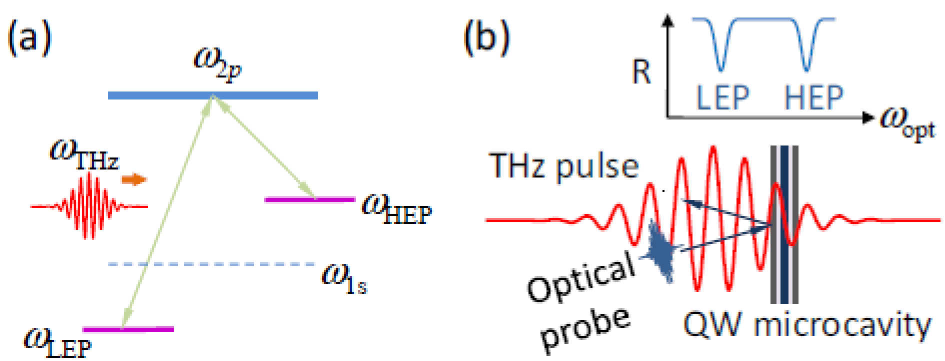
Dipartimento di Fisica, Università degli Studi di Bari, via Amendola 173, 70126 Bari, Italy

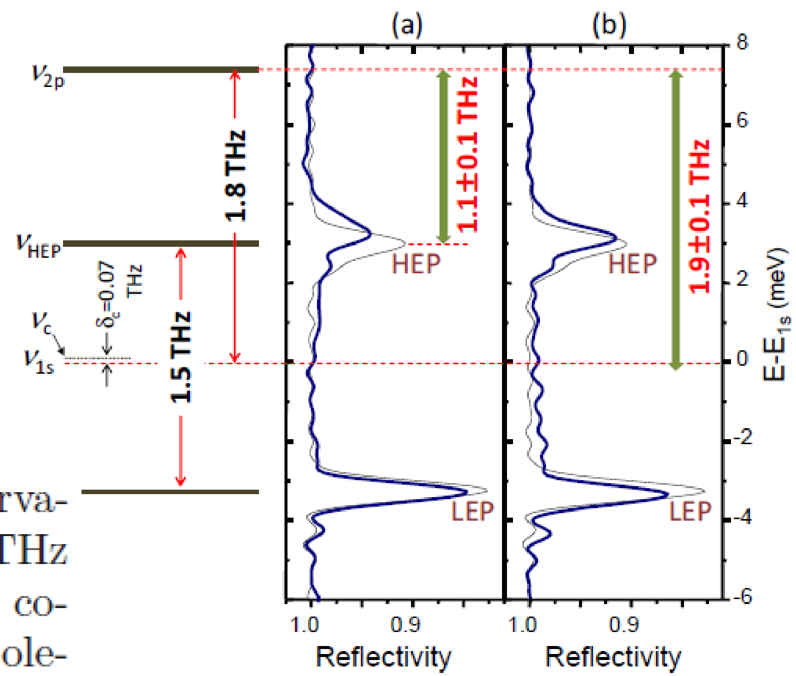
K. Ploog

Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-7000 Stuttgart 80, Federal Republic of Germany

(Received 18 January 1989)

1s – 2p terahertz transition in a microcavity

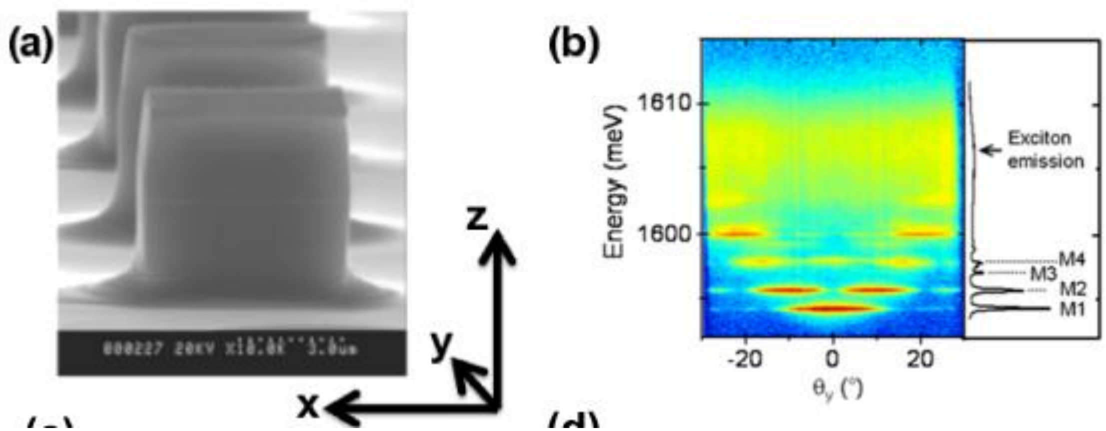




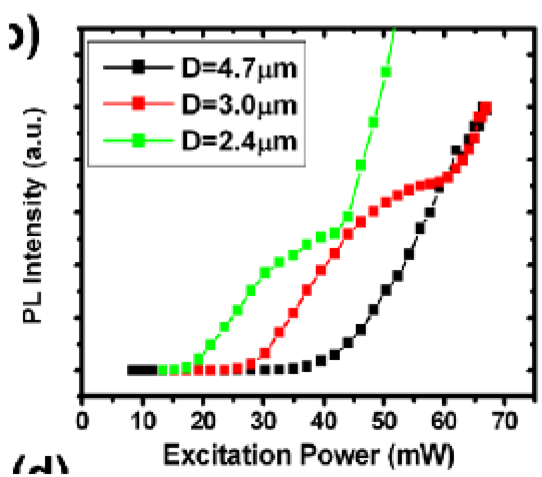
Our experimental observations and theoretical analysis show that a resonant THz field couples the optically induced exciton-polariton coherences to the dark $2p$-exciton state while direct dipole-transitions between the two polariton modes are forbidden.

J.L. Tomaino et al., **arXiv:1112.2185v1**

Coherent injection of microcavity polaritons through two-photon absorption



Polariton lasing with a two-photon pump in a pillar GaAs microcavity



Courtesy of Alberto Bramati,
Elisabeth Giacobino, LKB, Paris

Theoretical treatment

$$\frac{d\varrho}{dt} = \frac{i}{\hbar}[\varrho, H_c] + \hat{L}\varrho,$$

Liouville equation for the density matrix

$$\frac{dN_p}{dt} = Tr\left\{p^+ p \frac{d\varrho}{dt}\right\} = \frac{2}{\hbar\zeta}\mathrm{Re}\{\mathrm{Tr}\left(\varrho[H^-; [p^+p; H^+]]\right)\}$$

Master equation

Rate equations:

Second order coherence of pumping light

$$\frac{dN_p}{dt} = -\frac{N_p}{\tau_p} + W_g\left[\frac{g^{(2)}(0)}{2}N_a^2 - N_p(2N_a+1)\right] + \\ +W_G\left\{N_sN_c\left(N_p+1\right) - N_p\left(N_s+1\right)\left(N_c+1\right)\right\},$$

2p-population

$$\frac{dN_s}{dt} = -\frac{N_s}{\tau_s} - \\ -W_G\left\{N_sN_c\left(N_p+1\right) - N_p\left(N_s+1\right)\left(N_c+1\right)\right\},$$

1s-population

$$\frac{dN_c}{dt} = -\frac{N_c}{\tau_c} - \\ -W_G\left\{N_sN_c\left(N_p+1\right) - N_p\left(N_s+1\right)\left(N_c+1\right)\right\},$$

Terahertz population

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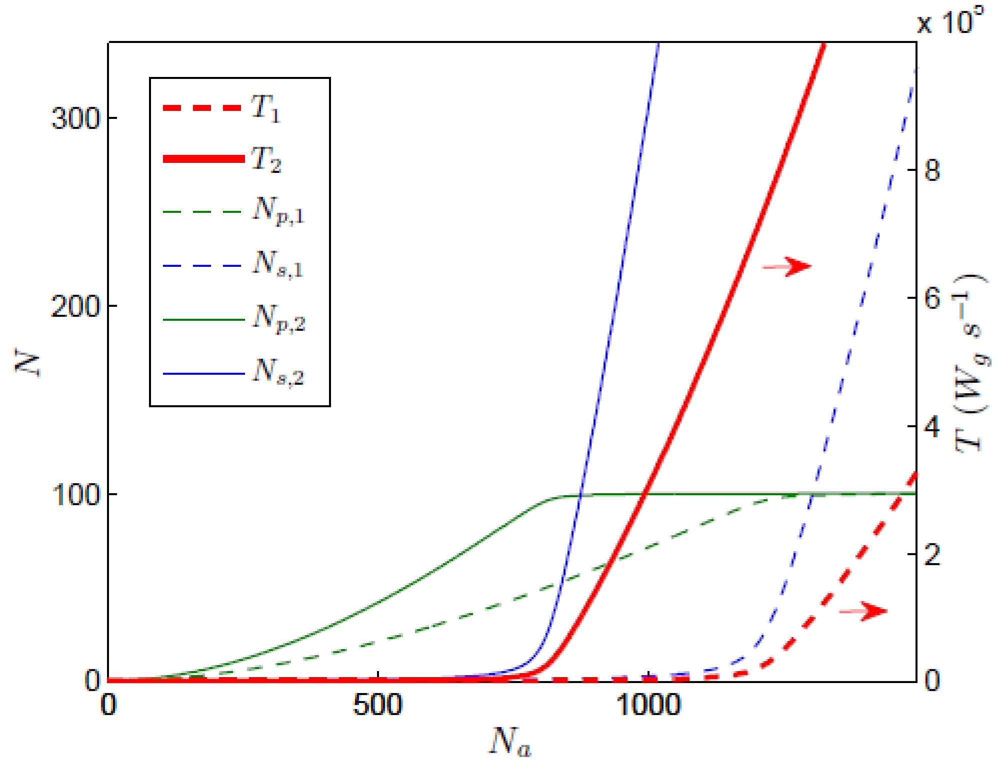
Terahertz VCSEL: results of simulation



- Terahertz emission rate increases at the onset of polariton lasing
- 2p population saturates
- 1s population increases exponentially at lasing threshold

New quantum optical effect: Threshold depends on the statistics of photons of pump!

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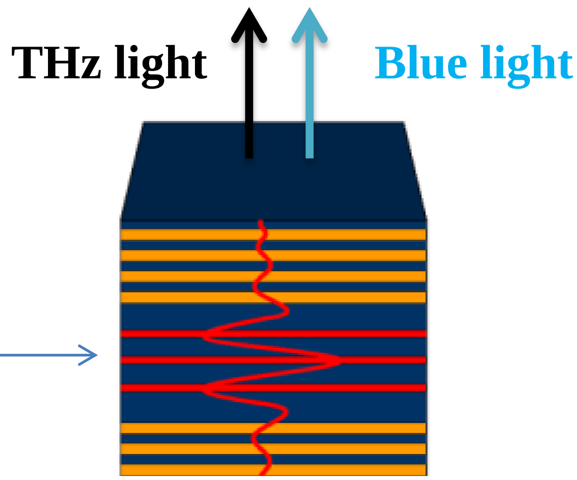
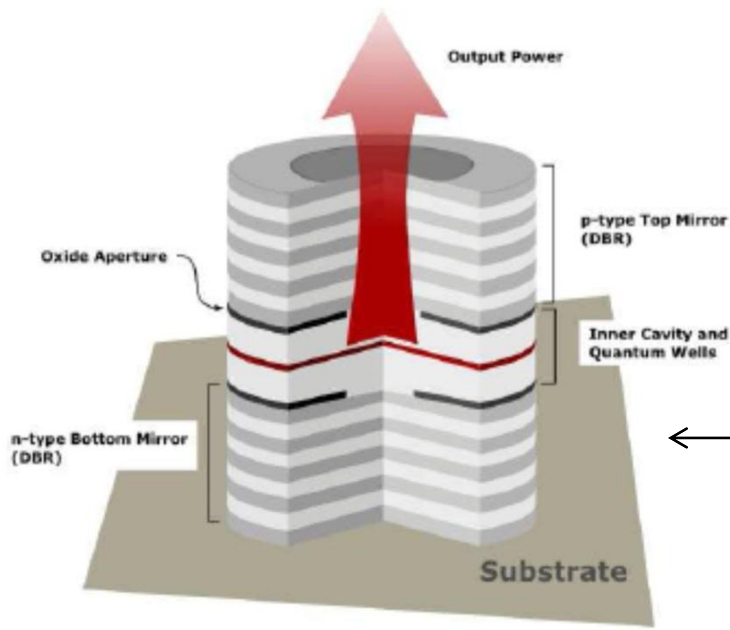
Schematic of a hybrid GaAs/GaN terahertz polariton laser



GaN based microcavity
No doping needed!

T=300 K

GaN:
E(2p)=$2\hbar\omega$(LED)



Red Light Emitting Diode based on GaAs

Conclusions

- Polariton lasers: low threshold coherent light sources, realised in GaAs, CdTe, GaN, ZnO,…
- Two photon pumping of polariton lasers allows building a THz source
- Polariton mediated THz lasers based on GaN: compact, room temperature, vertical geometry, no THz cavity needed
- Hybrid blue light/THz lasers: one can see where to shoot!

A.V. Kavokin, I.A. Shelykh, T. Taylor, M. Glazov, arXiv.org > cond-mat > **arXiv:1201.4010**