11.45 QMC4

Third Harmonic Generation Microscopy of GaN

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The recent demonstration of high-brightness light-emitting-diodes and laser diodes has established the III-V nitrides as key materials for optoelectronics operating in the green-ultraviolet (UV) wavelength range While the optical and electrical properties of the nitride materials were widely explored, their extraordinary nonlinear optical properties have recently attracted intensive studies Our recent investigations revealed their large close-resonant third order nonlinearities, including two photon absorption coefficient and nonlinear refractive index For second-order nonlinear process of second harmonic generation (SHG) in GaN, several research groups including Miragliotta *et al.* [1] have experimentally determined the second order susceptibility $\chi^{(2)}$ in bulk GaN and have found increased nonlinearities when a large DC electric field was applied to the surface of a GaN film It is well known that second order nonlinear effects can only be observed in noncentro-symmetric structures These were commonly realized by applying an external electric field or by using compositionally asymmetric coupled quantum wells In nitride-based quantum wells, the intrinsically present piezoelectric field breaks the inversion symmetry automatically and makes the second-order nonlinearity possible Taking advantage of these properties, we have recently demonstrated the SHG microscopy of GaN for the piezoelectric field distribution mapping in nitride based materials, including bulk GaN and InGaN/GaN MQWs

During our SHG experiments of GaN using a femtosecond Cr:forsterite laser, we also observed strong third harmonic generation (THG) in the bulk GaN. Since THG exists in centro-symetric structures, it can be served as an excellent label for the mapping of the crystal property itself, in contrast to SHG as the label for the strength of piezoelectric field With 40 mW 100fs-Cr:forsterite laser input, we can easily obtain third harmonic generation at purple wavelength on the order of 10 nW with an 80X objective Figure 1 shows the input and output spectra of THG in a 2 μm-thick bulk GaN With input wavelength centered at 1230 nm, we observed the THG spectrum centered at 410 nm The room temperature bandgap of GaN is located around 365 nm The THG microscopy can then by accomplished by scanning the GaN sample using a computer controlled XYZ stage By comparing the THG microscopy with SHG microscopy, detailed information on the crystal properties can then be obtained In this presentation, we will compare the THG microscopy with the SHG microscopy as well as two-photon and three photon confocal microscopy. By comparing these imaging obtained through different nonlinear optical microscopy, we can obtain complete and interesting information not observed before

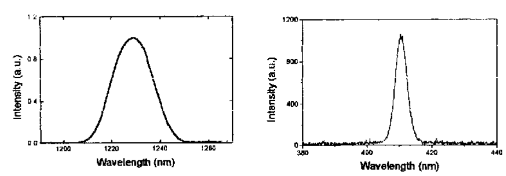

Figure 1 (Left) Input spectrum of a Cr:forsterite laser centered at 1230 nm (Right) THG output spectrum of the Cr:forsterite laser in a bulk GaN centered at 410 nm

Reference:

[1] S Nakamura, *et al.*, *Appl. Phys. Lett.* 72, 211 (1998)

[2] J Miragliotta and D. K Wickenden, *Phys. Rev. B* **53**, 1388 (1996).

11.00-12.30 QMD - Novel Developments in Coherent Light Sources

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11.00 QMD1

HIGHER-ORDER FRACTAL LASER MODES

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Our recent unexpected discovery that fractal pattern formation occurs in the modes of unstable optical resonators [1] has opened up a new area in laser science. In this paper, we present recent results on the generation of higher-order fractal modes in unstable cavity lasers.

Our initial work was performed in cavities with only one transverse dimension [1]; this was then generalised to encompass resonators with fully two-dimensional (2D) transverse characteristics [2]. The mode profiles in this case are of such complexity and beauty that we have christened the device the "kaleidoscope laser". Excellent agreement between experiment and theory has been obtained in regard to the detailed properties of 2D modes [2]. Moreover, the fractal topology of unstable cavity eigenmodes becomes at once apparent when they are represented in a 2D phase space (the transverse plane) since their fractal dimension lies between 1 and 2. However, even though higher-order modes are routinely generated in experiments, theoretical work has to date been limited to only lowest-loss 2D modes.

In this paper, we consider two different ways of removing this restriction. Firstly, we generalise the Virtual Source (VS) method to the case of a fully 2D transverse geometry. The VS approach is attractive because there is a transparent relationship between the mathematics and the underlying physical processes. Mode patterns are built up from successive diffraction of a plane wave through a sequence of apertures representing the unfolded cavity. Each aperture creates diffracted edge waves, and the family of eigenmodes is formed from different weighted sums of the edge waves, together with a plane-wave component. Edge wave patterns therefore need to be determined for each transverse geometry; indeed to deal with the widest range of possibilities, we have made a further generalisation of the technique to include transverse apertures of arbitrary shape.

Secondly, we discuss a computational approach that mimics the standard experimental solution to the generation of higher-order modes in which a narrow-band spectral filter is included in the cavity. Higher-order mode patterns derived from both the VS and filtering approaches will be compared for a variety of kaleidoscope laser geometries. Work is also currently under way to interpret the fractal patterns in terms of the constituent edge-wave profiles that arise in the unfolding of the laser resonator. This approach provides a physical basis for analysing the topology of fractal characteristics as well as for the dynamic construction of excess noise factors.

[1] G.P. Karman and J P. Woerdman, Opt. Lett., **23** (1998) 1909.

[2] G.P. Karman, G.S. McDonald, G.H.C. New and J.P. Woerdman, Appl. Opt., **38** (1999) 6874; Nature 402 (11 Nov 1999) 138.