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Nonlinear Mid-IR Photonics using Silicon Nanophotonic Wires

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ABSTRACT

Photonic research on silicon platforms has attracted much attention over the past several decades because this silicon CMOS photonics is speculated to be an important future foundation for a unified photonic platform. Such a foundation could in principle enable production of most telecommunication components at a low-cost, highly-compact and mass-production-ready fashion [1]. However, the capability of silicon photonic platform has never been limited to, the area of telecommunication. This interest has spurred research into novel application areas based on the components produced using the same CMOS photonics technology, including mid-infrared silicon photonics [2-9], silicon bio-photonics [10-13], and other applications [14-15].

Here we discuss our recent development using silicon nanophotonic wires as nonlinear media to explore various nonlinear applications. Silicon's lowest-order nonlinearity is the third-order nonlinearity or Kerr effect [16]. Considering the high refractive index contrast on the silicon platform, the effective nonlinear parameter for a silicon nanophotonic wire is five orders of magnitude larger than that of an optical fiber (100 $W^{-1}m^{-1}$ vs. 1 $W^{-1}km^{-1}$) [17]. As a result, strong optical nonlinear interaction can be observed in a silicon nanophotonic wire with a length scale of only a few millimeters compared with several hundred of meters in the case of an optical fiber. In recent years, various third-order nonlinear effects in silicon nanophotonic wires have been studied [17-20]. In these studies it has been shown that the nonlinear efficiency in the telecom band is largely suppressed by the optical limiting effect due to silicon's two-photon absorption (TPA) loss as well as its TPA-induced free-carrier absorption (FCA) loss [17-19]. Although the FCA loss can be drastically suppressed by reducing free carrier lifetime by means of reverse biasing and ion implantation, the inherent loss of TPA in silicon remains unchanged. An effective way to bypass the strong TPA in silicon is to shift the wavelength of operation from telecom to mid-infrared. At room temperature, silicon has a bandgap ~ 1.12 eV which corresponds to a linear absorption cut-off wavelength of 1.1 μm. Therefore the cut-off wavelength for TPA in silicon is ~ 2.2 μm. The vanishing two-photon absorption (TPA) for mid-infrared wavelengths beyond 2.2 μm [16], which, coupled with silicon's large nonlinear index of refraction and its strong waveguide optical confinement, enables efficient nonlinear processes in the mid-infrared. By taking advantage of these nonlinear processes and judicious use of dispersion engineering in silicon photonic wires, we have recently demonstrated a handful of silicon mid-IR nonlinear components, including optical parametric amplifiers (OPA) [3], broadband sources [6], a wavelength translator [2] and an optical parametric oscillator [21]. Silicon nanophotonic waveguide's anomalous dispersion design enabled by varying the wire cross-section and/or changing the surrounding materials, providing four-wave-mixing (FWM) phase-matching, has led to the first demonstration of silicon mid-IR optical parametric amplifier (OPA) with a net off-chip gain exceeding 13 dB. In addition, by exploiting a new phase-matching scheme with a balanced second and fourth order waveguide dispersion, an OPA with an extremely broadband gain spectrum from 1.9-2.5 μm and >50 dB parametric gain has been demonstrated, upon which several novel silicon mid-IR light sources have been built, including a mid-IR optical parametric oscillator, and a supercontinuum source. Finally, a mid-IR wavelength translation device, capable of translating signals near 2.4 μm to the telecom-band near 1.6 μm with simultaneous 19 dB gain, has been demonstrated.

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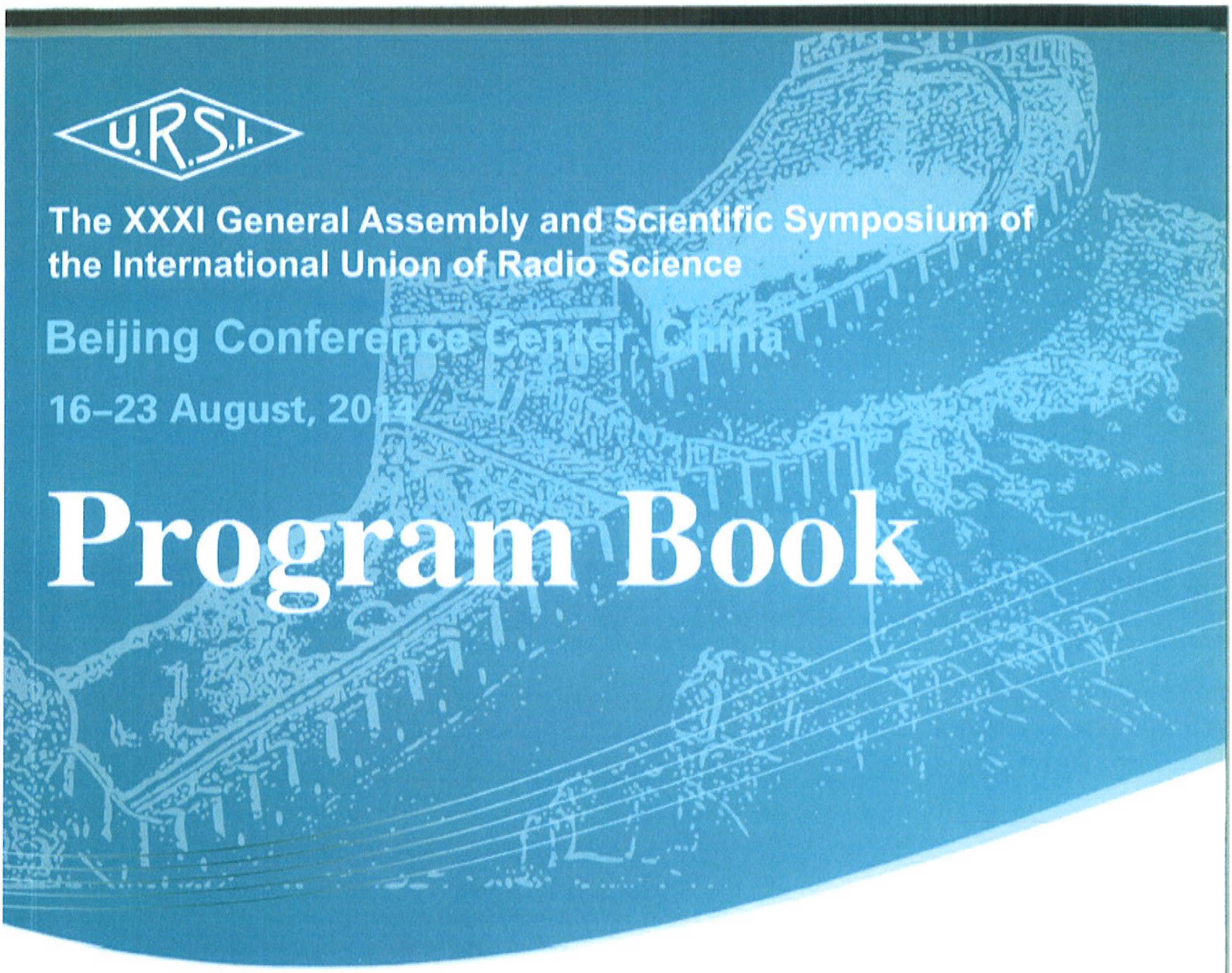

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