Heavy noble gas (Kr, Xe) irradiated (111) InP nanoporous honeycomb membranes with enhanced ultrafast all-optical terahertz emission

K. Radhanpura,[1] S. Hargreaves,[1] R. A. Lewis,[1,a)] L. Sirbu,[2] and I. M. Tiginyanu[3]
[1]*Institute for Superconducting and Electronic Materials, University of Wollongong, Wollongong, New South Wales 2522, Australia*
[2]*Institute of Electronic Engineering and Nanotechnologies, Academy of Sciences of Moldova, Chisinau MD-2028, Moldova*
[3]*National Center for Materials Study and Testing, Technical University of Moldova, Chisinau MD-2004, Moldova*

(Received 28 September 2010; accepted 5 October 2010; published online 5 November 2010)

Nanoporous honeycomb membranes on InP (111) surfaces emit ultrafast coherent terahertz pulses under near-infrared optical excitation. Irradiating the membranes with heavy noble gas Kr or Xe ions enhances the terahertz emission. The emission does not vary with in-plane magnetic field rotation and exhibits three-cycle dependence on azimuthal-angle rotation. Both suggest the terahertz source is not transient currents but optical rectification enhanced by the heavy-ion irradiation. © *2010 American Institute of Physics*. [doi:10.1063/1.3509404]

Materials with nonlinear optical (NLO) properties under intense optical excitation exhibit difference-frequency mixing. This may result in emission of electromagnetic radiation of frequencies in the "terahertz gap" lying between electronics and photonics.[1] Semiconductors may be used thus as terahertz emitters. We focus here on InP. Terahertz emission from bulk InP has been found to depend on whether it is *n*- or *p*-type, with lightly doped ($<10^{17}$ cm^{-3}) crystals being the best emitters.[2] A single-cycle in-plane magnetic field dependence on the terahertz emission as well as a saturation of the emission at relatively low excitation fluences (<0.20 μJ/cm^2) indicates the primary mechanism is due to a transient current (TC) induced by the photoexcited carriers.[2] (Conversely, an absence of magnetic field dependence and nonsaturation with excitation fluence, as exemplified by GaBiAs,[3] rule out the influence of TC.) Porous membranes on (100) InP surfaces give an enhanced NLO response for both second-harmonic and terahertz generation, related to optical rectification (OR) rather than to TC effects, and attributed to strong local fields in the porous network.[4] Similar enhancements to the terahertz emission in porous samples relative to the bulk precursors have been observed for (111) InP.[5] Measurements and modeling on charge carriers in porous InP membranes indicate a lower density and lower mobility but much longer recombination lifetime than for bulk InP, attributed to upward bandbending at the pore surfaces.[6] Here we extend the modification of the base material by the creation of radiation defects through Kr and Xe noble-gas ion irradiation of InP nanoporous membranes. Swift heavy-ion irradiation studies in GaN and ZnO have shown that nanostructuring the surface improves radiation hardness.[7,8] While enhanced terahertz emission has been noted for As implantation into GaAs,[9] no studies are known of the effect on the terahertz emission of irradiating InP with any ion, or of any ion being used to irradiate a nanoporous membrane.

(111)-oriented substrates of 500-μm thick *n*-InP single crystals of free electron concentration 5×10^{18} cm^{-3} (Crys-Tec GmbH, Germany) were anodically etched in the dark at room temperature in a 5% HCl aqueous solution in the potentiostatic regime using an electrochemical double cell.[10] The sample, of exposed area 1 cm^2, was mounted between the cells. The electrolyte was continuously pumped through both cells. Four Pt electrodes were used: a reference electrode in the electrolyte, a sense electrode on the sample, a counter electrode, and a working electrode. After pore growth a shock voltage was applied for a few seconds to detach the nanoporous layer from the substrate. The top nucleation layer was removed by isotropic wet etching.

Both bulk and nanoporous samples were irradiated at room temperature by 85 MeV Kr^{+15} ions at doses of 10^{12} and 10^{13} cm^{-2}, or by 130 MeV Xe^{+23} ions at doses of 5×10^{11} and 5×10^{12} cm^{-2}, at the IC-100 cyclotron of the Joint Institute for Nuclear Research, Dubna, Russia.

A VEGA TESCAN TS 5130MM scanning electron microscope with an Oxford Instruments energy-dispersive x-ray (EDX) system was used to analyze the morphology and chemical composition of the samples. The EDX microanalysis confirmed the stoichiometric composition of the InP nanoporous skeleton both before and after ion irradiation. Figure 1 is micrograph of a typical nanoporous structure. The

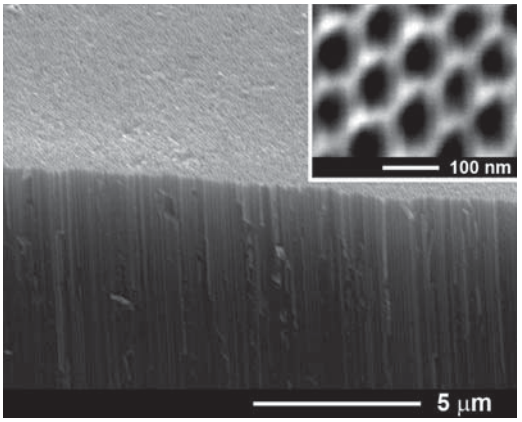

FIG. 1. Scanning electron micrograph of a nanoporous InP (111) membrane. The inset gives a top view of the hexagonal arrangement of the pores.

a)Electronic mail: roger@uow.edu.au.

