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Measurement of the nonlinear optical phase response of liquefying gallium

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Abstract: We report a direct measurement of the nonlinear optical phase response of gallium/silica interface close to the metal's melting point. A reversible phase modulation of ~0.15 radians and ~30% change in reflectivity was observed for 5mW of power at 1549nm.

OCIS codes: (190.4400) Nonlinear optics, materials; (120.5050) Phase measurement.

Recently we showed that the optical reflectivity of an interface formed by the elemental metal gallium and silica can become highly nonlinear when held at a temperature just below the bulk melting point of the metal [1]. We have shown that such an interface can exhibit as much as 40% reversible change in reflectivity when excited with just a few mW of optical power. The phenomenon is extremely broadband (extending from at least 450nm to 1700nm), and is relatively fast (<1ns rise time and <1μs recovery time). We believe that the effect is due to an optically-induced, surface-assisted phase transition of the confined α-gallium surface to some as yet unidentified metastable phase of a more metallic nature [2]. We have already used the effect for a number of applications including the construction of broadband optical switches [3], and passive Q-switching of both erbium and ytterbium fiber lasers [4].

To date our nonlinear reflectivity experiments and applications have only been sensitive to the magnitude of the induced reflectivity change, and no direct measurements have been made of any associated nonlinear optical phase change. In this paper we present what we believe to be the first such measurement. The data is important as it provides further more detailed information on the microscopic processes underlying the phenomena, and will allow an accurate assessment of the performance of the technology in optical phase based/sensitive devices and applications.

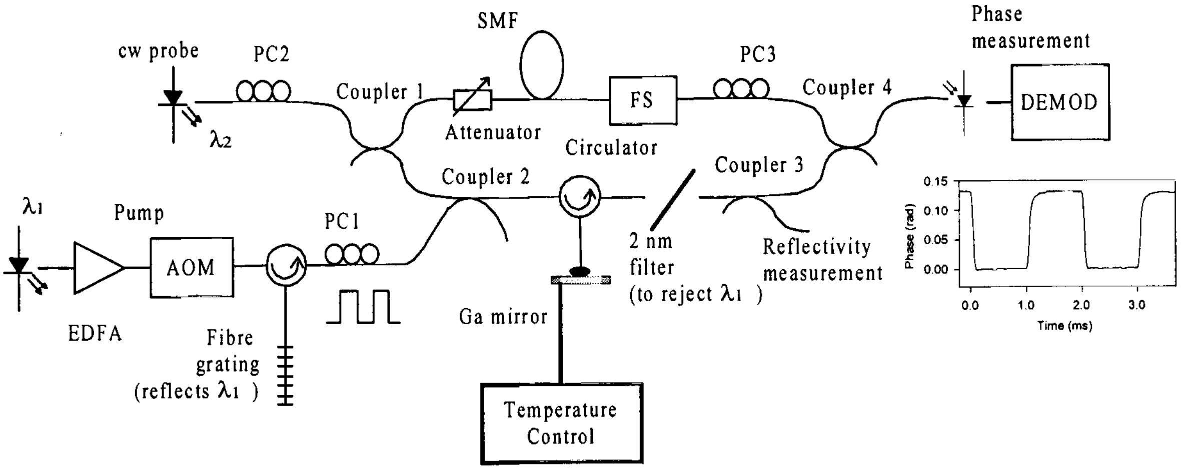

Fig. 1. Experimental set up. The square wave modulated pump beam had a 50% duty cycle, 500Hz repetition rate, a controllable peak power up to 5mW, and a central wavelength of 1536nm. The continuous wave probe beam had a power of 100μW and a central wavelength of 1549nm with a linewidth of 70MHz. The temperature of the FGM could be set anywhere in the range 0 to 35°C and was stabilized to 0.01°C. Inset is a scope trace showing the induced change in the optical phase of the reflected signal due to the presence of the pump beam, for a mirror temperature of 26.8°C; the pump peak power was 5mW.

Our experimental set up is shown in Fig.1. A high intensity pump beam was used to modify the reflection characteristics of a fiberized gallium mirror (FGM), fabricated as in Ref[1]. The FGM was placed within a fiber Mach-Zehnder interferometer (MZI) and the corresponding system response measured using a weak probe beam at a second wavelength. The MZI incorporated a monitor port to allow a direct measurement of the FGM amplitude response, and a frequency-shifter to allow a direct measurement of the FGM phase response using the heterodyne technique and employing a standard phase-demodulator. The resolution of the phase measurement was 1.3mrad, and the measurement bandwidth ~6kHz.

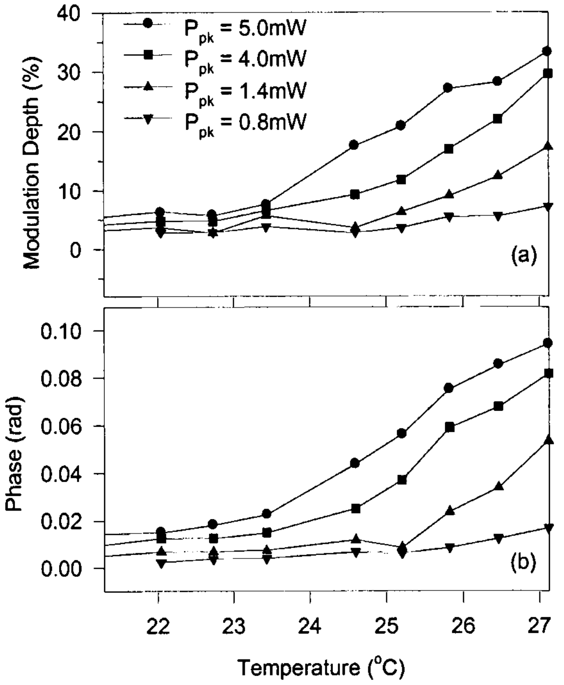

Fig. 2. The maximum induced reflectivity (a) and optical phase change (b) as a function of FGM temperature, for various pump power levels.

In Fig.2 we plot the induced reflectivity and phase change as a function of FGM temperature, for various pump power levels. The intensity and phase modulation are observed to follow the same form of critical behavior. Reflectivity changes of up to ~35% and phase modulations of up to ~0.15rads are observed at temperatures within a few degC of the bulk melting point. Using previous data on the refractive index of α-gallium (n=3.19-*i*3.38) [5], and our experimental data we can readily determine the effective complex index of the gallium, confined at the interface as function of both temperature and optical intensity. For example, we estimate an effective index of n=3.73-*i*5.11 for the interface at the point of maximal nonlinear optical phase change. Note that this observed maximum phase change is about half that predicted for a transition between α-gallium and liquid gallium, providing further direct evidence that the effect is not due to simple bulk-melting. The detailed information obtained from these experiments should prove invaluable in understanding the physical mechanisms underpinning this remarkably large optical nonlinearity.

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