Attachment 1 – DAGSI Research Topic Template

NOTE: Under the Cooperative Agreement, Technical Directorates have three options for topics. First, a topic can strictly be considered in the pool for the state allocation of funding. DAGSI will work across the TDs for this allocation. Second, the TD can be prepared to be a funding partner with the State of Ohio. This would include: providing additional funds to support additional recipients of a topic, or expand the proposers team to include additional members on a topic. Third, the TD may elect to fully fund a topic not selected for State of Ohio funding or to pursue University teams outside the State of Ohio. Contact Terry.Cunningham.2@us.af.mil for questions

1. **Research Title:** Coherent LiDAR on a Chip
2. **Individual Sponsor:**

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3. **Academic Area/Field and Education Level**

Department of Physics and Optical Science (PhD level)

4. **Objectives:**

The objective of this proposal is to develop integrated 3D waveguide technology enabling an interferometry based imaging scheme capable of measuring the full optical wavefront field on an infrared detector with a single optical intensity measurement. Interferometry converts optical phase differences to intensity variations, which can be extracted from conventional detectors if the amplitude of each field is known. The basic architecture of the field-resolving focal plane array (FPA) is illustrated in the Fig. 1. Consider the pixel (i, j), where the sensor (i, j) measures the intensity of EM field, and 4 other nearest neighbor sensors are shared with one adjacent pixel. This combination measures the both the EM amplitude and phase on each pixel. As an example, the relative phase $\theta_{i,j+1}^{i,j}$ between pixel (i, j) and pixel $(i, j+1)$ can be extracted according to

$$\theta_{i,j+1}^{i,j} = \cos^{-1}\left(\frac{V_{j+\frac{1}{2}}^{i} - V_{j}^{i} - V_{j+1}^{i}}{2\sqrt{V_{j}^{i}V_{j+1}^{i}}}\right),$$

where V_j^i is the voltage readout of the sensor (i, j) which is proportional to the intensity of EM field on pixel (i, j), and $V_{j+\frac{1}{2}}^{i}$ is the voltage readout of the sensor $(i, j+\frac{1}{2})$ which reflects the

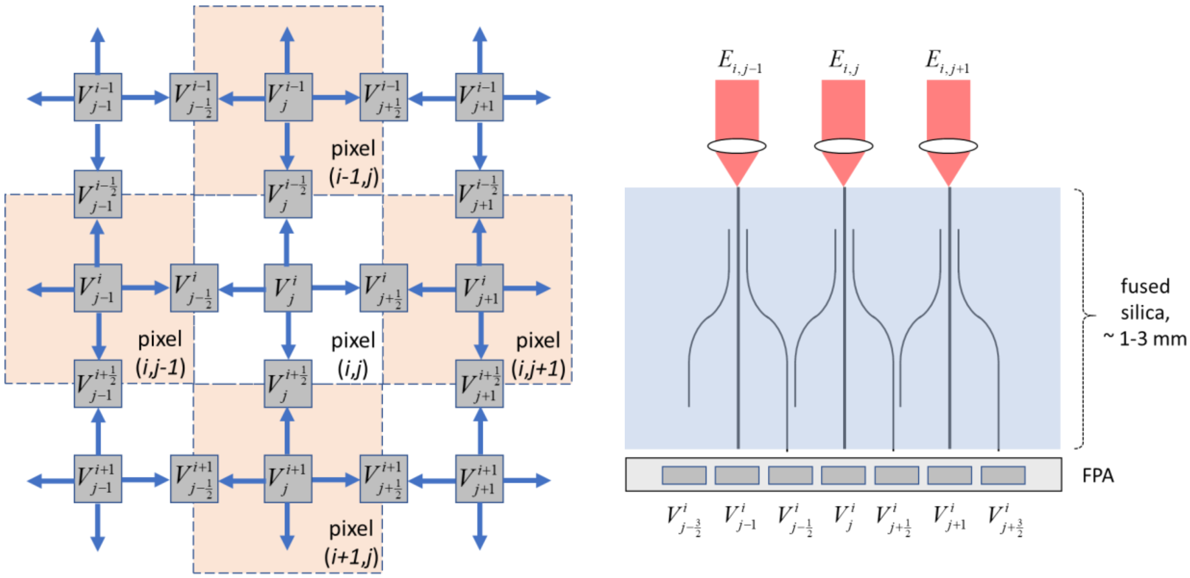

Figure 1 - Diagram of the pixel array connected to the 3D waveguide structure for interferometric coherent sensing on a chip.

interference between pixel (i, j) and pixel $(i, j+1)$. An *N*-pixel FPA requires 4*N* coupling and 3*N* sensors in the FPA. To implement such a dense grid of coupling in a FPA format requires a compact 3D configuration. In this work, we propose to realize such coupling using 3D waveguide couplers embedded in a thin fused silica slab. A schematic of a 1D sub-array of embedded couplers for 3 pixels is shown in Fig. 2.

We propose to fabricate such embedded waveguides using femtosecond laser-direct-writing (LDW) technique [1]. A schematic of the fabrication scheme for horizontal writing is shown in Fig. 2. The middle panel shows an optical image of the 2x2 waveguide coupler. The right panel shows the coupling length dependence of the power transfer ratio for an 8-µm waveguide separation, indicating that a coupling length of 1 mm is sufficient for a 3dB coupling.

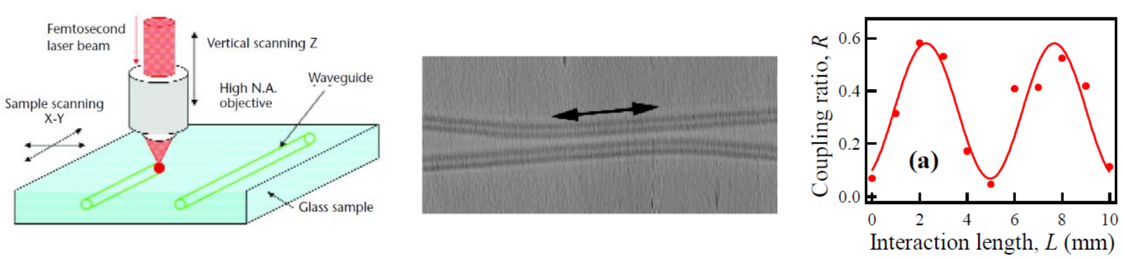

Figure 2- Femtosecond pulsed lasers can be used to write waveguides in fused silica [1].

5. Description:

Literature study: (0.5 month)

a. In this task we study literature with an emphasis on longitudinal writing scheme for embedded waveguides. A potential issue with longitudinal writing is the non-uniformity of the waveguide dimension at bending.

b. Single-mode waveguide fabrication and characterization: (4 months)
   In this task we aim to obtain the laser processing parameters to realize a low-loss, single-mode (SM) straight waveguide. These include construction of femtosecond workstation with imaging capability, 3-axis motorized stage control, waveguide facet polishing, modified refractive index profile measurement, near-field modal characterization, optical propagation loss propagation using such as cut-back method, and if necessary waveguide modeling. This will be an iterative process. Refractive index profile measurement is new to use which requires additional time to construct.
c. Fabrication, characterization, and modeling of 2x2 coupler. (1 month)
   Once the SM waveguide processing parameters is attained, we will demonstrate a 2x2 coupler. The variables are the separation between two waveguides and the coupling length. Samples will be end-polished and subject to coupled power measurement. If necessary modeling in Rsoft can be performed for optimization.
d. Fabrication, characterization and modeling of 1x5 star coupler. (2.5 month)
   Once basic coupling scheme is demonstrated, we will fabricate the 1x5 star coupler where one waveguide is coupled to additional 4 symmetric side waveguides. The aim to have equal power partition among these 4 side waveguides. The coupling geometry will be investigated using numerical modeling, which can be either simultaneous (all 4 side waveguides couple to the main waveguide at once) or discrete (distributed along the main waveguide). Coupling performance will be determined using a butt-coupled multimode fiber.
e. Fabrication, characterization, and calibration of 2x2 array of star couplers: (2 month)
   In this task we will fabricate 4 star couplers in 2x2 fashion and make additional 3dB coupling between adjacent side waveguides from neighboring pixels. The last step is to perform interferometric measurement to determine their relative phase. Due to uncertainty in the modified refractive index and the waveguide length, we will calibrate these interferometric pixels using a spatial light modulator (SLM) that can generate controlled phase profile. Need micro lens array to couple light in FOV into each SM main waveguides.
f. Demonstration of 2x2 field-resolved FPA. (2 month)
   In this task we aim to demonstrate a field-resolved FPA. We will incorporate a 2D array of 15 sensors to match the 2x2 array of star couplers, whose readouts will be acquired and processed in NI DAQ and LabVIEW.

6. **Research Classification/Restrictions:** Unclassified
7. **Eligible Research Institutions:** University of North Carolina Charlotte

NOTE: Topics submitted to DAGSI must be approved for public release. Need PA Approval #

References:

[1] Minoshima, et. al. “Fabrication of coupled mode photonic devices in glass by nonlinear femtosecond laser materials processing.” Optics Express 10 (645) 2002.