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On

ARRAY OF NANOKLYSTRONIS FOR FREQUENCY AGILITY OR REDUNDANCY

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Array of Nanoklystrons for Frequency Agility or Redundancy

Multiple, individually selectable klystrons would be contained in a single, compact unit.

NASA's Jet Propulsion Laboratory, Pasadena, California

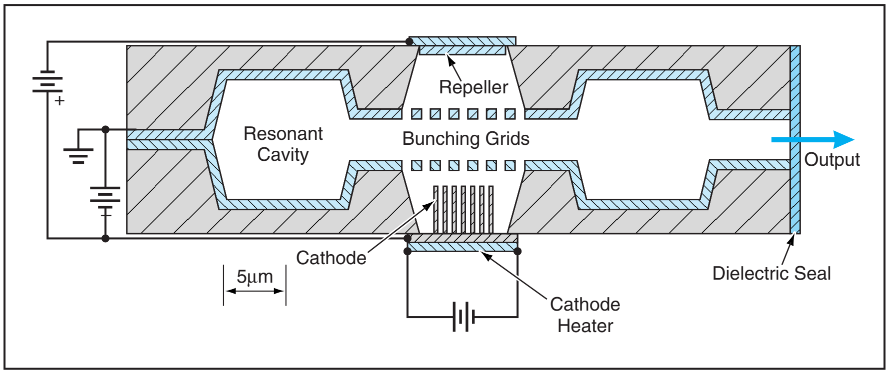

Figure 1. A **Nanoklystron** would resemble a conventional klystron but would be many times smaller, with resonant cavities formed by micromachining in silicon.

An array of monolithically fabricated nanoklystrons has been proposed as a frequency-agile and/or redundant source of electromagnetic radiation at frequencies ranging from about 0.3 to about 3 THz. Each nanoklystron would, as its name suggests, be a very small klystron. Like other klystrons, a nanoklystron would operate at a frequency determined primarily by the dimensions of its resonant cavity and the spacing of its electron-bunching grids, with some dependence on applied voltages. An individual nanoklystron could be fabricated in top and bottom halves from silicon wafers and would contain an integral output waveguide and feed horn (see Figure 1). In typical operation, a nanoklystron without a mechanical tuner would generate power only at a fixed frequency. Thus, frequency agility and/or redundancy could be obtained by incorporating into the array multiple nanoklystrons that are pretuned to generate signals at all required frequencies.

The array of nanoklystrons would be fabricated in substantially the same manner as that of a single nanoklystron, except that the nanoklystrons would be spaced at angular intervals near the periphery of the wafer. The output port of each nanoklystron would then be oriented along the edge of the wafer (see Figure 2). Each nanoklystron would be fabricated to oscillate at a different predetermined frequency within the desired output band. A particular frequency would be selected by indexing the wafer.

The dimensions of silicon wafers [the present industry standard diameter is 8 in. (≈20 cm)] and the horn dimensions required for operation in the intended submillimeter wavelength range are compatible with making thousands of nanoklystrons on a single wafer in a single production run. Contact pads for supplying power to individual klystrons could be formed on the top and bottom of the disk, and registration notches could be formed at corresponding angular locations on the top or bottom of the disk; this would make it possible to simply rotate the disk to a detent at a designated angular position in order to obtain radiation at the frequency of the nanoklystron at that position. The contacts and detents would be arranged so that the feed horn of the selected nanoklystron would be in the proper position for output coupling.

This work was done by Peter Siegel of Caltech for **NASA's Jet Propulsion Laboratory**.

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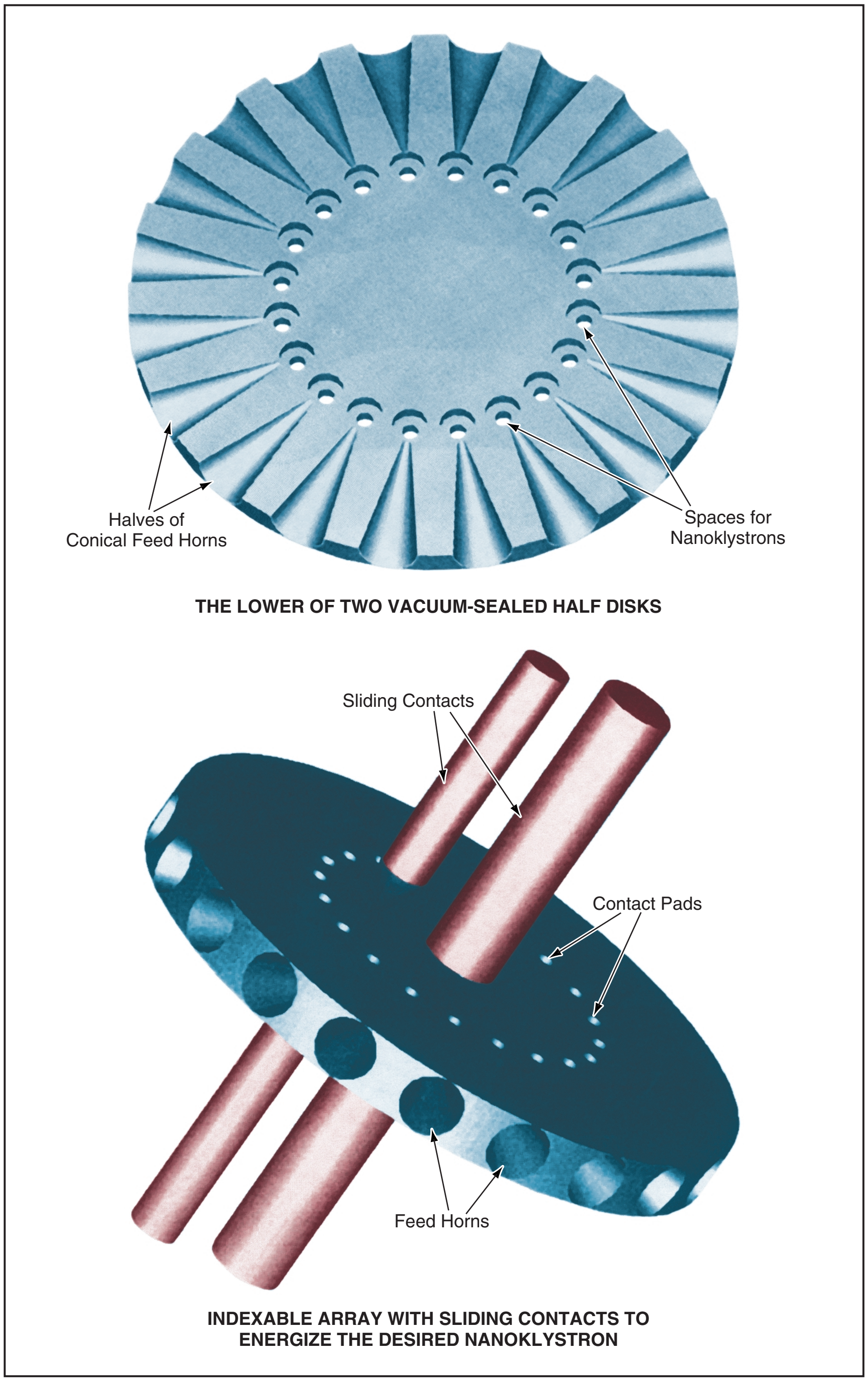

Figure 2. An **Array of Nanoklystrons** with integral output waveguides and feed horns would be fabricated in top and bottom halves of a disk made from silicon wafers. A desired nanoklystron would be selected by rotating the disk to register the top and bottom power contact pads of that nanoklystron with fixed top and bottom contacts.

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A Frequency Agile Nanoklystron

Peter H. Siegel (JPL)

Introduction

A critical need in the submillimeter-wave bands (300 GHz to 3 THz) is a remotely controlled tunable power source that can reach a number of key frequencies scattered throughout this wavelength range. Such a source would have immediate applications as a local oscillator for broadband heterodyne sensors which are now available throughout the submillimeter, as frequency agile radar transmitters, and as multifrequency communications transceivers. At the current time the only available THz sources are very low power fixed frequency, narrow band varactor multiplier chains (which have been demonstrated up to 1.2 THz), extremely expensive, large, heavy, high voltage, backward oscillators (which die off above 300 GHz, but can produce microwatts of power up to 1 THz), large, difficult to lock, even more expensive dual-pumped gas laser systems (CO2 laser pumping a far IR laser), or broadband photomixers (which although they have great bandwidth, produce extremely low power levels (<1microwatt) and are very difficult to stabilize).

In a prior report [1] the author proposed a new type of THz source – the nanoklystron (see Fig. 1) – which has the potential of producing milliwatt levels of power at any fixed frequency in the submillimeter wave bands. This report extends the nanoklystron concept to realize a frequency agile source that can target from one to more than one hundred fixed frequencies anywhere in the submillimeter. The concept can also be employed to produce a hundred nanoklystrons all operating at the same frequency for extended life or as redundant sources. Since the background on the nanoklystron concept and fabrication details have already been presented in [1], we will get right to the point of this report.

Description of the Invention

The concept proposed in this report is one which can be used to realize a frequency agile nanoklystron without changing the fabrication details or adding extra mechanical or electronic tuning elements to the circuit. The idea is a simple one and is illustrated in Fig. 2. The nanoklystron frequency behavior is determined by the size of the resonator cavity, the applied voltages and the spacing of the electron bunching grids. These parameters are all controllable in the proposed monolithic fabrication process [1]. Frequency agility or redundancy at a single frequency can be realized by fabricating an array of nanoklystrons formed around the perimeter of a circular wafer as depicted in Fig. 2.

Each nanoklystron is formed with an integrated RF output waveguide (Fig. 1). In the frequency agile nanoklystron, this waveguide is expanded monolithically into an integrated rectangular or conical feed horn formed half in the bottom wafer and half in the top (Fig. 2). The feed horn length and aperture can be adjusted to match any desired submillimeter wave frequency. Similarly the cavity dimensions and grid spacing can be coordinated to produce the desired output frequency. The frequency agility comes by simple rotation of the array about its center. Directionality of the output beam can be controlled simply and accurately by including micromachined registration notches on the wafer top or bottom. Single electrode operation is possible using the scheme shown in Fig. 3., where contacting sliding spring finger tips register on the appropriate pads on the top and bottom of the wafer at each output port. When the wafer is rotated, a new nanoklystron is energized and we get a new frequency or a new output power beam appearing at the same spatial point.

The natural dimensions of the wafers used as well as the required horn aperture values are compatible with making hundreds of nanoklystrons on a single wafer and in a single processing run. The limitations are only on the wafer dimensions themselves, and the industry standard for silicon is now 8" diameter!

Proposed Fabrication Steps

Fabrication of the frequency agile nanoklystron follows exactly the same steps as the single nanoklystron element described in [1]. The only difference is that the individual cavities and waveguide output structures are arranged in a circle centered on the host wafers. No special techniques are required for the horn elements beyond those being employed to make the RF waveguide and cavities.

Significance of the Invention

The nanoklystron in and of itself is a valuable component for THz applications. The only missing element is frequency agility. The concept presented in this report solves this problem by forming many nanoklystrons in a single monolithic processing run. Each nanoklystron is tailored to operate at a specific frequency. By increasing the host wafer diameter hundreds of frequencies can be targeted, all with similar output beam properties. Simple rotation of the wafer brings a particular nanoklystron tube into proper beam position.

** References

[1]. P.H. Siegel, T.H. Lee and J. Xu, "The Nanoklystron: A New Concept for THz Power Generation," JPL New Technology Report, NPO 21014, submitted March, 24, 2000.

****Please obtain references from sources listed.**

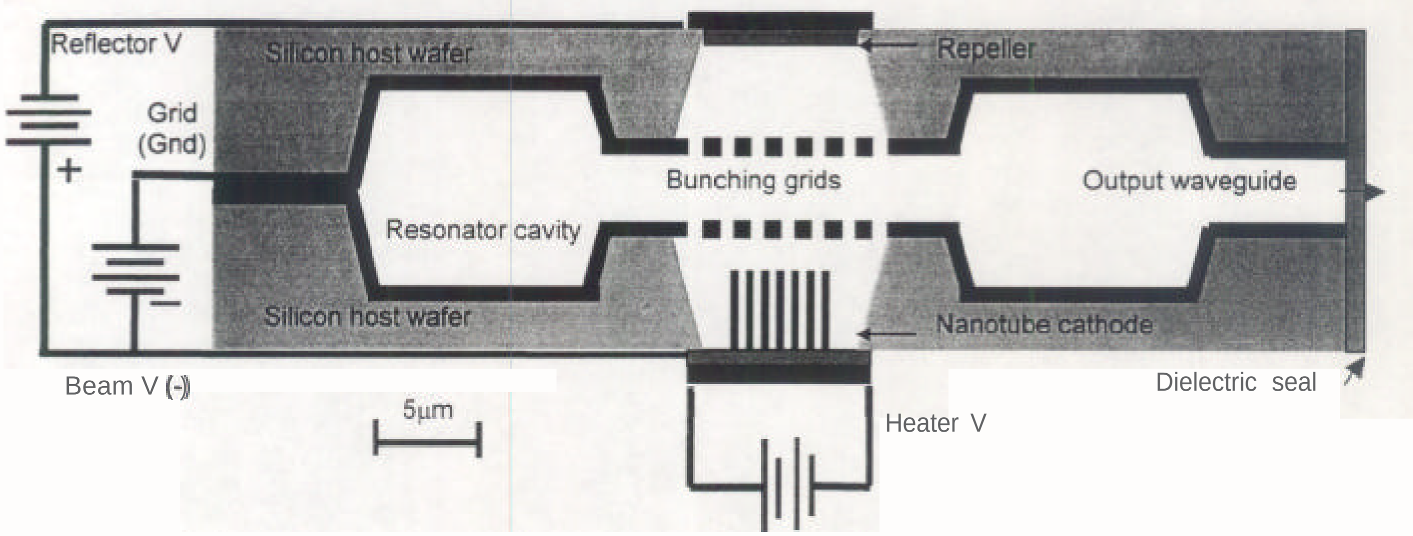

Figure 1. Schematic view of a single nanoklystron. For fabrication steps see [1].

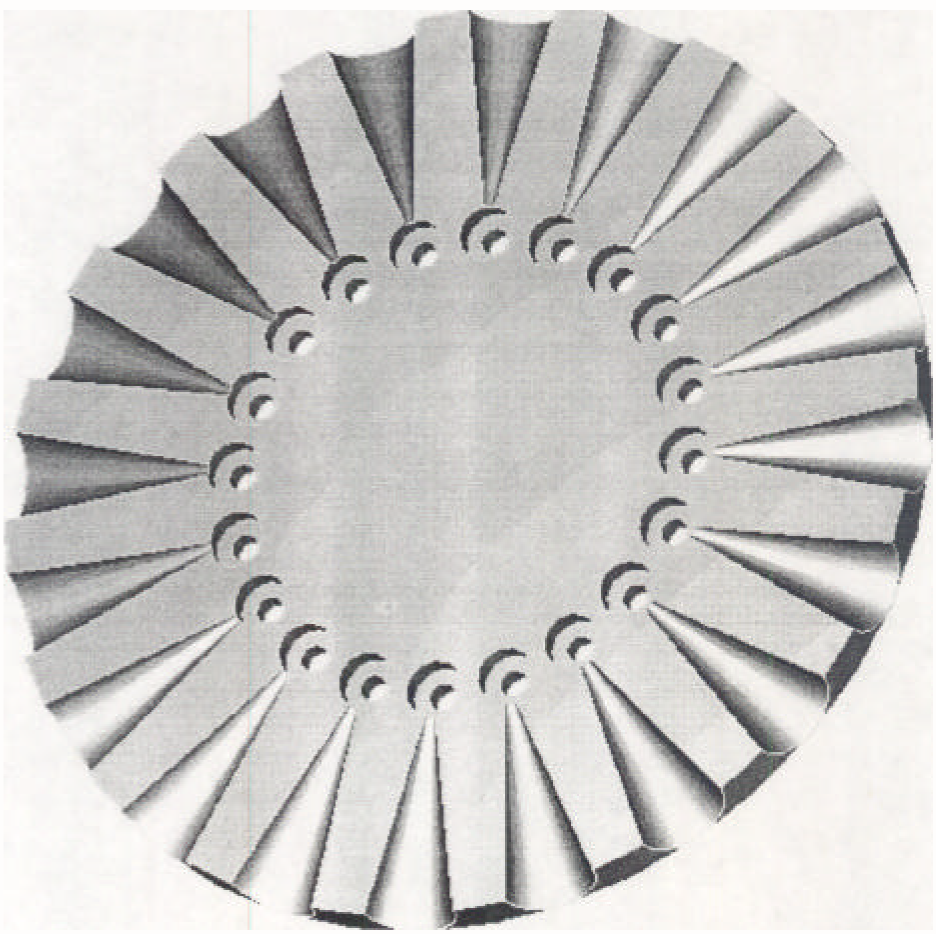

Figure 2. Array of nanoklystrons and RF waveguide feedhorns for multiple frequency or multiple power output (top view of the lower of two vacuum sealed wafers).

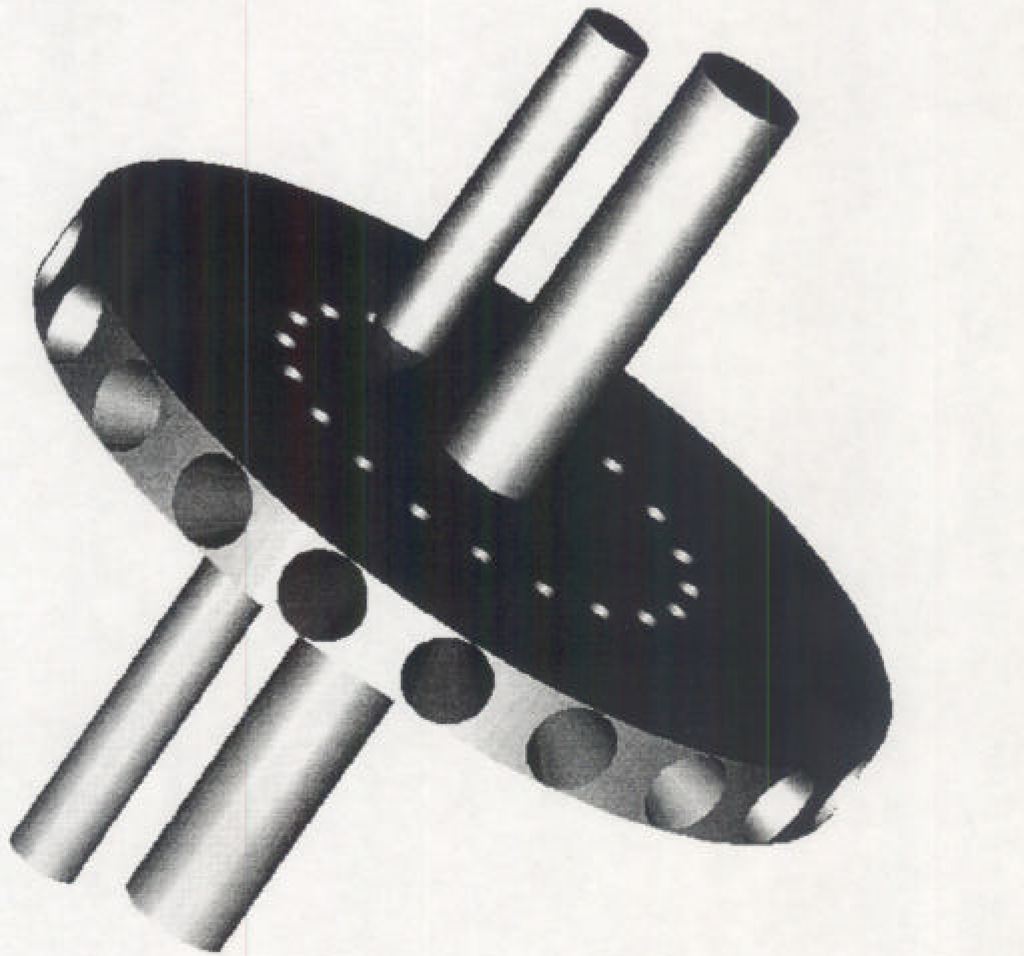

Figure 3. Indexable nanoklystron array with sliding emitter and anode contacts to energize appropriate element.

“The work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.”